On the Applicability of Analytical Techniques for the Selection of AMTs in Small-Medium Sized Firms

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ABSTRACT. The appraisal and selection of investments in advanced manufacturing technologies (AMTs) have received a considerable attention in the literature over the last decade. In particular, many articles, after highlighting the major shortcomings of traditional financial techniques when applied to the analysis of AMTs, have proposed alternative approaches, such as modified discounted cash flow techniques, strategic approaches and multi-attribute decision making methods. However, little attention has so far been paid to the applicability of such "non-conventional" approaches to small-medium sized firms (SMFs). This omission is particular critical for two reasons. First, in most SMFs the decision to adopt a given AMT is usually not supported by any technique, but is based rather on an "act of faith" in a new technology on the part of the entrepreneur. Second, there are some non-conventional techniques that seem particularly suitable for SMFs, in that they do not require major financial and strategic competencies or complex information and planning systems. This article seeks to increase the awareness of major non-conventional approaches among the owners and managers of SMFs and analyse critically the applicability of such approaches.

1. Introduction

The appraisal and selection of investments in AMTs (e.g., computer aided design, computer aided manufacturing, computer aided process planning, robotics, flexible manufacturing systems, information technologies, etc.) have received a considerable attention in the literature over the last decade. In particular, several authors have pointed out the shortcomings of conventional financial approaches (i.e. discounted cash flows or DCF techniques), which do not consider intangible benefits (i.e. benefits that cannot be converted into monetary terms), such as quality, flexibility, timeliness, learning, corporate image, employee satisfaction, etc. (Hayes and Garvin, 1982; Golmar and Jelinek, 1983; Kaplan, 1986; Meredith and Suresh, 1986; Meredith and Hill, 1987). Since these benefits are becoming ever more important in justifying the adoption of AMTs, conventional DCF techniques often fail to assess the effectiveness of AMTs and, thus, do not support correctly managers' decision making. For this reason, many new approaches have been proposed. These can be grouped into three major categories (e.g., Azzone and Bertelè, 1991; Boucher and McStravic, 1991):

1) *"modified" DCF techniques*, aimed at including intangible benefits in DCF analysis (e.g., Kaplan, 1986; Azzone and Bertelè, 1991);
2) *strategic approaches*, that assess investments in AMTs on the basis of their ability to support the implementation of a company's business strategy (Goldhar and Jelinek, 1983; Shewchuk, 1984);
3) *multi-attribute decision making (MADM) methods*, that consider the selection of AMTs as a typical MADM problem, in which profitability is only one of the issues that should be taken into account (Buss, 1983, Nelson, 1986, Mohanty and Venkataramam, 1993, Liang and Wang, 1993).

Even though various authors have discussed and compared the different pragmatic problems and areas of application of these non-conventional techniques (e.g., Azzone, Bertelè and Masella, 1992; Meredith and Hill, 1987), little attention has so far been paid to their applicability to small-medium sized firms (SMFs).

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This omission in the literature seems to be especially critical if we consider that:

– in most SMFs, the decision to adopt a given AMT is usually not supported by any technique, but is driven rather by an “act of faith” in a new technology on the part of the entrepreneur. This approach has been justified by some authors who assert that the introduction of a new technology in a SMF is an “entrepreneurial act” based on intuition and the perception of an opportunity (e.g., Gagnon and Toulouset, 1993).

  We certainly agree that investments in a new AMT requires extensive intuition, but believe that the use of analytical techniques could effectively support the decision also in a SMF by increasing the information frame. This is especially important when: (i) there are several alternative technologies which present a large number of effects with trade-offs between them; and (ii) the investments required for the new technologies are large in proportion to the overall capital of the firm and, consequently, have major impact on financial structure and risk (Gerwin, 1988; Noori and Templer, 1983; Munro and Noori, 1988; Mowshowitz, 1989);
- some non-conventional techniques recently proposed in the literature (the MADM approach) seem to fit well the specific features of SMFs and, paradoxically, their adoption in many SMFs could be favoured precisely by the lack of a deep-rooted financial culture and a tradition in DCF analysis, which have hindered their introduction in several large firms.

We are thus inclined to believe that the limited diffusion of analytical techniques of investment appraisal in SMFs is more the result of a low awareness of such techniques among owners and executives than of an explicit refusal to use these approaches. The objective of this article is to increase this awareness. More precisely, the article aims to compare the major non-conventional techniques in the light of their applicability to SMFs, showing, on the basis of a contingent approach, the different areas of application.

The article is divided into two major sections. The first briefly discusses modified DCF, the strategic approach and MADM methods, pointing out the specific requirements in terms of competencies and systems that a given SMF has to meet in order to adopt these approaches effectively. The outcome of this section is that MADM methods seem to fit well the features of many SMFs, in that they do not require advanced skills nor competence and sophisticated financial and/or strategic planning systems. In the second section, attention is focused on the MADM approach, and three major techniques within this category (namely scoring methods, AHP and fuzzy linguistic models) are compared, underlining the relative strengths and weaknesses and their different areas of application.

2. Non-conventional approaches

In this section, the major approaches to the appraisal and selection of AMTs suggested in the literature are briefly reported. The aim is not to describe these approaches in detail, since a great deal of literature is available in this regard, but rather to point out those features which allow their applicability to SMFs to be evaluated.

2.1. *“Modified” DCF approach*

This category includes those methods aimed at including intangible benefits in DCF analysis. Sponsors of these techniques claim there is no a conceptual obstacle to the application of DCF techniques to AMTs appraisal, and, hence, their effectiveness depends on the possibility of translating intangible benefits into cash flows. Authors have therefore focused on proposing methodologies, frameworks and techniques able to measure different types of intangible benefits in monetary terms. Specifically the main contributions in the literature have concentrated on four issues that have been disregarded by traditional DCF techniques:

– the measurement of the impact on cash flows of an improvement in *flexibility*, that is the ability of the company to respond to environmental changes (Azzone and Bertelè, 1989);
– the assessment, in terms of reduced costs, of improved *efficiency* due to better quality, reduced lead time and thus also stock, increased labour productivity, etc. (Godfrey and Pasewark, 1988; Plunkett and Dale, 1988; Meredith and Suresh, 1986);

– the measurement of the effects on cash inflows of improvements in the *performance of products and/or of services* (e.g., quality, delivery time, dependability, etc.) and, consequently, in customer perceived value;
– the assessment of the economic effects of the *future investment options* kept open by the adoption of a given AMT (Person, 1994; McDonald and Siegel, 1986; Azzone and Bertelè, 1991a; Kensinger, 1988).

Various authors have highlighted the strengths of modified DCF techniques, such as their ability to calculate the overall impact of the investment on shareholder value and to allow the post-auditing of the investment. However, the application of modified DCF techniques is complex, given the difficulties in data retrieval and analysis and the computational efforts required. For this reason, an effective application of modified DCF methods demands:

– advanced financial skills and competencies, especially with regard to DCF analysis;
– sophisticated information systems able to provide both financial data (e.g. unit material cost, cost of capital) and non-financial data (e.g. productivity, set-up time, stock);
– the availability of financial and business analysts to support managers in the development of the DCF model and in the process of data retrieval and analysis.

For these reasons, the applicability of a modified DCF technique in SMFs is usually low. In most SMFs, the financial culture of the entrepreneurial and management team is poor, conventional DCF techniques are not used (except in some cases of pay back time) and there are no staff specifically dedicated to financial analysis (financial decisions are often delegated to external experts, such as bankers or business advisors).

2.2. *Strategic approach*

The models included in this category aim to justify investments in AMTs on the basis of their ability to support business strategy (Goldhar and Jelinek, 1983; Shewchuk, 1984,). Sponsors of this approach underline the major impact of an AMT on a company's competitive advantage and suggest using competitive analysis models, such as Porter's five competitive strengths and value chain (1980 and 1985), to assess such investments. Let us assume, for instance, that a company seeks cost leadership. According to this approach, the investment in a given AMT should be assessed in terms of lower cost with respect to all the value-activities of the company and to the linkages between these and the activities of suppliers and customers.

The strategic approach, which aims to link strategic analysis and investment assessment, is conceptually sound. However, in order to be effective, executives must be used to carry out strategic analysis and use explicit models of competitive analysis.

Many SMFs do not undertake such explicit strategic planning process, or if they do, it is not usually based on formal and well-defined models of competitive analysis (e.g., Stoner, 1982; Orpen, 1994) but rather only on qualitative judgements and discussions within the entrepreneurial and management team.

For this reason the application of strategic approaches to the appraisal and selection of AMTs presents major limitations in a SMF environment.

2.3. *MADM approach*

Methods included in this category see the selection of AMTs as a typical MADM problem. These models require first of all to identify all performance variables related to the overall objective of the company that are affected by the adoption of AMTs. It is important that these performance variables, which represent the criteria on which the selection is based, are independent and not redundant. In support of this step, it may be useful to develop a hierarchical structure in terms of overall objective, criteria, and decision alternatives (see Figure 1).[1]

MADM models can be divided into the following major steps:

1) determine the relative importance of performance variables (i.e. criteria) in contributing to the achievement of the overall objective of the company;
2) assess each alternative decision with respect to every criterion, taking account of the ability of the alternative to meet such criterion;

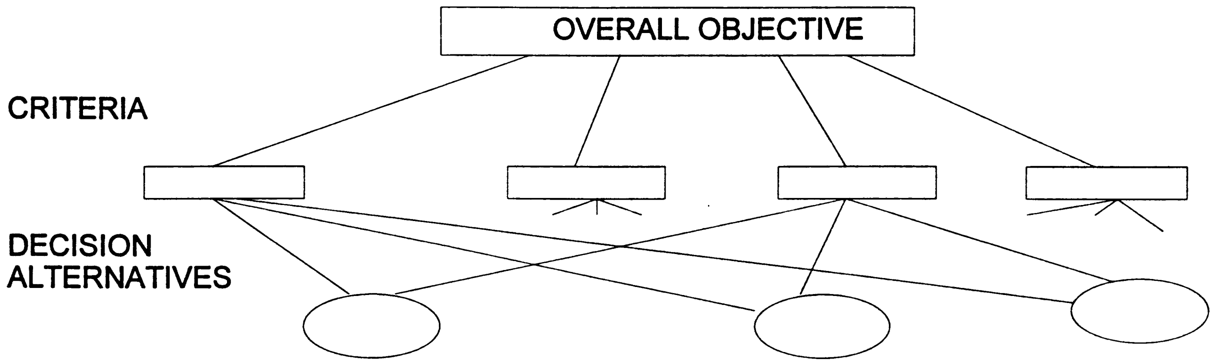

Fig. 1. The hierarchical structure of the decision problem.

3) calculate the overall suitability ratings of the alternatives and rank them.

The application of MADM techniques is fairly simple, since they do not require specific competencies or sophisticated information and planning systems. Furthermore the logic is fairly intuitive, being similar to that employed by every human being in dealing with a complex decision (i.e. assessment of the level of suitability of alternative decisions with respect to major criteria and a summary of these as an estimate of the overall suitability of each alternative). Depending on the individual MADM technique used, the only prerequisite is a certain level of analytical skill and mathematical sensitivity, as shown in the next section.

Figure 2 illustrates the different areas of application of the three types of approach to the appraisal and selection of AMTs in SMFs, in terms of financial and strategic competence and systems. This Figure reveals that, as MADM methods can be applied even in companies with low financial and strategic competence and systems, they may be particularly suitable for SMFs. Paradoxically, the introduction of such techniques in many SMFs could also be favoured by the lack of a deep-rooted financial culture and a tradition in DCF analysis, which have hindered their introduction in many large firms.

In the next section, attention is thus focused on MADM techniques.

3. Major MADM methods

This category includes several techniques that differ from each other in terms of: i) the measurement scales used to carry out steps 1 and 2 of the previous section; and ii) the algorithms that

	FINANCIAL COMPETENCE AND SYSTEMS	
STRATEGIC COMPETENCE AND SYSTEMS	**LOW**	**HIGH**
LOW	• MADM METHODS	• MODIFIED DCF TECHNIIQUES • MADM METHODS
HIGH	• STRATEGIC APPROACH • MADM METHODS	• MODIFIED DCF TECHNIQUES • STRATEGIC APPROACH • MADM METHODS

Fig. 2. Different application areas of non-conventional approaches in SMFs.

perform step 3. In this section, three major techniques are briefly reported, namely: scoring methods, Analytic Hierarchy Process and fuzzy models. The objective of this section is not to describe in detail the application of these methods to the appraisal and selection of AMTs, since to this aim various sources can be found, but rather to show the basic principles of the three MADM methods in order to compare them with respect to their applicability to SMFs.

3.1. *Scoring methods*

Scoring methods are the simplest MADM techniques and, for this reason, are widely used (Fishburn, 1965; Edwards, 1977; Buss, 1983; Canada, 1986; Noori and Gillen, 1995).

In a typical scoring method, the steps listed in the previous section are performed as follows:

1) the relative importance of the performance variables is measured by numeric weightings expressed as real numbers from 0 to 1 whose sum is equal to 1 (i.e. W_i is the importance weighting of the i-th performance variable);
2) the assessment of each AMT with respect to performance variables is made using a scoring scale from, for instance, 1 to 10 (i.e. A_{ij} is the score of the j-th alternative AMT with respect to the i-th criterion);
3) the overall suitability rating Λ_j of each alternative is calculated by averaging the score of the alternative with respect to every criterion with the corresponding importance weighting, as follows:

$$\Lambda_j = \sum_i W_i A_{ij}$$

In spite of the simplicity of the underlying mathematical tools, the application of scoring methods can present some problems as a result of the unfriendly interface with the decision maker. In particular, scoring methods require the decision maker to give absolute judgements, of both suitability ratings and importance weights using artificial numeric measurement scales.

3.2. *Analytic Hierarchy Process (AHP)*

The AHP is a multi-attribute decision tool aimed at integrating several performance measures into a single overall score ranking alternative decisions. Its main characteristic is that it is based on pairwise comparison judgements (Saaty, 1980, 1988, 1994). The AHP, which is implemented by various software packages (for a review see Buede, 1992) available on the market, has been applied to several managerial problems, including the appraisal and selection of AMTs (Frazelle, 1985; Wabalickis, 1988; Golden et al., 1989; Oeltjenbruns et al., 1995; Kuei et al., 1995).

The AHP performs the indicated above steps as follows:

1) the relative importance of the criteria are attributed on the basis of pairwise comparison assessments, using a scale such that shown in Figure 3 (Saaty, 1980).

   Thus, if criterion X is judged to be "very strongly preferred" to criterion Y, a score of 7 is given. The reciprocal values are used to express the opposite judgements. The results of pairwise comparisons are organised in a matrix. For instance if four criteria have to be considered in the evaluation, the pairwise comparison data measuring their relative weightings are organised in a 4×4 matrix, say M. The m_{ij} value of the matrix represents the relative importance of the ith criterion relative to the jth criterion. However, only six of the sixteen values of the matrix must be obtained directly from managers, since the remaining ten are automatically generated considering both reflexivity ($m_{ij} = 1$ if $i = j$) and reciprocity ($m_{ij} = 1/m_{ji}$). Such relative values are translated into absolute priority weightings W_i (used in step 3 to calculate the overall suitability rating of each alternative decision), on the basis of Saaty's eigenvector procedure (see Appendix 1 and, for more details, Saaty, 1980), which is implemented by any AHP software program;
2) the decision alternatives are assessed on a pairwise basis with respect to the criteria, using the same procedure as described in step 2. The output from this step is the absolute ratings of the alternatives with respect to all criteria (A_{ij});
3) the overall suitability ratings of the alternative investments (Λj) are calculated averaging the absolute ratings with respect to each criterion with the corresponding absolute importance weightings.

VERBAL JUDGEMENT	DEGREE OF PREFERENCE
EQUALLY PREFERRED	1
MODERATELY PREFERRED	3
STRONGLY PREFERRED	5
VERY STRONGLY PREFERRED	7
EXTREMELY PREFERRED	9
	Intermediate levels can be used to provide additional levels of discrimination

Fig. 3. An example of measurement scale for the AHP.

The AHP is based on the same logic as scoring methods. The overall suitability ratings of the alternatives are calculated on the basis of a weighted average of the data given is steps 1 and 2. The fundamental difference between the two approaches is the type of user/technique interface. While, as already pointed out, scoring methods require the decision maker to give *absolute* judgements of both importance and suitability, the AHP allows the user to judge on a *pairwise basis*. It is believed that more accurate estimates of the rankings can be obtained with this pairwise comparison approach, particularly when qualitative performance/criteria are considered (Saaty, 1988).

3.3. *Fuzzy linguistic approach*

Fuzzy set theory has recently been applied to a wide variety of management decision problems (e.g., production scheduling, transport planning, strategic planning, etc.) (Zimmerman, 1992), including investment selection (Liang and Wang, 1991 and 1993; Perego and Rangone, 1997). As fuzzy set theory can deal with linguistic expressions, the appraisal process can employ natural language, which well fits the qualitative nature of many benefits related to AMTs (e.g., quality of working life, employee satisfaction, learning, corporate image, etc.). Fuzzy set theory thus takes account of the vagueness and imprecision of every human being's qualitative judgements in the appraisal and selection of AMTs (Zadeh, 1975; Lee, 1990; Karwowsky and Mital, 1992).

Some basic concepts of the fuzzy set theory are briefly reported in Appendix 2 (for more details see, for instance, Zimmerman, 1992). Here we report only those aspects of the fuzzy approach relevant to AMT selection.

The fuzzy linguistic approach is based on the concept of linguistic variables. A linguistic variable is a variable whose value is not a number but words or sentences in a natural or artificial language (see, e.g., Zimmerman, 1992). A linguistic variable is characterised by a given set of *linguistic values*, with each value being a fuzzy set.

The fuzzy approach to the selection of AMTs requires two linguistic variables:

– *W*, assessing the importance weighting of the criteria, could be measured on the following linguistic scale (Liang and Wang, 1993): S_W = {VL, L, M, H, VH}, where VL = Very Low, L = Low, M = Medium, H = High, VH = Very High are triangular fuzzy numbers;
– *A*, assessing the suitability ratings of the alternative AMTs with respect to every criterion, could be measured on the following linguistic scale (Liang and Wang, 1993): S_A = {VP, P, F, G, VG}, where VP = Very Poor, P = Poor, F = Fair, G = Good, VG = Very Good are triangular fuzzy numbers.

With the fuzzy linguistic approach, the steps of the MADM approach are performed as follows:

1) the relative weightings of the criteria are measured using the linguistic scale S_W;
2) the assessments of the alternative AMTs with

respect to each criterion are made using scale S_A;

3) the overall suitability rating Λ_j of each alternative is derived from a numeric operator that calculates the mean of the fuzzy linguistic assessments given in steps 2, taking account of the fuzzy linguistic weightings attributed in step 1 (Azzone and Rangone, 1996). Since Λ_j are fuzzy numbers, they must be converted into numeric values in order to rank the investment alternatives. This can be done by using one of the various ranking algorithms proposed in the literature (e.g., Bortolan and Degani, 1985), such as that based on the centre of gravity of fuzzy numbers Λ_j (Azzone and Rangone, 1996).

In the fuzzy linguistic approach the use of natural language (i.e. linguistic values) to assign suitability ratings and importance weightings has a positive impact on the man/technique interface, and thus on the final ranking of the alternative decisions. Zimmer (1983), for instance, has asserted that humans are unsuccessful in making quantitative predictions, whereas they are more efficient in qualitative predictions. People are more prone to bias their evaluations if they are forced to provide numerical estimates of items which are not easy to assess, as numerical estimates require more mental effort than that required for less precise verbal statements (Karwowsky and Mital, 1986).

However, the fuzzy approach is based on more complex mathematical modelling, implying greater difficulty for the entrepreneurial and managerial team in understanding the logic of the technique.

3.4. *A comparison*

This paragraph, pointing out the major strengths and weaknesses of the three MADM methods previously described, aims to show their different areas of application in SMFs.

All the three techniques present several benefits when used in SMFs, since:

– they are *flexible*, i.e. are applicable to a large number of decision contexts involving different types of investment (e.g., CNC, DCN, CAD, CAM, IT, robotics, FMS, CIM, etc.) and different criteria (including financial and strategic ones);
– they are *simple* to use, as they can be easily implemented by software programs and do not require quantitative data;[2]
– the value of the informational output can be enhanced by *sensitivity analysis* (aimed at testing the sensitivity of the ranking with respect to changes in the input data).

However, the three methods differ from each other in two major aspects (see also Zimmerman, 1992):

– *discrimination*, i.e. the capacity of the technique to discriminate between different alternatives. This depends both on: i) the user-technique interface allowing the decision maker to express his/her judgements without bias, and ii) the inherent mathematical tools and assumptions which convert the input data into output; and
– *transparency*, i.e. the extent to which the user can understand the mathematical tools and assumptions of the technique. This is an important requirement for an investment selection technique, since, if it not transparent, it will be perceived as a "black box" by the user, who, consequently, is unlikely to rely on its output (the ranking of the alternative decisions), and will not use the result in decision making.

Figure 4 reports the suitability ratings of the three MADM techniques with respect to discrimination and transparency.

The lower rating attributed to the discrimination of scoring methods is due to the rather unfriendly user/technique interface of their rating systems, while both AHP and the fuzzy approach, using pairwise comparisons and linguistic scales respectively, have a more effective user/technique interface. On the other hand, the transparency of AHP and, above all, that of the fuzzy models is lower because of their rather complex mathematical tools.

The three MADM techniques may thus have different areas of application in SMFs, depending on the specific characteristics of the individual company. In particular, two main factors can influence the choice of the technique:

– the "amount" of initial effort (in terms of the time and money required, for instance, for training, consulting and software programming) that the entrepreneurial and managerial team

	DISCRIMINATION	TRANSPARENCY
SCORING METHOD	MEDIUM	HIGH
AHP	HIGH	MEDIUM
FUZZY APPROACH	HIGH	LOW

Fig. 4. The suitability ratings of MADM techniques with respect to discrimination and transparency.

are willing to invest in order to introduce the technique;
– the analytical skills and mathematical sensitivity of the entrepreneurial and managerial team.

Figure 5 shows the different areas of application of the three MADM techniques:

- in companies where the owners and executives have low analytical skills and do not wish to invest too much time and money in the introduction and initial set-up of the tool, scoring methods are the most suitable option;
- in companies where either:
  (i) there are good analytical skills but there is the need to limit the effort needed to introduce the new techniques, or
  (ii) the entrepreneurial and managerial team can dedicate time to the introduction of the tool but have poor analytical skills, the right choice may be AHP, which presents a good trade-off between discrimination and transparency and is well supported by commercial software programs;
- in companies with good analytical skills where the entrepreneurial and managerial team can invest time and money in the introduction of the technique, the fuzzy linguistic approach may represent a good choice.

4. Conclusion

This article discusses the applicability to SMFs of major non-conventional approaches to AMT assessment and selection, which have been proposed in the literature over the last decade. Such an analysis has pointed out that MADM techniques seem particularly suitable for SMFs, even though in those companies with high financial and strategic competencies and systems, modified DCF and strategic approaches could be also effectively used.

Summarising the considerations pointed out in the previous sections, the major benefits of MADM methods when applied to SMFs are the following:

– they are fairly intuitive, since they are based on a human-like logic;
– they are simple to use, since they do not require specific competence and sophisticated information systems and can be implemented by user friendly software programs. The only prerequisite is a certain level of analytical skill and mathematical sensitivity. This level depends on the specific MADM technique used and increases from scoring methods to AHP and the fuzzy approach;
– they can effectively support the entrepreneurial and managerial team in selecting AMTs. To this end, MADM techniques must not to be used as

	ANALYTICAL SKILLS	
INITIAL EFFORT	**LOW**	**HIGH**
HIGH	AHP	FUZZY APPROACH
LOW	SCORING METHODS	AHP

Fig. 5. The areas of application of MADM techniques.

"black boxes" that translate certain input data into a given ranking of the alternative investments, but should be used to enhance the information support to the decision, by structuring the decision problem in terms of objectives, criteria and alternative decisions, addressing trade-offs among criteria, testing alternative scenarios through sensitivity analysis, etc.;
- they are flexible and can be applied to various decision contexts.

However, MADM techniques are not the panacea for assessing investments in AMTs in SMFs, since they also present some shortcomings, such as:

- the user/technique interface is rather unfriendly, being based on artificial rating systems, even though in passing from scoring methods to AHP and fuzzy linguistic approach, the interface improves;
- they do not allow the impact of the investment on shareholder value to be calculated. Here DCF techniques must be used;
- they do not allow post-auditing of the investment, since the ratings attributed to criteria are not usually related to an ex-post measurable performance.

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Appendix 1 – Saathy's eigenvector procedure

The pairwise comparison data are translated into the absolute values by solving the following matrix equation:

$$\mathrm{M} * H = \mathrm{k} * H$$

where:

M = the pairwise comparisons matrix;
H = the vector of the absolute values;
k = the highest of the eigenvalues of the matrix M.

This procedure is automatically carried out by any software program that implements AHP.

Appendix 2 – Basics of the fuzzy set theory

Fuzzy sets

A fuzzy set is a collection of elements with smooth boundaries, in which transmission from membership to non-membership is gradual rather than abrupt. A basic concept of the Fuzzy Set Theory is that an element can belong partly to a fuzzy set. Let X be the space of elements x. A fuzzy set A in X is characterised by a membership function $\mu_A(x)$ which associates a real number in the interval [0; 1] with each element x in X, to represent the "degree of membership" of x in A. Thus, if $\mu_A(x) = 1$ then x belongs fully to the set A. If $\mu_A(x) = 0$ then x does not belong to A. In all other cases, i.e. $0 < \mu_A(x) < 1$, x belongs partially to A (the nearer the value of $\mu_A(x)$ to 1, the higher the grade of membership of x in A). In particular, a fuzzy number A is a fuzzy set of the real line. For the sake of computational efficiency and ease of data acquisition, triangular membership functions are often used. Figure 1 illustrates a triangular fuzzy number defined by the following membership function:

$$\mu(x) = \begin{cases} (x-a)/(b-a) & a \le x \le b \\ (x-c)/(b-c) & b \le x \le c \\ 0 & \text{otherwise} \end{cases}$$

which would be expressed as the triplet (a; b; c). If c is less than or equal to 1 the fuzzy number is called normalised.

Extended algebraic operations

By the Zadeh's extension principle (1965), the extended algebraic operations on triangular fuzzy numbers that are used in the framework are as follows:

Addition

$$(a_1, b_1, c_1) \oplus (a_2, b_2, c_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2)$$

Multiplication

$$(a_1, b_1, c_1) \otimes (a_2, b_2, c_2) \cong (a_1a_2, b_1b_2, c_1c_2)$$

Division

$$(a_1, b_1, c_1) \varnothing (a_2, b_2, c_2) \cong (a_1/c_2, b_1/b_2, c_1/a_2)$$

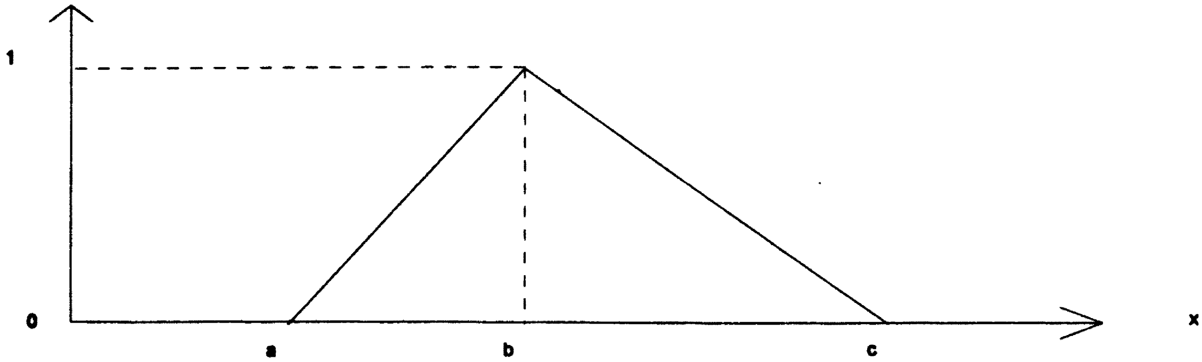

Fig. 6. A triangular membership function of a fuzzy number.

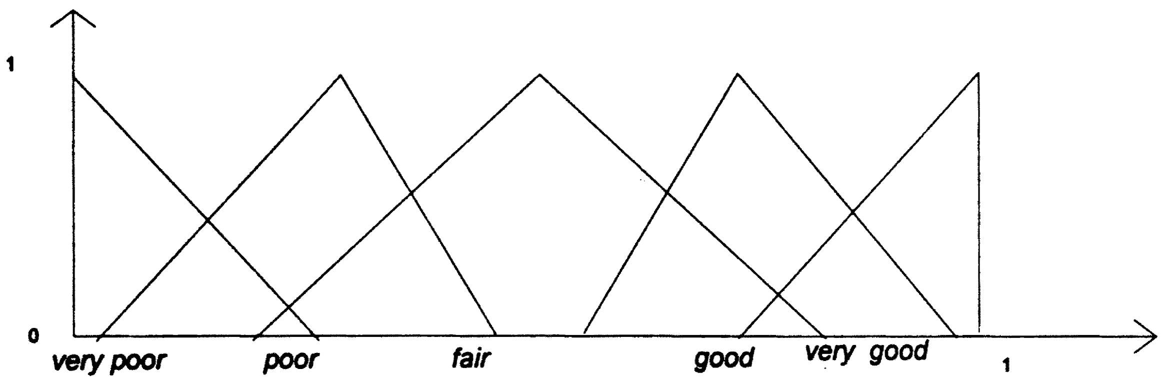

Fig. 7. Examples of membership functions of linguistic values.

Reciprocal

$$(1, 1, 1) \varnothing (a, b, c) \cong (1/c, 1/b, 1/a)$$

Linguistic variables

A linguistic variable is a variable whose values are not numbers but words or sentences in a natural or artificial language (Zimmermann, 1991). A linguistic variable H is characterised by the *term set*, i.e. the set of the *linguistic values* of H, with each value being a fuzzy set. Figure 3 shows the triangular membership functions of the linguistic values Very Poor, Poor, Fair, Good, Very Good of a variable H.

Notes

[1] It should be noted that for simplicity, in this article we do not consider the possibility that between criteria and decision alternatives there are other intermediate levels of subcriteria. However, MADM methods can be applied also when there are subcriteria.

[2] It is important to remark that while several software packages are available to implement scoring methods and AHP, the implementation of the fuzzy linguistic models requires in-house software programming.

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