Applying supplier selection methodologies in a multi-stakeholder environment: a case study and a critical assessment

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In the contemporary global market, Supplier Selection represents a crucial process for enhancing firms' competitiveness. In firms operating in low-complexity sectors, Supplier Selection generally leverages on few significant variables (price, delivery time, quality) and it is often left to the buyers' experience. On the other hand, in industries characterised by remarkable product complexity, supplier selection systems gain the characteristics of a multi-stakeholder and multi-criteria problem, which needs to be theoretically formalized and realistically adapted to specific contexts.
An increasing number of researches has been devoted to the development of different 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, that are mainly tested on numerical examples or computational experiments and focused on a dyadic version of the problem, overlooking the wider set of actors involved in the decision-making problem. The result is a clear dichotomy between academic theory and business practice.
Therefore, the paper contributes to understand the above dichotomy by evaluating the applicability to real-world multi-stakeholder problems of the two main approaches proposed in the literature to deal with supplier selection, the Analytic Hierarchic Process (AHP) and the Fuzzy Set Theory (FST). Based on an industrial case study, a thorough discussion is developed, dealing with the issues arising during the implementation and practical functioning of such decision support systems, also providing provide practical guidelines and managerial implications.

Keywords: supplier selection, analytic hierarchy process, fuzzy set theory, complex industries.

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1. Introduction
In the contemporary global market, Supplier Selection (SS) represents a crucial process for enhancing firms' competitiveness and to rapidly react to market requirements and innovation process (Esposito and Raffa, 1994; Gules and Burgess, 1996; Ghodsypour and O'Brien, 2001; Prahinski and Benton, 2004; Sarkar and Mohapatra, 2006; Saen, 2007, Esposito and Raffa, 2007).
In firms operating in sectors characterized by a low level of complexity, SS generally leverages on one or two significant variables (such as price, delivery time, quality); the selection process is often entirely ruled by buyers' experience. On the other hand, in industries characterised by remarkable product complexity, SS systems gain the characteristics of a multi-criteria problem, which needs to be theoretically formalized and realistically adapted to specific contexts (Esposito and Raffa, 2007; Bruno et al., 2012).
An increasing number of researches has been devoted to the development of different 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; Bruno et al., 2012). Moreover, the analysis of the literature shows that authors tend to stress the strengths of their models neglecting or giving little attention to the weaknesses. It is not by chance that, in many cases, proposed models are tested on generic applications, numerical examples and computational experiments (Bhutta, 2003; Saen, 2007; Rodriguez et al., 2013), with less emphasis on issues and problems emerging in the actual implementation and on the inherent complexities

deriving from the multi-stakeholder nature of the problem, just focusing on basic and dyadic versions of the problem.

The result is a clear dichotomy between theory and business practice (Bruno et al., 2012). In other words, the literature is rich of models which present a variety of approaches that are rarely used to solve real problems in the corporate practice (Genovese et al., 2013a; Genovese et al., 2013b).

Considering this evidence, the goal of this paper is to contribute to understand the above dichotomy by evaluating the two main approaches proposed in the literature to deal with the SS, Analytic Hierarchic Process (AHP) and Fuzzy Set Theory (FST). Starting from the characteristics of these two approaches, we propose an integrated model which combines their respective strengths. The usability of the model and its adaptability to real-world problems are investigated through an empirical study carried out in a large firm operating in the industry of railway and transportation systems design. Issues emerging during the implementation phase and subsequent results trigger some interesting implications regarding the model itself and its usability in a complex supply chain.

The paper is organized as follows. Firstly, a thorough literature review is proposed. It describes the main methods available in the literature for dealing with the SS problem, with a special focus on AHP and FST approaches. Then, based on emerging literature gaps, the integrated model is introduced, indicating how it combines the strengths and overtakes some of the weaknesses of traditional AHP and FST approaches. Thereafter, the empirical study (based on a real-world case study) is outlined; a discussion about managerial implications is then developed. Finally, conclusions are reported.

2. The Supplier Selection Problem: a Literature Review

In the contemporary market, firms have implemented various actions and strategies to ensure their competitiveness: in particular, a special attention has been paid to vendor assessment processes, which represent a compulsory and critical starting point for the achievement of a collaborative customer–supplier relationship. Vendors are required to have an adequate set of competencies, in order to create a supply system capable of facing market challenges (de Boer et al., 2001; Zhao and Zhang, 2012; Garcìa et al., 2013; Karande and Chakraborty, 2013).

In this context, some fundamental decision-making problems arise (Ho et al., 2010). The first concerns the selection process (selection problem) of new suppliers for inclusion in the vendor list. It is generally performed through ranking or rating (evaluation problem) a set of qualified suppliers. Once suppliers have been evaluated, in tactical operations an order allocation problem has to be tackled, consisting in the determination of the order size to be assigned to each supplier, with the objective of optimizing a given utility function.

Since 1960s, the identification of attributes and criteria to be considered in the SS problem 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 (De Boer et al., 2001). Dickson (1966) listed the most utilized criteria for SS. The analysis showed that price, quality, delivery and performance history could be considered the most important criteria. Ha and Krishnan (2008) enlarged the list to a set 30 attributes, very often conflicting with each other, requiring either quantitative or qualitative measurements. The intrinsic multi-criteria nature of the problem requires focussing not only on what has to be computed but also on how multiple criteria have to be combined. Therefore, a broad body of literature dealing with decision support methods and systems for the SS problem has been developed.

Several literature reviews (De Boer et al., 2001; Ha and Krishnan, 2008; Ho et al., 2010; Bruno et al., 2012) show that, especially in the last years, Analytic Hierarchy Process (AHP)

(Saaty, 1980 and 1994) and Fuzzy Set Theory (Zadeh, 1965) are the most widely adopted methodologies (Bhutta, 2003; Sarkar and Mohapatra, 2006; Amin and Razmi, 2008; Bottani and Rizzi, 2008; Chan and Kumar, 2007; Labib, 2011) for dealing with the SS problem. The following sub-sections provide a review of approaches based on these methodologies, also highlighting the gaps in the extant literature.

AHP-based approaches

The main steps of the application of the AHP methodology can be summarised as follows:

1) 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.
2) 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 elements i and j, a value a_{ij} is attributed on a ratio scale ranging from 1 (meaning equally important) to 9 (meaning extremely more important) is generally used (Saaty, 1980). At each hierarchical level the decision-maker establishes scores between elements by defining a_{ij} values. In general a reciprocity condition should be satisfied, i.e. $a_{ji}=(a_{ij})^{-1}$. However, AHP allows for inconsistencies in pair-wise judgments, i.e. $a_{ij}*a_{jk}$ do not need to be equal to a_{ik}.
3) Calculation of the attribute weights. Starting from the data obtained through the comparative judgments, the objective 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.
4) Calculation of global score. Using the attribute and characteristic weights and considering the related measures, global scores are calculated.

In solving the SS problem, as regards the fourth step, alternatives can be evaluated in different ways: (i) through a pair-wise comparison of the alternatives for each criterion; (ii) by assigning an absolute normalised performance measure to each alternative for each criterion; (iii) by scaling performances through a set of qualitative ranges and then assigning to each range a relative weight on the basis of a pair-wise comparison among the ranges. In any case, performances are combined through an additive synthetic methodology using the weights of each criterion to get the final ranking.

In case of multiple decision-makers, pair-wise comparisons performed at each step can be combined through the calculation of geometric averages among the a_{ij} values assigned by each decision-maker (Forman and Peniwati, 1998).

Along with a huge literature about the application of the above-mentioned classical version of the AHP approach, specific proposals for the SS have been provided. Narasimhan (1983), Soukup (1987), Nydick and Hill (1992), Barbarosoglu and Yazgac (1997), proposed the use of the AHP to deal with imprecision in SS. Ghodsypour and O'Brien (1998) integrated AHP with linear programming to consider both tangible and intangible factors in order to maximize the total purchasing value. Sarkis and Talluri (2002) also utilised a more sophisticated version of AHP, the Analytical Network Process (ANP) in dealing with purchasing decisions.

AHP (and ANP) appears to be among the most utilized methodologies to cope with the supplier selection problem (Chai et al., 2013); this is due to several reasons. Having been widely applied in multi-attribute decision-making problems, AHP provides a hierarchical representation of the problem that helps analytic decision-making. It can handle both tangible and intangible attributes and characteristics, also providing mechanisms to monitor the consistency of judgments. Nevertheless, it can be used, in a very flexible and creative way, in combination with many other approaches (fuzzy set theory, optimization, etc.).

FST-based approaches

FST deals with approximate rather than precise evaluations. In contrast to classical set theory, it permits the gradual assessment of elements through membership functions with values generally in the range [0, 1]. In the context of decision-making, this approach can be applied to each step of the process, when weights and performances have to be calculated. In particular, weights of the criteria and values associated with performances may be expressed through fuzzy numbers (i.e. triangular or trapezoidal fuzzy numbers) in order to take into account uncertainty due to various reasons such as incomplete information, variation and approximation of data, dynamics of the problem. Then, fuzzy weights and performances are aggregated and subsequently transformed, through a defuzzification process, into crisp numbers representing the final score of each alternative.

In presence of multiple decision-makers, fuzzy numbers defined by each decision-maker should be aggregated, in order to define further fuzzy numbers including uncertainties derived from each decision-maker.

In the extant literature, Li et al. (1997), Holt (1998) and Osiro et al. (2014) discussed the application of FST in SS. Sarkar and Mohapatra (2006) introduced a fuzzy set approach to measure performance (short-term criteria) and capability (long-term criteria) considering that many suppliers' evaluation criteria cannot be measured precisely. Jain et al. (2007), developed a FST approach to support decision-makers by enhancing flexibility in presence of both tangibles and intangibles attributes. Bayrak et al. (2007) and Lee et al. (2008) proposed fuzzy methods in which both weights and vendor ratings were represented through fuzzy numbers. Amid et al. (2006), Amid et al. (2009), and Pan et al. (2014) discussed the integration of FST with optimization techniques for dealing with the SS problem.

The main advantages in the use of this approach in dealing with SS problem is represented by the possibility of capturing more uncertainty and imprecision in information along the process, in order to reduce the approximations and truncation introduced by using crisp numbers (Bottani and Rizzi, 2008).

AHP and FST-based approaches for SS: a comparison

AHP and FST are among the most popular techniques for decision-making. In particular, in relation to the SS, their popularity is confirmed by the vast literature providing AHP and FST based approaches to solve the problem, also in combination with other techniques (Ho et al., 2010).

It has to be noticed that the combination of FST and AHP based approaches applied to SS is not a novelty (Buyukozkan, 2012; Chen and Chao, 2012; Ertay et al. 2011; Lee at al. 2011a; Lee et al., 2011b; Li et al. 2012; Shaw et al., 2012; Zeydan et al. 2011). However, all the proposals that can be found in the extant literature are mainly focused on the fuzzification of the AHP, through the introduction of fuzzy numbers in the pair-wise comparison matrices (see also approaches developed for slightly different selection and evaluation problems, such as: Cho and Lee, 2013; Ishizaka and Nguyen, 2013; Abdullah and Najib, 2014; Rezaei et al., 2014; Abdullah and Zulkifli, 2015). The final outcome can be viewed as a sort of contamination of the AHP with the Fuzzy Logic, resulting in a higher computational complexity (calculation of eigenvalues, eigenvectors and consistency ratios) and a more complex framework which increases the difficulties in the implementation phase, so reducing the practical usability of the model (Saaty and Tran, 2007). In addition, a vast literature (Narasimhan, 1983; Soukup, 1987; Nydick and Hill, 1992; Barbarosoglu and Yazgac, 1997; Eagan, 1999; Cheng et al., 2007; Saaty, 2010) claims the limited usefulness of this approach as the pair-wise comparison matrix used in AHP is itself able to represent the fuzziness of judgements.

Literature Gaps and Research Objectives

AHP and FST applications to SS problems present some critical issues, particularly in the perception, evaluation and computation of performances and weights associated with the adopted criteria.

While AHP approaches are particularly valuable in the evaluation of weights, they may introduce significant biases in the assessment and quantification of performances associated with the criteria, given the strong sensitivity to the qualitative ranges defined by decision-makers for the evaluation criteria (see Bruno et al., 2012).

For these reasons, when AHP is adopted, differences are not properly tracked and the final outcomes may appear significantly altered and flattened. Then the classical guidelines formulated to appropriately apply AHP should be carefully adapted when the SS problem has to be solved (Triantaphyllou and Mann, 1995).

Conversely, when FST-based approaches are applied for dealing with criteria performances, membership functions can help in smoothing discontinuity introduced by AHP approaches. On the other hand, in real-world practice, some other shortcomings may be identified. In particular, when decision-makers are required to state judgments about the weights of the criteria, some further bias can occur. Firstly differences between levels of importance of criteria can be lost with a consequent overestimation of some criteria. This happens due to decision-makers attitude to evaluate a significant set of criteria as very important. This tends to produce difficulties in assuring selectivity among criteria.

Therefore, AHP models appear suitable for weights determination, meanwhile for performance evaluation may lead to some biased results; FST models, instead, seem to be appropriate for performance estimations, but on the other side, may introduce some distortions in weights assessment.

As a first aim of the paper, the above-mentioned considerations have led to propose a model based on an integrated AHP-FST framework (introduced in Section 3). In such a model, AHP is utilised for criteria weights determination while FST is adopted to deal with the representation of supplier performances in such a way that the nuances of buyers' perceptions are taken into account without losing information due to the approximations introduced by crisp numbers. In other words, the proposed model does not contaminate AHP with FST (or vice-versa) but keeps the two approaches separate and aims at exploiting the respective strengths, so reducing the computational complexity and facilitating its practical application.

Furthermore, it must be mentioned that, despite the large number of studies appeared in recent years (Bhutta, 2003; Ho et al., 2010; Genovese et al., 2013a), academic papers published in the field of supplier selection seem to be more oriented to the development of methods and techniques, overly emphasizing the need of quantitative methods and overlooking the importance of integration with business strategic thinking when it comes to supplier evaluation. Indeed, 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; Bruno et al., 2012). Indeed, 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. Furthermore, most of the approaches available in the literature fail to capture and discuss the inherent complexities deriving from the multi-stakeholder nature of the problem. Indeed, models and method often just focus on a dyadic version of the problem, overlooking the wider set of actors involved in the decision-making problem (such as managers from different departments at the purchasing firm, second tier suppliers, end-users and their respective requirements), and the challenges deriving from their involvement.
This evidence highlights that despite the wide spectrum of techniques and methods available for tackling the SS problem, there is a lack of thorough empirical tests regarding the practical usability of such methods in real corporate environments. The result is a deep dichotomy between theoretical frameworks and business practice. In other words, the literature is rich of a variety of approaches, but their usability in practical applications is questionable.

Therefore, the main aim of the paper is to contribute to understand further the cited dichotomy between theoretical and practical approaches by verifying the practical and actual usability of the proposed model (based on widely applied approaches from the extant literature) in a real-world corporate context in which multiple stakeholders are involved. The effective usability and adaptability of the proposed model in firms' practices are investigated through an empirical study that will be described in Section 4 and thoroughly discussed in Section 5.

3. An Integrated Model for Supplier Selection

As mentioned above, the integrated model proposed in this paper is based on the use of FST to represent suppliers' performances and on AHP for weights' calculation. The model keeps the two approaches separate, aiming at exploiting the respective strengths.
The developed approach can be regarded as a closed decision-making system, as it works on a known set of decision alternatives (namely, suppliers to be evaluated); the outcome of the model will be the ranking of these alternatives, based on the available information (namely, supplier performance) and on the overarching objective (selecting the best supplier).

The effective usability and adaptability of the proposed model in firms' practices are investigated through the empirical study described in the next section.
The steps of the proposed approach are illustrated in Figure 1. In particular, we can distinguish between some shared steps and some specific steps. The first ones deal with the definition of the basic ingredients of the model (step S1) and with the combination of the results provided by the specific steps (steps S2 and S3). The second ones are devoted to the implementation of the classical operations needed to calculate weights in AHP (steps A1, A2 and A3) and to the performance representation through FST (steps F1, F2 and F3). In the following we briefly describe each step according to the flow chart depicted in Figure 3.

Step S1- Model identification and definition of the hierarchical framework
This step is focused on the definition of the components of the model (criteria, sub-criteria, alternatives) through the identification of purchasing firm's needs. Then these elements are organised in a hierarchical framework.

Step A1- Priorities and judgement evaluation
After the definition of the hierarchical schema, the relative importance of the evaluation criteria from the same level of the hierarchy is determined. In particular this phase deals with the identification of the elements of the pair-wise comparison matrix for each involved decision-maker, and the calculation of priority vectors thanks to the eigenvalues identification.

Step A2- Verification of consistency
Consistency of the pair-wise matrices are verified utilising methodologies prescribed by Saaty (1980).

Step A3 – Calculation of the final weights values
Consistent matrices are then utilised to derive a coherent priority vector corresponding to the weights of the criteria (Saaty, 1980).

Step F1 - Definition of performances as linguistic variables
This phase aims at describing alternatives' performances through a FST approach. In particular criteria performances are defined as linguistic variables defined on the basis of five qualitative levels: very poor (VP), poor (P), medium (M), good (G) and very good (VG).
The method chosen for the determination of the membership function has been the manual direct estimation method (Watanabe, 1979) which appears as the most suitable in order to exploit all the collected information. Membership functions are derived by direct estimation assuming the following hypothesis:

- the different points of view of the multiple decision-makers should be incorporated in the definition of the membership function;
- each decision-maker indicates numerical ranges for each qualitative level (VP, P, M, G, VG);
- trapezoidal and triangular membership functions are selected to represent the term sets.

Given these assumptions, the membership functions of the fuzzy numbers representing the terms VP, P, M, G, VG associated to the linguistic variable performance, are then evaluated by direct estimation. The used approach is described in detail in the next Section.

Step F2 - Performance evaluation
It consists in the measurement of indicators associated to criteria, through an appropriate data collection process.

Step F3 - Performance fuzzification
Performance fuzzification consists in the translation of numerical values given by indicators in fuzzy numbers. In this case the numerical values measured for each criterion are compared to the term set of the linguistic variables defined for it. The output values of membership functions are combined according to the inferred weights of the members through a fuzzy weighted operator. The result of this procedure is a fuzzy number translating the crisp value measured for that criterion. This procedure is applied for each criterion.

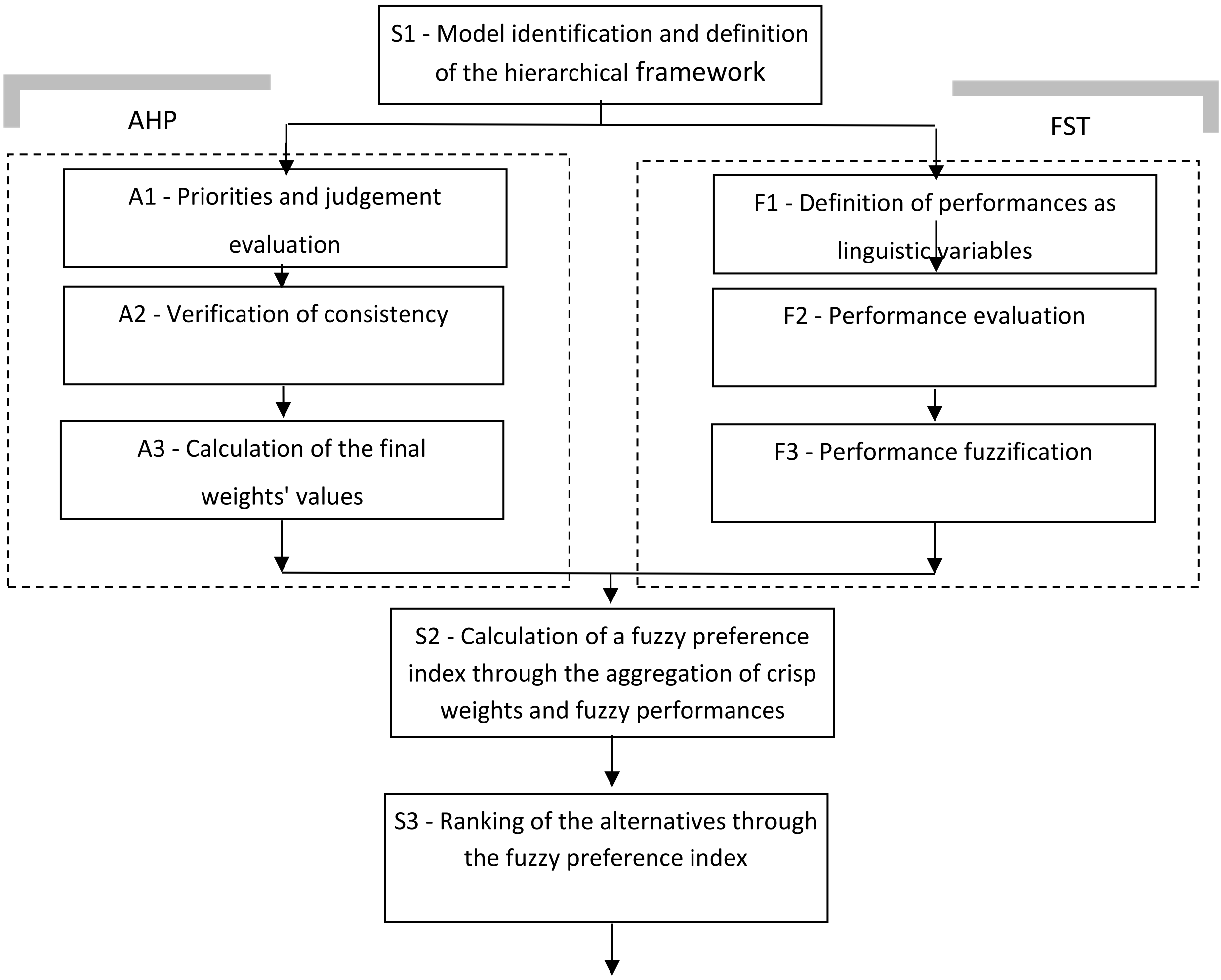

Figure 1 - Flow chart of the proposed integrated approach

Step S2 - Calculation of a fuzzy preference index through the aggregation of crisp weights and fuzzy performances

Fuzzy performances and crisp weights need to be combined to provide the final vendor rating. The issue crucial issue, in this step, is represented by the need of picking a fuzzy aggregation operator that avoids spreading the entropy related to fuzzy numbers when they are combined. On this basis, the weighted mean operator has been used, also because of its calculation simplicity (Zadeh, 1965; Zimmermann, 1992).

Step S3 - Ranking of the alternatives through the fuzzy preference index

The ranking of trapezoidal fuzzy numbers representing the score associated with the different alternatives represents the last step associated with the integrated model implementation. It appears fundamental to utilise the final fuzzy scores of alternatives for profiling a final rank of the alternatives, in order to identify the best one, as this is an important component of the decision process. Abbasbandy and Hajjari (2009) reported more than 30 fuzzy ranking indices, although a heated debate has been developing about the counter-intuitiveness and absence of discrimination capability of many of these methods. According to Bortolan and Degani (1985), each ranking method involves some losing of information; still, nowadays, there is a lack of an universally accepted ranking methodology (Kaufmann and Gupta, 1988; Abbasbandy and Hajjari, 2009); Brunelli and Mezei (2013) have proven that rankings may differ significantly depending on the adopted methodology.

Within ranking methods, defuzzification techniques provide a way to associate a crisp real number to fuzzy sets, in such a way that a ranking can be developed by utilizing a simple ordering relation. These specific techniques can be classified in three main categories (Saletic et al., 2002): distribution techniques, maxima techniques, area techniques. Distribution and area techniques are suggested for use in fuzzy controllers; the maxima techniques are suggested for use in general fuzzy expert systems and fuzzy decision-making systems (Saletic et al., 2002), mainly for the low computational complexity which characterizes them. Therefore, since the main purpose of the step is to provide a simple and straightforward ranking to industrial decision-makers, maxima technique (and, in particular, the Middle of Maxima defuzzification method) are judged as the most suitable to profile the final ranking of the alternatives.

4. An empirical case study

An implementation of the proposed approach was performed in collaboration with the management of Ansaldo Breda (AB), a large leading Italian company in the railway and transportation industry. A state owned firm operating at an international level, AB outsources about 70% of parts and subsystems for the construction traction systems. AB's supply system includes over 500 suppliers globally (Esposito and Passaro, 2007), encompassing vendors characterized by different standards of quality, technology, cost and relationships with second tier suppliers. Given the continuous effort in strategically managing its supply system, AB is interested in the adoption of formalized methodologies for supplier selection, thus being an excellent test-bed for the objectives of this research.

The component analysed 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.

The case study deals with the SS among a set of four candidates (Alfa, Beta, Gamma, Delta), which were asked to provide the bogie (part of the traction system) according to a set of requirements indicated by AB. These companies act as first tier supplier, coordinating a large number of second tier vendors. Therefore, the selection problem is not just concerned with the evaluation of a set of companies, rather involving the assessment of the entire supply systems being coordinated by the first tier suppliers.

On the other hand, the evaluation should be performed by two decision-makers, in the following referred to as DM1 and DM2, representing two different AB corporate functions (respectively representing Sales and Engineering departments), whose different point of views have to be included in the model. Due to their interactions with counterparts in their final customers (railway operators), these decision-makers will be also embedding, in their judgments, influences related to their clients' key requirements. Therefore, it is clear that, in these contexts, the supplier selection problem becomes a strategic and multi-stakeholder issue (as shown in Figure 2).

AB top management asked to provide a methodology able to highlight how potential different opinions were considered in the definition of the final ranking.

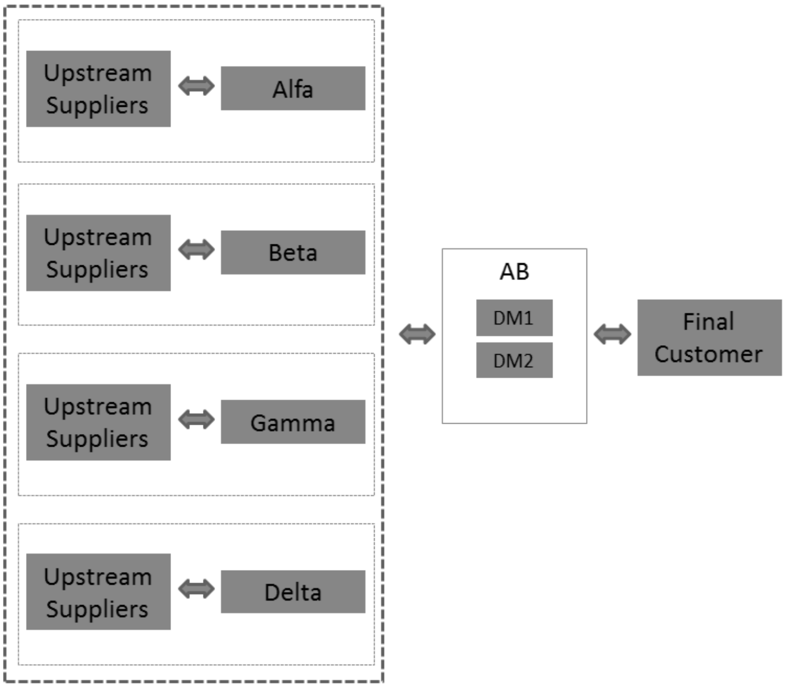

Figure 2 – AB supply system stakeholders map

Therefore, the objective of the presentation is twofold: on the one hand it helps the illustration of the features of the proposed approach; on the other hand it allows for pointing out its potential benefits and crucial aspects (that will be then discussed thoroughly in Section 5), in relationship with the above-mentioned dichotomy between academic theory and corporate practice in SS.

In the following we describe each performed step on the basis of the flow chart indicated in Figure 1.

Step S1- Model identification and definition of the hierarchical framework

This step was performed by merging some insights coming from the literature (Dickson, 1966; Weber et al., 1991) with specific requirements pointed out by the AB management (including executives from both the departments), after a thorough consultation with their final customer. The final result of the process was represented by the identification of 15 criteria which were grouped according to the hierarchical framework indicated in Figure 3, considering 4 main criteria (C16: Quality performance history; C17: Service level; C18: Organization and innovation; C19: Financial position) at first level. For each single criterion a specific indicator was defined and its measure was normalized in a range between 0 and 1. The full detail of categories, criteria and employed indicators is reported in Appendix I. Also, suppliers needed to be consulted, at this stage, for checking the availability of data for all the identified indicators, to ensure the applicability of the hierarchical framework to all the potential vendors.

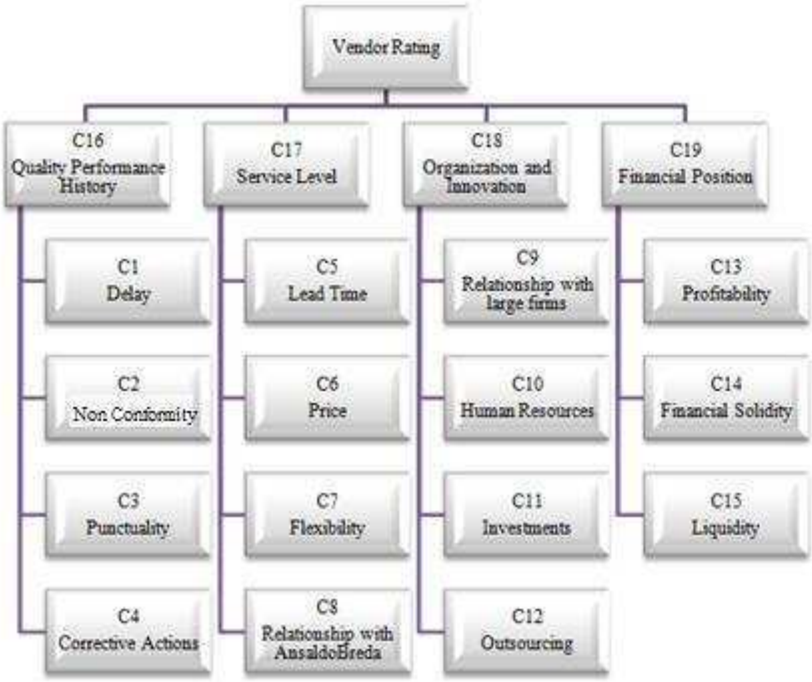

Figure 3 - Hierarchy of criteria

Step A1- Priorities and judgement evaluation

Each DM was asked to provide pair-wise judgments, according to Saaty's (1980) scale for each level of the hierarchy. So each DM provided 5 pair-wise matrices. Each pair of matrices of each level was combined through a geometric average. Table 1 indicates, as an example, the combined pair-wise matrix for the main criteria at the first level of the hierarchy.

	Quality Performance History	Service Level	Organization and Innovation	Financial Position
Quality Performance History	1.00	1.68	3.22	3
Service Level	0.59	1.00	3.76	3.93
Organization and Innovation	0.31	0.27	1.00	0.54
Financial Position	0.33	0.25	1.86	1.00

Table 1 - Combined pair-wise matrix for the main criteria

Step A2- Verification of consistency

The principal eigenvalue (λ_{max}) of each pair-wise matrix was then calculated and the associated consistency index (CI) and consistency ratio (CR) were then derived. Considering the matrix shown in Table 1, we obtained λ_{max}=4.11, CI= 0.04 and CR=0.04. Therefore, as CR is less than 0.1, the consistency of the matrix is verified and the judgments can be considered coherent.

Step A3 - Calculation of the final weights values

Once verified the consistency of the matrix, the final priority vector can be derived. The eigenvector associated to the principal eigenvalue (λ_{max}), was calculated and normalized to obtain the final priority vector. Following the same procedure, for each level of the hierarchy, values of the weights for each single criterion were obtained as indicated in Figure 4.

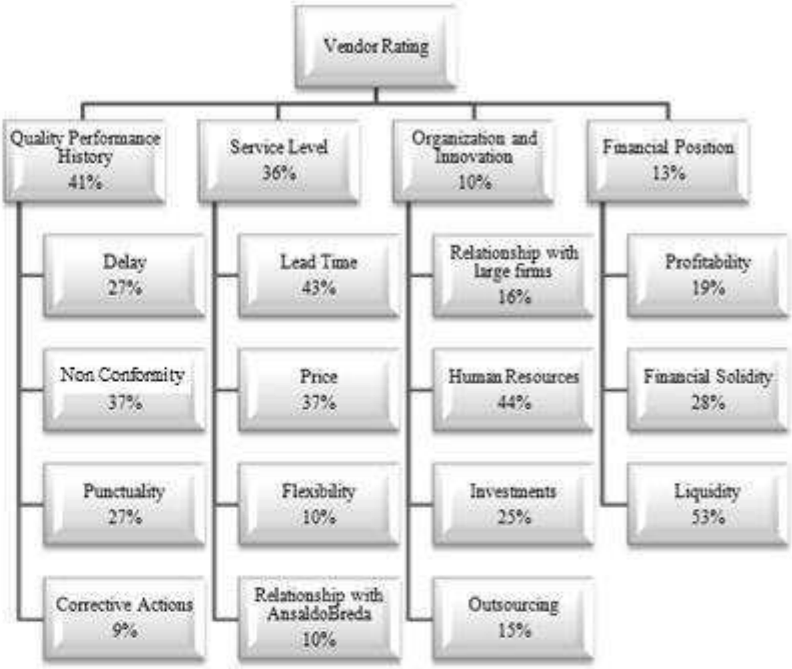

Figure 4 - Crisp weights associated to each criterion of the hierarchical model

Step F1 - Definition of performances as linguistic variables

The crucial phase involving the FST approach in this integrated model is represented by the definition of performances as linguistic variables. In order to show how this step is performed, we describe, in the following, the process with reference to the criterion "Delay" (C1). As specified, each criterion was measured on a normalised scale in the range [0,1]. Then each decision-maker was asked to associate an interval of this range to each of the five qualitative levels (VP, P, M, G, VG). Table 2 provides the indications of each decision-maker (DM1, DM2) for the criterion Delay.

Qualitative levels	**VP**	**P**	**M**	**G**	**VG**
DM1	[0.0 , 0.5[	[0.5 , 0.6[	[0.6 , 0.8[	[0.8 , 0.9[	[0.9 , 1.0]
DM2	[0.0 , 0.3[	[0.3 , 0.5[	[0.5 , 0.7[	[0.7 , 0.9[	[0.9 , 1.0]

Table 2 - Ranges of the qualitative levels for the criterion Delay

It is apparent that, apart from the level VG, the two DMs have different opinions about the ranges to be attributed to each qualitative level. Then the different ranges values are combined in order to produce a trapezoidal membership function associated to each qualitative level. Assuming that a trapezoidal membership function can be defined through 4 values (a, b, c, d) as shown in Figure 5, it is necessary to appropriately combine, for each qualitative level, values indicated in Table 3. It is apparent that if b=c the trapezoidal function becomes triangular.

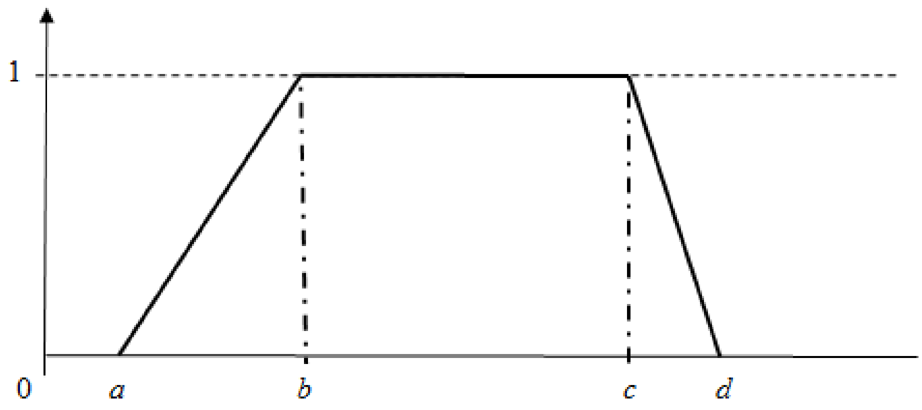

Figure 5 - Example of trapezoidal membership function

We show how a, b, c, d are derived with reference to the qualitative level M. The value a is calculated as the minimum of the lower extremes (a=min(0.6, 0.5)=0.5) while the value d as the maximum of the upper extremes (d=max(0.8, 0.7)=0.8). Then, the intersection of the values of the indicated ranges ([0,6; 0.8[∩ [0,5; 0.7[= ([0,6; 0.7[ ) is calculated. So b and c are considered equal to the extremes of the intersection set (b=0.6; c=0.7). Obviously the procedure can be easily extended to the case of more than two decision-makers. Applying the described operations to each qualitative level, it is possible to obtain the values a, b, c, d indicated in Table 3. Figure 6 shows the obtained membership functions for each qualitative level for the criterion Delay.

Qualitative levels	**VP**	**P**	**M**	**G**	**VG**
A	0.0	0.3	0.5	0.7	0.9
B	0.0	0.5	0.6	0.8	0.9
C	0.3	0.5	0.7	0.9	1.0
D	0.5	0.6	0.8	0.9	1.0
Membership function	Trapezoidal	Triangular	Trapezoidal	Trapezoidal	Trapezoidal

Table 3 - Calculated parameters for the trapezoidal membership function starting from the values indicated in Table 2

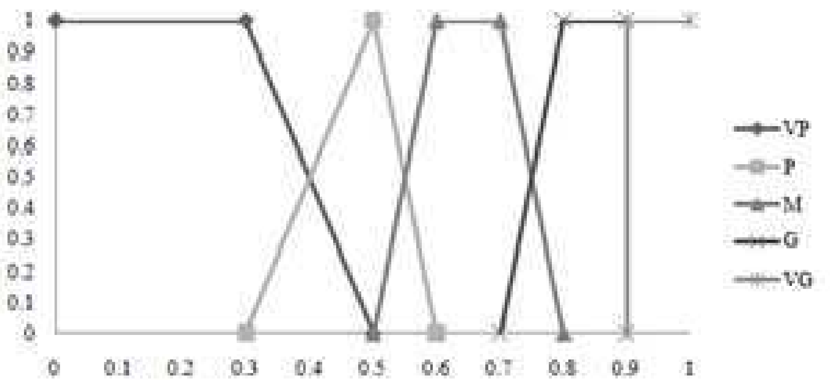

Figure 6 - Obtained membership functions for each qualitative level for the criterion Delay.

Step F2 - Performance evaluation
Crisp performance values were than associated to each candidate (Alfa, Beta, Gamma, Delta) for each criterion.

Step F3 - Performance fuzzification
Performance fuzzification consists in transforming crisp performance values into fuzzy numbers. In order to explain the process we show, as an example, the fuzzification of the performance of a given candidate (Alfa) in relation to the criterion Lead Time, considering that its crisp performance value (defined according to the corresponding indicator shown in Appendix A) for the criterion was equal to 0.58. This value has to be compared to the set of linguistic variables defined for the criterion, according to the process described in the step F1, and depicted in Figure 7.

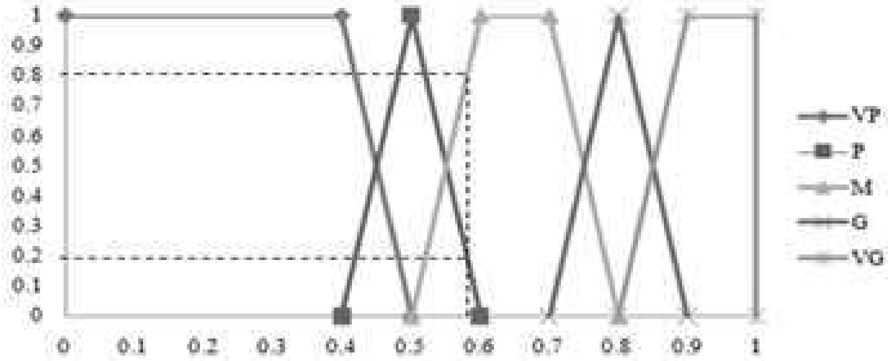

Figure 7 - Obtained membership functions for each qualitative level for the criterion Lead Time

As it can be noticed from Figure 6, the performance value 0.58 corresponds to two different membership functions associated to the qualitative level P and M, whose parameters a, b, c, d are indicated in Table 4. The values of the membership functions corresponding to the performance value 0.58 can be easily derived as intersection of the membership functions with the value 0.58. Then, performances are fuzzified by considering the values of parameters a, b, c, d reported in Table 4 and averaging them considering the membership function values as weights, as shown in Table 5.
The same process was applied to get fuzzy numbers representative of the performances, for each candidate, of each sub-criterion, then obtaining the values of parameters a, b, c, d reported in Table 6.

Qualitative level	a	B	c	d	Membership function	Value of membership function corresponding to 0.58
P	0.4	0.5	0.5	0.6	Triangular	0.2
M	0.5	0.6	0.7	0.8	Trapezoidal	0.8

Table 4 - Parameters for the membership functions of qualitative level P and M for the criterion Lead Time

A	b	c	d	Membership function
0.4*0.2+0.5*0.8=0.48	0.5*0.2+0.6*0.8=0.58	0.5*0.2+0.7*0.8=0.66	0.6*0.2+0.8*0.8=0.76	Trapezoidal

Table 5 - Fuzzy number representing performance of supplier Alpha for the criterion Lead Time

		Alpha				Beta				Gamma				Delta			
C16	C1	0.90	0.90	1.00	1.00	0.70	0.80	0.90	0.90	0.90	0.90	1.00	1.00	0.90	0.90	1.00	1.00
	C2	0.90	0.90	1.00	1.00	0.90	0.90	1.00	1.00	0.90	0.90	1.00	1.00	0.90	0.90	1.00	1.00
	C3	0.26	0.43	0.47	0.59	0.24	0.40	0.46	0.58	0.50	0.60	0.70	0.80	0.50	0.60	0.70	0.80
	C4	0.90	0.90	1.00	1.00	0.90	0.90	1.00	1.00	0.00	0.00	0.30	0.50	0.90	0.90	1.00	1.00
C17	C5	0.48	0.58	0.66	0.76	0.80	0.90	1.00	1.00	0.78	0.88	0.96	0.98	0.80	0.90	1.00	1.00
	C6	0.80	0.90	1.00	1.00	0.80	0.90	1.00	1.00	0.80	0.90	1.00	1.00	0.80	0.90	1.00	1.00
	C7	0.00	0.00	0.30	0.50	0.00	0.00	0.30	0.50	0.60	0.80	0.80	0.90	0.00	0.00	0.30	0.50
	C8	0.32	0.40	0.48	0.58	0.45	0.55	0.60	0.70	0.00	0.00	0.40	0.50	0.00	0.00	0.40	0.50
C18	C9	0.70	0.80	1.00	1.00	0.70	0.80	1.00	1.00	0.70	0.80	1.00	1.00	0.70	0.80	1.00	1.00
	C10	0.00	0.06	0.08	0.35	0.01	0.12	0.13	0.39	0.00	0.01	0.03	0.31	0.00	0.04	0.06	0.33
	C11	0.80	0.95	0.95	1.00	0.00	0.00	0.30	0.50	0.00	0.00	0.30	0.50	0.33	0.53	0.53	0.73
	C12	0.00	0.00	0.07	0.30	0.80	0.90	1.00	1.00	0.00	0.00	0.07	0.30	0.80	0.90	1.00	1.00
C19	C13	0.00	0.00	0.40	0.40	0.00	0.00	0.40	0.40	0.00	0.00	0.40	0.40	0.00	0.00	0.40	0.40
	C14	0.00	0.00	0.40	0.40	0.46	0.52	0.62	0.66	0.00	0.00	0.40	0.40	0.00	0.00	0.40	0.40
	C15	0.80	0.90	1.00	1.00	0.80	0.90	1.00	1.00	0.70	0.70	0.80	0.90	0.76	0.82	0.92	0.96

Table 6 - Parameters of the membership functions of performances of each candidate supplier for each criterion

Step S2 - Calculation of a fuzzy preference index through the aggregation of crisp weights and fuzzy performances

Crisp weights and fuzzy performances were aggregated across the hierarchy, to obtain the fuzzy preference index through the weighted fuzzy operator.

In Figure 8 an example of Step S2 is reported showing how vendor rating was determined for supplier alpha starting from the fuzzy performance associated to the criteria quality performance history (C16), service level (C17), organization and innovation (C18) and financial position (C19) and the respective crisp weights associated with them.

	Fuzzy Performance (Alpha)				Crisp Weights
C16	0.726	0.772	0.857	0.888	0.41
C17	0.534	0.622	0.732	0.805	0.36
C18	0.314	0.393	0.442	0.608	0.1
C19	0.424	0.477	0.718	0.718	0.13

Weighted Fuzzy Operator

Alpha VENDOR RATING (fuzzy)	0.577	0.642	0.752	0.808

Figure 8 - Example of aggregation of crisp weights and fuzzy performances

Step S3 - Ranking of the alternatives through the fuzzy preference index

Finally, fuzzy numbers representative of the vendor ratings were defuzzified adopting the middle of maxima (MoM) defuzzification method. Also in this case, in Figure 9 an example of defuzzification is reported for the fuzzy vendor rating determined for the Supplier Alpha.

The same procedure was applied to determine the vendor rating for the suppliers Alpha, Beta, Gamma and Delta with the results reported in Figure 9.

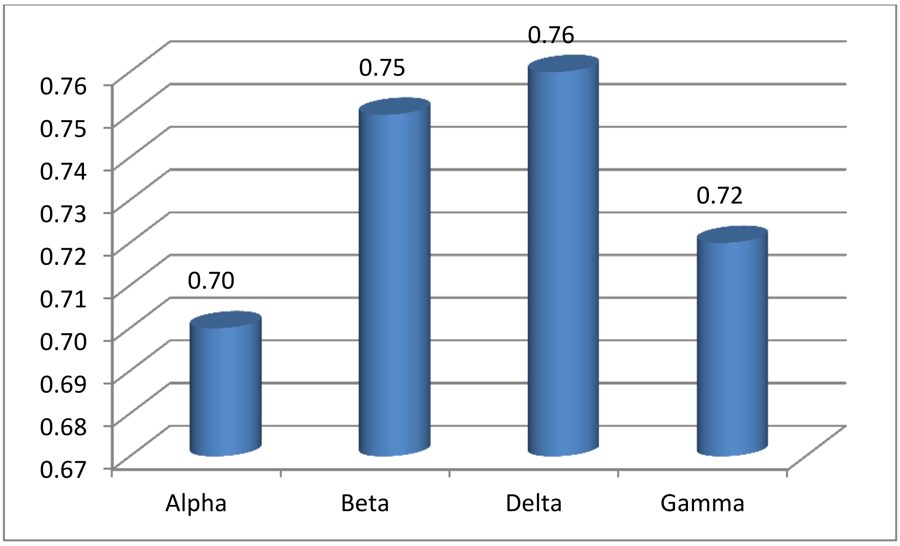

Figure 9 - Final ranking obtained with the integrated model

These results highlight that the proposed approach is characterized by a remarkable transparency, which allows suppliers to understand the key criteria on which they need to work to increase their overall rating; at the same time, it provides the focal firm (in this case, AB) with the possibility to advice suppliers on the actions they need to implement to better respond to their requirements. For example, Alpha appears as the worst supplier competing in this selection exercise. The full visibility of the performances for each criterion and of the weights associated with these criteria points out, for example, that Alpha could improve its position in the ranking working over the sub-criterion Lead Time (C5), whose value is definitely lower than other suppliers' and whose associated weight is considerably high (0.43).
Hence if supplier Alpha was advised to improve its performance for the sub-criterion "Lead Time", it could achieve a significantly better position in the final ranking.

5. Discussion

The implementation of the model shows that the integrated model allows identifying key assessment variables and to work on them in order to provide higher performances and remarkable advantages for both final customers, focal firms (in this case, AB) and suppliers; hence, it can be adopted as a strategic tool to manage successfully complex supply systems. Its practical relevance lays in the possibility to adopt it as a managerial support tool to drive suppliers to the best performances and purchasing firms (and their respective final customers) to a clear understanding and communication of the key requirements they ask to their suppliers. In order to evaluate in a thorough way the usability of the model in a real-world corporate context, several steps were undertaken. Firstly, a post-implementation focus group with involved stakeholders was performed, for understanding their perceptions about strengths and weaknesses of the model; then, findings were also critically analyzed on the basis of a theoretical framework for the evaluation of supplier selection approaches proposed by De Boer and Van der Wegen (2003), also leading to some managerial implications. The following sub-sections provide a detailed account of this process.

5.1 Post-Implementation Focus Group

The described integrated model for SS aims at combining AHP and FST methodologies by exploiting their respective strengths. However, the model is not immune from some residual weaknesses. In Table 7 we summarize the main strengths and weaknesses that characterize the proposed approach (and, in general, formalized supplier selection methodologies) as

identified by the main stakeholders in AB supply chain in a post-implementation focus group. Participants to this focus group included managers from the two AB departments involved in the evaluation process, representatives from the four first tier suppliers, a representative of the final customer. Participants were asked to list strengths and weaknesses of the methodology by individual interviews; then, findings were consolidated in the mentioned focus group, in which a consensus was reached. Table 7 provides a classification of the mentioned strengths and weaknesses, that are also classified as general (as they can be referred to any formalized approach for supplier selection) or specific (if they are solely referred to the proposed approach).
The main issues highlighted by practitioners are related to the time consuming procedure to carry out the investigations and collect all the required information, and to the need for expert advice throughout this process. Also, given the variables involved in the evaluation exercise, and the need to calculate quantitative indicators, practitioners highlighted the potential heavy requirements in terms of data sharing, storage and collection. This may imply a heavy burden on vendors that could have a cascade effect throughout the supply chain, also involving suppliers from upstream tiers that may not be ready to cope with these requirements. Moreover, it was also pointed out that such a model assumes that relationships between the focal firm and suppliers are trustful and based on cooperation: this is a strong requirement for ensuring the consistency and accountability of shared data.
Furthermore (this consideration was mainly highlighted by the focus group facilitators), there may be a strong dependence of the final results on some decisions related to parameters required for the operationalization of FST measurements. This means that the definition of membership functions, the selection of the aggregation operators to combine fuzzy performances and crisp weights and the defuzzification method are still closely related to the specific application. Consequently, changing the context (i.e field of application or the specific problem) the overall model should be redefined.

On the other hand, the introduced approach presents several strengths, that were highlighted by the interviewed stakeholders. First of all, it was agreed in the focus group that the method permits the disclosure of the explicit and tacit needs of the focal firm (and of its final customer); it allows handling also incomplete information characterized by uncertainty and vagueness (for instance, with respect to performance evaluation); it permits accounting for multiple perspectives which can be computed and aggregated properly. Stakeholders also highlighted that, through AHP mechanisms, the approach favours the detection of inconsistent judgments in weight determination; hence, it handles the subjectivity of weights definition in a rigorous way. It was also agreed that no complex calculation are involved, neither costly tools are required to run model implementation.
Moreover, facilitators also pointed out that this integrated approach is capable of dealing with qualitative ranges defined for the indicators ensuring to keep track of the variation of supplier performances avoiding over- and/or underestimations. The definition of membership functions for these qualitative ranges allows overcoming all these issues and representing suppliers’ performances in a way that is very close to customers’ perceptions, avoiding evaluation approximations due to the use of crisp numbers.

STRENGTHS	General	Specific	WEAKNESSES	General	Specific
Clear and detailed mapping of customers' needs (explicit and latent)	✓		Time consuming procedures for data collection and evaluation		✓
Possibility of handling incomplete information, uncertainty and vagueness		✓	Heavy burden on suppliers (at every tier) for data sharing, storage and collection	✓	
Multiple perspective analysis		✓	Need for expert advice throughout the implementation process		✓
Transparency	✓		Need for trustful relationship between buyer and supplier for data consistency and accountability	✓	
No complex calculations required		✓	Heavy influence on results of: - membership function characterization - aggregation operators - defuzzification method		✓
Limited implementation cost		✓			
Reduction of subjectivity in weights definition		✓			
Ability to detect inconsistent judgments		✓			
Possibility to overcome the ambiguity of border values of qualitative ranges		✓			
Possibility to keep track of gaps between numerical values (no over/under estimations)		✓			

Table 7 - Strengths and Weaknesses of the proposed model

5.2 Critical Analysis

A comprehensive analysis of the emerging issues in the use of the proposed approach can be performed following De Boer and Van der Wegen (2003) evaluation framework, whose criteria are listed in Table 8.

Dimensions	Symbol	Criteria
Complexity Fit	CR1	Does the model aggregate information in a proper way?
	CR2	Does the model sufficiently utilise available information?
	CR3	Is it (to a satisfactory extent) possible to incorporate opinions and beliefs?
	CR4	Is it (to a satisfactory extent) possible to achieve a fair participation of individual members in case of a group decision
	CR5	Is the model sufficiently flexible for changes in the decision situation?
Cost vs Benefit	CR6	Is the outcome of the decision model useful?
	CR7	Is the outcome of the decision model acceptable?
	CR8	Are the required investments justifiable?
	CR9	Is the model sufficiently user-friendly?
	CR10	Is the way the decision model works sufficiently clear?
	CR11	Does the decision model increase the insight in the decision situation?
	CR12	Does the decision model contribute to the communication about and the justification of the decision?
	CR13	Does the decision model contribute to decision-making skills?

Table 8 - Criteria for supply selection methodologies (De Boer and Van der Wegen, 2003)

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 the integrated model, taking advantage of the AHP structure, lays in the capability of aggregating information (criterion CR1), through the decomposition of the problem in a hierarchical frame. Therefore, the integrated model is useful in constructing structured and formalized approaches for supplier evaluation, as it allows taking into account multiple criteria, indicators and data for the calculation of a final supplier score.

Similarly, the model makes good use of available information (criterion CR2), also permitting the incorporation of intangible and qualitative measures in the performance evaluation exercise; its performance, compared to the one of a simple AHP-based model can be rated as superior, as, thanks to the fuzzy logic, imprecise and vague information, reproducing managers beliefs and opinions in a much better way, especially regarding supplier performance evaluation (criterion CR3).

With regards to the possibility of achieving a fair participation of individual members in case of a group decision (criterion CR4 in Table 8), as the core of the model 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, is relevant. Moreover, judgments significantly depend on the specific point of views of the involved interviewees. This influence also includes the identification of indicators and their fuzzified value scales that strongly depend on involved management perceptions. Furthermore, 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. The model, however, can easily accommodate the multi-stakeholder nature of the problem. Indeed, the definition of the hierarchical structure and of the related indicators requires the involvement of both upstream suppliers and final customers.

A crucial aspect regards the flexibility of the model (criterion CR5). Indeed, it has been discussed that the supplier selection system must be tailored to a specific component and customized according to the specific requirements. This means that it is not possible identifying 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 the literature a wide set of attributes have been proposed (Ha and Krishnan, 2008; Dickson, 1966; Weber et al, 1991), the application has highlighted that these attributes can be considered generic and/or abstract. However it should be pointed out that, thanks to the flexibility of the approach, the model is easily adaptable to the evaluation of different components by systematically reproducing the stages of the procedure. Finally, once the model has been implemented on the basis of the focal firm's strategic objectives, any change in the latter implies a revision of the model itself. Thus, any SS methodology should be dynamic, in order to take this aspect into account. This means that 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 CR6 and CR7), all the above mentioned considerations (plus the ones emerging from the focus group), including the fact that the final ranking could be not so effective due to negligible differences in the final scores, underline why firms are reluctant to use these tools because they are often too distant from the reality of the corporate world. In fact, most firms approach the supplier selection problem by simply adopting a qualitative methodology based on judgment from some experts, as also stated by various authors (de Boer and van der Wegen, 2003; Bruno et al., 2012). This is strictly linked to required investments and their justification (criterion CR8) and easiness of implementation and user friendliness (criterion CR9) of the model. It is clear that, while employing qualitative and not formalized methodologies can present some advantages, the implementation of the presented model may require high start-up resources, due to substantial efforts in terms of time, training and skills of expert personnel; moreover, positive implications deriving from the implementation of such systems may become apparent just in the long run. Consequently, there are good reasons to believe that the model can work successfully only if applied in industries where SS appears as a multi-criteria problem, in which multiple stakeholders have to be involved in both the scoping and the decision-making process; thus, these complexities can justify high value investments for modelling SS problems. This peculiarity fits well with highly complex industries, in which the supply systems are crucial for large firms' competitiveness and where suppliers give a great contribution to the value chain. By contrast, in industries where decisions are made looking at their implications in the short term horizon, where well established relationships have a strong influence in vendors selection and where, essentially, few variables are computed to handle supplier assessment, qualitative (and even informal) methodologies could still be perceived as being the most effective approaches to be adopted for suppliers selection (see also Esposito and Passaro, 2007; Bruno et al., 2012; Monczka et al., 2015, pp. 245-284).

The developed approach also provides significant benefits that were also highlighted by AB managers in a post-implementation focus group. A first benefit is related to the development of a learning process. Indeed, thanks to the clear structure and functioning of the integrated methodology (criterion CR10), setting up such a methodology allows both the focal firm 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 utilisation of such methodology is able to provide the decision-maker with new insights for his purchasing decisions (criterion CR11) and to improve decision-making skills (criterion CR13). Indeed, a further advantage related to the adoption of the integrated model, compared to qualitative and not formalized approaches, is that this kind of model, differently from qualitative approaches, can be formalized (through the construction of IT-based decision support systems) and easily transferred from one person to another without wasting expertise or knowledge of purchasing managers when job rotation policies or change of roles take place. This implicates several advantages for companies, which despite the initial efforts in term of money and time decide to implement such integrated model as supporting tool for strategic supply chain management.

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 CR12) 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, according to a multi-stakeholder perspective. However, this could also lead to a side-effect: firms could simply focus on the criteria considered highly relevant for the selection (and, for instance, associated with very high weights in the evaluation model), completely disregarding the ones that are associated with low weights or not even included in the evaluation model.

5.3 Managerial Implications

Considering the consequences on the relationships within the supply system, two main managerial implications emerge from the experience in the practical implementation of the approach.

As regards the focal firm, the proposed methodology facilitates the management of the whole supply chain, beyond the dyadic supplier-buyer relationship, by allowing a continuous realigning of the suppliers' aims to those of the final 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 aim, they have to consider both external and internal aspects of the buyer-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 buyer-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, it 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.

6. Conclusions

In recent years, an increasing number of researches has been devoted to the development of different methodologies to cope with the Supplier Selection Problem. Nevertheless, while the number of applications is growing, the practical usefulness of such tools is often questionable, with an emerging dichotomy between academic theory and business practice.
This paper has strived to understand to a greater extent this dichotomy, by proposing a model based on the integration of Analytic Hierarchy Process and Fuzzy Set Theory (two of the most employed methodologies for dealing with the Supplier Selection Problem) and evaluating its practical usability through a case study concerning the evaluation of suppliers in a real-world company from a complex industry. The analysis has been carried out by analysing, in a detailed manner, each step of the implementation of the model, highlighting benefits and shortcomings related to its use.
The case study has shown that the integrated model can be adopted as a strategic tool to manage complex supply systems, providing advantages to the focal company in terms of clarity in mapping the decision-making process and transparency of the evaluation process. Also, the model provides the possibility of incorporating multiple perspectives in the analysis, and, thanks to the fuzzy elements, of handling incomplete information, uncertainty and vagueness. Nevertheless, problems related to the practical implementation of the model have been highlighted, including: potential time consuming procedures for data collection and evaluation; heavy burden on suppliers for data sharing, storage and collection; need for expert advice throughout the process; dependence of the outcome on technical aspects.
The study has therefore contributed to understand the above-mentioned persistent dichotomy between academic literature and corporate practice concerning supplier selection approaches, highlighting a trade-off between the benefits that can be achieved through formal methodologies and the investment required in terms of skills, time and resources.
Further researches will be devoted to a further and deeper understanding of the dichotomy between theoretical approach and empirical application in the SS problem, by employing other formalized methodologies (for instance, based on other Multi-Criteria Decision-making techniques) and testing the benefits deriving from their implementation in a corporate context.

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Appendix I

Indicators employed in the integrated model with their full description.

Category	*Denomination*	*Definition*	*Range and Target Value*	*Further considerations*
Quality Performance History	**Delay**	$DI = 1 - \frac{delayedllines}{totalorderlines}$	$0 \leq DI \leq 1$ $DI \approx 1$	Delay Index (DI) is evaluated looking at the purchasing order and assessing how many order lines are in delay compared to the total number of order lines. The target value is 1 which correspond to no order lines in delay in the purchasing order.
	Non Conformity	$VR_{NC} = 1 - \frac{(NC_{at\ the\ desk} + NC_{on\ the\ production\ lines})}{Total\ quantityarrived}$	$0 \leq VR_{NC} \leq 1$ $VR_{NC} \approx 1$	VR_{NC} indicator was inherited from the "ancient" supplier evalution method adopted in AnsaldoBreda. VR_{NC} target value is 1 which corresponds to no conformity detected at the desk, neither across the production lines as well.
	Punctuality	$PI = \frac{(Scheduled\ Date + 20) - (\text{Purchasing}Order\ Date)}{(Material\text{Release}\ Date + 3) - (\text{Purchasing}Order\ Date)}$		In PI definition the scheduled date is increased of 20 days to account technical time required for making, signing and sending the purchasing order to the supplier. The material release time is, instead, increased of 3 days which is the estimated time for making the release material bill.
	Corrective Actions	$CA = 1 - \frac{CorrectiveActionsClaims}{Audits}$	$CA \approx 1$	CA indicator measures the number of corrective actions claims in comparison to the total number of audits. If corrective actions are claimed for each audit received by the supplier this indicator is around 0 and indicates bad performances. In particular, even if the ratio Corrective Action Claims/ Audits is greater than 1, the value assigned to CA is 0.
Service Level	**Lead Time**	$LTI = \frac{LT_{target}}{LT}$	$LTI \approx 1$	Lead Time Indicator (LTI) is given by the ratio between the LT_{target} which was estimated by engineering department as equal to 7 months and LT, which is the lead time estimated by the supplier to process the order. If $LT < LT_{target}$, hence $ILT = 1$
	Price	$PI = \frac{P_{AB}}{P_{supplier}}$	$PI \leq 1$	Price Indicator (PI) was calculated as ratio between P_{AB} which was the price proposed by AnsaldoBreda and $P_{supplier}$, which is the price offered by the supplier. If $P_{AB} < P_{supplier}$, hence $PI = 1$
	Flexibility	$TI = \frac{Other\ SectorsTurnover}{Total\ Turnover}$		Turnover Indicator (TI) aims to measure the ability of the suppliers to work crosswise different sectors. It indicates supplier's turnover in sectors different from the railway transportation one compared to its total turnover. High values for TI indicate high supplier's involvement in different business.
	Relationship with AnsaldoBreda	$RI_{AB} = \frac{Total\ Sales to\ AB}{Total\ Sales}$	$0 \leq IR_{AB} \leq 1$ $IR_{AB} \approx 1$	Relationship with AnsaldoBreda Index (RI_{AB}) compares supplier volume of sales to AnsaldoBreda with supplier total sales. High values for RI_{AB} means AnsaldoBreda strong possibility to influence supplier's behavior.
Organization and innovation	**Relationship with large firms**	$RI_{large\ firms} = 1 - \lvert x - 0.75 \rvert$ $x = \frac{S_1 + S_2 + S_3}{S_{TOT}}$	$RI_{large\ firms} \approx 1$	The Relationship with large firms indicator ($RI_{large\ firms}$) is based on the hypothesis that suppliers get some advantages from interacting with multiple large firms in terms of know how sharing. In the formula for , S_1, S_2 and S_3 represent the suppliers' sales to the three biggest firms with whom the supplier makes business; S stands for total volume sales makes by the supplier. $RI_{large\ firms}$ closer to one means that suppliers gains advantages having strong relationships with its biggest customers.
	Human Resources	$HR = \frac{Numberof\ graduatedemployees}{Total numberof\ employees}$	$0 \leq HR \leq 1$	HR indicator is based on the assumption that academic education of employees working in the firm can positively influence the performance of the supplier
	Investments	$IE = \frac{Invested Capital}{Fixed\ Assets}$		Investments Elasticity (IE) is given by the ratio between Invested Capital and Fixed Assets considering that the Fixed Assets include tangible, intangible and financial assets. IE often present values higher than 1, in this case it is considered the value of the best performing supplier and all the other performances are normalized on it.
	Outsourcing	$OI = \begin{cases} 1 & all\ in\ house \\ 1 & 0.33 \leq out \leq 0.5 \\ 0 & out \leq 0.33\ or\ out \geq 0.5 \\ 0 & out = 1 \end{cases}$ $out = \frac{OutsourcedActivities}{Total numberof\ \text{suppliers}}$		For Outsourcing Index (OI) it was considered the value of *out* which represent the total number of activities outsourced for bogie manufacturing compared to the total number of suppliers who are in charge to carry out these activities. This indicator, aims to estimate the ability of the supplier to rely on other subcontractors to lean its management system.
Financial Position	**Profitability**	$ROE = \frac{Net\ Income}{Shareholder's Equity}$		Profitability is measured through the Return on Equity (ROE) ratio
	Financial Solidity	$Equity\ Ratio = \frac{Total\ Owner's\ Equity}{Total\ Assets}$		Financial Status is evaluated through Equity Ratio (ER) indicator.
	Liquidity	$Acid\ Test\ Ratio = \frac{(Current\ Assets - Stock)}{Current Liabilities}$		Liquidity is evaluated through Acid Test Ratio (ATR). If ATR is >1, value 1 is assigned to this indicator.