Scientific Research and Essays Vol. 6(31), pp. 6487-6498, 16 December, 2011
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE11.1079
ISSN 1992-2248 ©2011 Academic Journals

Full Length Research Paper

Selecting the best ABS sensor technology using fuzzy MADM

Majid Elahi*, Mohsen Alvandi, Hassan Khodaei Valehzagharad and Mostafa Memarzade

Department of Industrial Management, Imam Khomeini International University (IKIU), Qazvin, Iran.

Accepted 8 November, 2011

In the competitive world today, maintaining and developing market share are of great importance to any business, and technology plays an important role here. Technology selection, influencing the competitive advantages of an enterprise or a country is a multi-criteria decision problem which can be improved by integrating different MCDM[1] methods. Many different resources including financial, human and time are spent to access a needed technology. Utilization of these resources can be optimized by integrating them with appropriate technologies. The objectives of this study are: 1) identifying the effective criteria of technology selection to improve the performance of CROUSE companies in Iran's auto industry by using Fuzzy Delphi, Fuzzy AHP and Fuzzy TOPSIS techniques, and 2) providing a systematic model to prioritize ABS[2] sensor technology alternatives. We contributed to the technology selection by identifying critical criteria in technology selection. Our findings show that indicators of technology selection are not only some internal factors of the organization, but also include some factors external to the organization, and that the most effective criteria on technology selection are not merely financial, and some other factors such as political issues or the impacts of technology on employment are also influential.

Key words: Fuzzy Delphi, fuzzy AHP, fuzzy TOPSIS, technology selection, technology selection criteria.

INTRODUCTION

A firm’s ability to make sound decisions is particularly important in the presence of increased global competition and the greater uncertainty from exposure to more competitors. Technology selection which influences the competitive advantages of an enterprise or a country is a multi-criteria decision problem that can be improved by integrating different methods. Furthermore, increase in the number and complexity of available technologies makes it more and more difficult to identify the right technology and may render some methods less dependable if used alone. A company has to select and invest in a technology field with comparative advantage from various technology alternatives under multiple economic, technological and social criteria in a complicated environment (Torkkeli and Tuominen, 2002).

An enterprise can waste its competitive advantages by investing in wrong alternatives at the wrong time or by investing too much in the right ones (Torkkeli and Tuominen, 2002). In order to realize this competitive advantage, it is vital to understand both the specific technologies and the ways in which organizations can best manage technology (Phaal et al., 2001). Selection of key technologies helps the firms and countries to establish their advantage in a competitive environment (Clark, 1989; Lee and Song, 2007). Increasing complexity of the relations between Technologies and economic problems combined with the occurrence of national or organizational budget resource restrictions imply new challenges for science and technology (Ronde, 2003). There are many studies in technology selection but there are a few studies that identify the critical indicators to

---

*Corresponding author. E-mail: memarzade_mostafa@hotmail.com. Tel: (+98) 281 3780021.

[1] multi-criteria decision making
[2] Anti-blocking system

select technologies. The aim of this study is identifying the effective indicators of technology selection and selecting the best technology. In real life, modeling of many situations may not be sufficient or exact, as the available data are inexact, vague, imprecise and uncertain by nature (Sarami et al., 2009). This gives rise to the question that: “how the importance weights can be calculated?” In this study we integrate the Fuzzy Delphi method and Fuzzy analytical hierarchy process to identify and weigh indicators and then select the appropriate technology by Fuzzy TOPSIS. In many real situations, experts’ judgments cannot be properly reflected in quantitative terms. Some ambiguity will result due to the differences in the meanings and interpretations of the expert’s opinions.

Since people use linguistic terms such as ‘good’ or ‘very good’ to reflect their preferences, the concept of combining fuzzy set theory and Delphi was proposed by Murray et al. (1985) and named the Fuzzy Delphi method (FDM). We used fuzzy Delphi method because according to Noorderhaben (1995), applying the Fuzzy Delphi method to group decision can solve the fuzziness of common understanding of expert opinions. We used fuzzy AHP for this study to investigate which evaluation criterion is the most important in overall technical committees and make this study more sensible and gain a more representative description of the decision-making process. This research adopts the fuzzy TOPSIS to improve the gaps of alternatives between real performance values and pursuing aspired levels in each dimension and criterion and find out the best alternatives for achieving the aspired/desired levels based on proposed technologies. The remainder of this paper is organized as follows: Subsequently, it presents how we adopt the methodologies, Fuzzy AHP and Fuzzy TOPSIS in real world; after which it briefly describes the case study; then, the data analysis and the paper ends with concluding remarks.

LITERATURE REVIEW

Technology as a major source of competitive advantage for manufacturing industries is widely accepted by practitioners, governments and academics. Management of technology is comprised of five generic processes: identification, selection, acquisition, exploitation and protection (Gregory, 1995). Technology selection process is an identification and selection of new or additional technologies which the firm seeks to master (Dussauge et al., 1992). Evaluation-and-selection processes often precede adoption and use (Fichman and Kemerer, 1999). The key theme in these definitions is that technology selection is a “process” that is closely linked to organizational objectives and is associated with the broader technological and market environment (Stacey and Ashton, 1990). Technology selection is a “process” that is closely linked to other business processes, and is associated with the broader technological, organizational and business environment (Shehabuddeen et al., 2006). Therefore understanding how organizations perceive the benefits and issues of a particular technology prior to acquisition can provide context and insight into subsequent evaluation or description of the technology (Langley et al., 1995). Yu et al. (1998) focus on the strategic importance, business effect, business opportunity, risk, present technology position and the cost to obtain the technology to evaluate feasibility. Piipo and Tuominen (1990) emphasize the matching of alternatives to the capabilities and strategies of companies and risks as major factors in the selection; in addition to the benefits and costs. Gregory suggested that evaluation was concerned with “the notions of cost, benefit and risk”. In 2010, Shen et al. (2010) proposed a technology selection process integrating fuzzy Delphi method, analytic hierarchy process (AHP) and patent co-citation approach (PCA) for technology selection. In 2011, Shen et al. (2011) proposed a hybrid process concerning the economic and industrial prospects along with critical technology streams toward a more effective selection of new technology. Both articles highlighted some criteria such as: cost, benefit technology development and risk.

In 2010, Lucheng et al. (2010) proposed a new hybrid approach based on technology foresight and a fuzzy consistent matrix to select and assess emerging technologies. In this study they used some criteria such as advancement of technology, market risk, customer surplus, value making, industrial policies, social development and job opportunities creation to select technology. In 2008 Stewart investigated information technology projects (Stewart, 2008). In this research he argued that the organization should set up a series of activity cost matrices for each stage of the IT project life cycle. In 2008, Zhang et al. (2008) developed a multiple-perspective model for technology assessment. They applied this model to mobile broadband technologies selection in China. They determined five criteria to select the best technology; performance, compatibility, political and social effects, economic valuation and technological improvements. In 2005, Kulak et al. (2005) investigated IT project selection. In this research they used five criteria to select the best IT project: technical and organizational risk, return on investment (ROI), user satisfaction or easy to use, operational agility and strategic competitiveness. As we may see, the criteria offered in technology selection literature are quite different. We have summarized some of the criteria highlighted by researchers (Table 1).

Fuzzy logic

Fuzzy set theory first was introduced by Zadeh (1965) to map linguistic variables to numerical variables within

Table 1. Indicators used in technology selection.

Criterion	Researchers
Economic attractiveness	Zaidmanand and Gevidalli (1989), Gimenez (2006), Zhang et al. (2008), Granstrand (2004), Daim and Kocaoglu (2008), Lee et al. (2009), Brown et al. (2010), Peças et al. (2009) and Chiesa (1998).
Usability	Leseure and Brookes (2004), Keogh et al. (2001), McAdam et al. (2005) and Chiesa (1998).
Value creation for customers	Siriram and Snaddon (2005) and Chiesa (1998).
Flexibility	Farooq and O'Brien (2010), Lefebvre et al. (1992), Da Silveira and Cagliano (2006), Prajogo and Sohal (2006), Husain et al. (2002) and Patterson et al. (2003).
Risk	Coldrick et al. (2005), Prajogo and Sohal (2006), Shen et al. (2010), Liu and Jiang (2001), Wu and Ong (2008), Stewart (2008), McAdam et al. (2005), Kulak et al. (2005), Farooq and O'Brien (2010) and Sung (2009).
Interdependency	Lee and Kim (2001).
Solution creation	Chiesa (1998)
Technology life cycle	Kim (2003) and Farooq and O'Brien (2010).
Cost	Coldrick et al. (2005), Prajogo and Sohal (2006), Shen et al. (2010), Lehtimäki et al. (2009) and Awazu (2006).
Complexity	Cantwell (1992), Shen et al. (2010), Lehtimäki et al. (2009), Hemmert (2004), Zhang et al. (2008), Lucheng et al. (2010) and Shehabuddeen et al. (2006).
Ease of use	Shen et al. (2010), Brown et al. (2010) and Farooq and O'Brien (2010).
Time to access	Shen et al. (2010), Coldrick et al. (2005), Stewart (2008), Farooq and O'Brien (2010), Peças et al. (2009) and Evans et al. (2009).
Impact on employment	Husain et al. (2002), Lucheng et al. (2010), Landeta (2006), Achilladelis and Antonakis (2001) and Venanzi (1996).
Environmental benefits	Lucheng et al. (2010), Peças et al. (2009), Evans et al. (2009), Hsu et al. (2010) and Choudhury et al. (2006).
Innovation	Prajogo and Sohal (2006), Shen et al. (2010), Lehtimäki et al. (2009), Siegel et al. (2004) and Husain et al. 2002).
Strategic attractiveness	Prajogo and Sohal (2006), Stewart (2008), Husain et al. (2002), Patterson et al. (2003), Farooq and O'Brien (2010), Shehabuddeen et al. (2006), Tingling and Parent (2004), Schweizer (2005), Walsh and Linton (2011), Lucheng et al. (2010) and Phaal et al. (2001).
ROI	Coldrick et al. (2005), Shen et al. (2010), Laurie (2001), Kulak et al. (2005).
Income creation	Siegel et al. (2004), Hemphill (2006), Swamidass and Kotha (1998), Siriram and Snaddon (2005).
Political effect	Zhang et al. (2008).

Table 1. Contnd

Cultural effect	Siegel et al. (2004), Stewart (2008), Daim and Kocaoglu (2008) and Farooq and O'Brien (2010).
Technical knowledge and learning	Lehtimäki et al. (2009), Kasvi et al. (2003) and Hänninen and Kauranen (2007).
Compatibility	Zhang et al. (2008) and Brown et al. (2010).
Current ability	Siegel et al. (2004), Short et al. (1976), Carlson and Zmud (1999), Daft and Lengel (1986) and Reinsch and Beswick (1990).
Exclusiveness	Siegel et al. (2004) and Hemphill (2006).
Our situation in technology	Awazu (2006), Husain et al. (2002) and Takayama and Watanabe (2002).

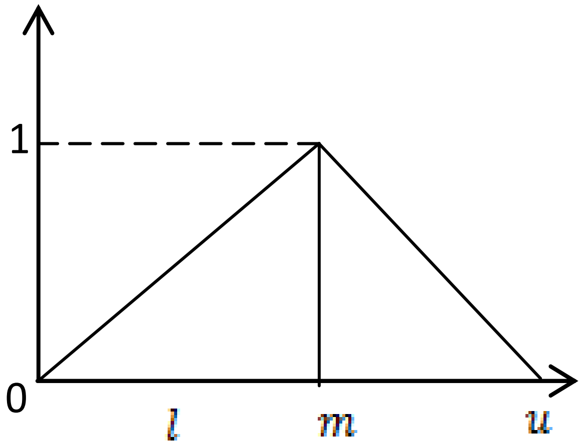

Figure 1. A triangular fuzzy number, $\tilde{M}$ Kah04 \l 1033 (Kahraman et al., 2004).

decision making processes. Then the definition of fuzzy sets were manipulated to develop Fuzzy multi-criteria decision making (FMCDM) methodology by Bellman and Zadeh (1970) to resolve the lack of precision in assigning importance weights of criteria and the ratings of alternatives against evaluation criteria.

A fuzzy set is characterized by a membership function which assigns to each element a grade of membership within the interval [0, 1] indicating to what degree that element is a member of the set (Bevilacqua et al., 2006). As a result, in fuzzy logic, general linguistic terms such as "bad", "good" or "fair" could be used to capture specifically defined numerical intervals. A tilde "$\sim$" will be placed above a symbol if the symbol represents a fuzzy set. A triangular fuzzy number (TFN) $\widetilde{M}$ is shown in Figure 1. A TFN is denoted simply as (l, m, u). The parameters l, m and u denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event (Kahraman et al., 2004). When l = m = u, it is a non-fuzzy number by convention (Chan and Kumar, 2007). Each TFN has linear representations on its left and right side such that its membership function can be defined as (Kahraman et al., 2004):

$$\mu_{\tilde{A}} = \begin{cases} \mathbf{0}, \mathbf{x} < l, \\ {(\mathbf{x}-\mathbf{l})}/{(\mathbf{m}-\mathbf{l})}, \mathbf{l} \leq \mathbf{x} \leq \mathbf{m}, \\ {(\mathbf{u}-\mathbf{x})}/{(\mathbf{u}-\mathbf{m})}, \mathbf{m} \leq \mathbf{x} \leq \mathbf{u}, \\ \mathbf{0}, \mathbf{x} > u. \end{cases} \quad (1)$$

$\otimes$: multiply fuzzy numbers, for example assuming two triangular fuzzy numbers:

$$\tilde{A} = (a_1, b_1, c_1), \tilde{B} = (a_2, b_2, c_2)$$

$$\tilde{A} \otimes \tilde{B} = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2) \quad (2)$$

$\oslash$: divide fuzzy numbers, for example: assuming two triangular fuzzy numbers $\widetilde{A} = (a_1, b_1, c_1)$, $\tilde{B} = (a_2, b_2, c_2)$:

$$\tilde{A} \oslash \tilde{B} = (a_1/a_2, b_1/b_2, c_1/c_2) \quad (3)$$

METHODOLOGY

This study proposes a process integrating fuzzy Delphi, AHP and fuzzy TOPSIS methods to deal with the challenge of technology selection. For executing Delphi method, we identified research experts who are ten people of CROUSE Company with over 10 years of experience in this industry. Four people of them are from technical management department and six people of them are from business management department. Firstly, we define technology selection criteria that are extracted from technology selection literature. Then the fuzzy Delphi method effectively gathers information about critical technology selection criteria. In this technology selection problem, the relative importance of different decision criteria involves a high degree of subjective judgment and individual preferences. The linguistic assessment of human judgments is vague and it is not reasonable to represent them in terms of precise numbers. It feels more confident to give interval judgments; therefore triangular fuzzy numbers were used in this problem to decide the priority of one decision criteria over another. The triangular fuzzy numbers were determined from reviewing literature (Kahraman et al., 2003). In order to evaluate the weights of criteria that were obtained by fuzzy Delphi method, fuzzy AHP was used. Then we used fuzzy TOPSIS to rank the technology alternatives.

Fuzzy Delphi method

Murry et al. (1985) proposed the concept of integrating the traditional Delphi method and the fuzzy theory to improve the vagueness of the Delphi method. Membership degree is used to establish the membership function of each participant. Ishikawa et al. (1993) further introduced the fuzzy theory into the Delphi method and developed max to min and fuzzy integration algorithms to predict the prevalence of computers in the future. In this study we used Fuzzy Delphi method as proposed by Ishikawa et al. (1993) which was derived from the traditional Delphi technique and fuzzy set theory. Noorderhaben (1995) indicated that applying the Fuzzy Delphi method to group decision can solve the fuzziness of common understanding of expert opinions. The FDM steps are as follows:

Collecting opinions of decision group

Finding the evaluation score of each alternate factor's significance given by each expert by using linguistic variables in questionnaires.

Setting up triangular fuzzy numbers

Calculating the evaluation value of triangular fuzzy number of each alternate factor given by experts, finding out the significance triangular fuzzy number of the alternate factor. This study used the geometric mean model of mean general model proposed by Klir and Yuan (1995) for FDM to find out the common understanding of group decision.

The computing formula is illustrated as follows: assuming the evaluation value of the significance of No. j element given by No. i expert of n experts is:

$$\widetilde{w_{ij}} = \left(a_{ij}, b_{ij}, c_{ij}\right), i = 1,2,\ldots,n, j = 1,2,\ldots,m.$$

Then the fuzzy weighting $\widetilde{w_{ij}}$ of No. j element is:

$$\widetilde{w_{ij}} = \left(a_{ij}, b_{ij}, c_{ij}\right), = 1,2,\ldots,m.$$

Among which:

$$a_j = \min_i\left\{a_j\right\}, b_j = \frac{1}{n}\sum_{i=1}^{n} b_{ij}, c_j = \max_i\left\{c_{ij}\right\} \qquad (4)$$

Defuzzification

Using simple center of gravity method to defuzzify the fuzzy weight $\widetilde{w_{ij}}$ of each alternate element to definite value Sj, the followings are obtained:

$$s_j = \frac{a_j + b_j + c_j}{3}, j = 1,2,\ldots,m \qquad (5)$$

Screening evaluation indexes

Finally, proper factors can be screened out from numerous factors by setting the threshold a. The principle of screening is as follows:

If $Sj \geq \alpha$, then No. j factor is the evaluation index.

If $Sj < \alpha$, then delete No. j factor.

For the threshold value r, the 80/20 rule was adopted with r set as 8. This indicated that among the factors for selection, ''20% of the factors account for an 80% degree of importance of all the factors''. The selection criteria were:

If $MA \geq r = 8$, this appraisal indicator is accepted.

If $MA < r = 8$, this appraisal indicator is rejected.

Fuzzy analytic hierarchy process

Laarhoven and Pedrycz (1983) proposed the Fuzzy analytic hierarchy process in 1983 which was an application of the combination of analytic hierarchy process (AHP) and Fuzzy theory. The linguistic scale of traditional AHP method could not express the fuzzy uncertainty when a decision maker is making a decision. Therefore, FAHP converts the opinions of experts from previous definite values to fuzzy numbers and membership functions presents triangular fuzzy numbers in paired comparison of matrices to develop FAHP, thus the opinions of experts approach human thinking model so as to achieve more reasonable evaluation criteria. Laarhoven and Pedrycz (1983) proposed the FAHP which is to show that many concepts in the real world have fuzziness. Therefore, the opinions of decision makers are converted from previous definite values to fuzzy numbers and membership numbers in FAHP so as to present in FAHP matrix. The steps of this study based on FAHP method are as follows:

Determining problems

Determining the current decision problems to be solved so as to ensure future analyses being correct; this study discussed the "evaluation criteria for verification of technology selection criteria".

Setting up hierarchy architecture

Determining the evaluation criteria having indexes to be the criteria layer of FAHP, for the selection of evaluation criteria, relevant criteria and feasible schemes can be found out through reviewing the literature. This study screened the important factors conforming to target problems through FDM investigating experts' opinions to set up the hierarchy architecture.

Constructing pair wise comparison matrices among all the elements/criteria in the dimensions of the hierarchy system

Assigning linguistic terms to the pair wise comparisons by asking which is the more important of each two dimensions as following matrix$\tilde{A}$:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \tag{6}$$

Where:

$$\tilde{a}_{ij} \begin{cases} \tilde{9}^{-1}, \tilde{8}^{-1}, \tilde{7}^{-1}, \tilde{6}^{-1}, \tilde{5}^{-1}, \tilde{4}^{-1}, \tilde{3}^{-1}, \tilde{2}^{-1}, \tilde{1}^{-1}, \tilde{1}, \tilde{2}, \tilde{3}, \tilde{4}, \tilde{5}, \tilde{6}, \tilde{7}, \tilde{8}, \tilde{9} & i \neq j \\ 1 & i = j \end{cases}$$

Using geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each criterion by Hsieh et al. (2004):

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \ldots \otimes \tilde{a}_{in})^{1/n} \tag{7}$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} \tag{8}$$

Where $\tilde{a}_{ij}$ is fuzzy comparison value of dimension i to criterion j, thus, $\tilde{r}_i$ is a geometric mean of fuzzy comparison value of criterion i to each criterion; $\tilde{w}_i$ is the fuzzy weight of the ith criterion, and can be indicated by a TFN, $\tilde{w}_i = (lw_i, mw_i, uw_i)$. The lw_i, mw_i and uw_i stands for the lower, middle and upper values of the fuzzy weight of the ith dimension.

Fuzzy TOPSIS methods

In this study, we propose this method to evaluate the performance of technology alternatives for CROUSE Company. TOPSIS views a MADM problem with m alternatives as a geometric system with m points in the n-dimensional space of criteria. The method is based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution (that is achieving the minimal gaps in each criterion) and the longest distance from the negative-ideal solution (that is, achieving the maximal levels in each criterion). TOPSIS defines an index called similarity to the positive-ideal solution and the remoteness from the negative- ideal solution. Then, the method chooses an alternative with the maximum similarity to the positive-ideal solution (Hwang and Yoon, 1981; Wang and Chang, 2007). The merit of using a fuzzy approach is to assign the relative importance of attributes using fuzzy numbers instead of precise numbers for suiting the real world in fuzzy environment; in other words, to extend the TOPSIS to the fuzzy environment (Kuo et al., 2007; Yang and Hung, 2007). The mathematics concept borrowed from Büyüközkan et al. (2007), Kuo et al. 2007) and Wang and Chang (2007).

Determining the weighting of evaluation criteria

This research employs fuzzy AHP to find the fuzzy preference weights.

Constructing the fuzzy performance/decision matrix and choosing the appropriate linguistic variables for the alternatives with respect to criteria

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array} \tag{9}$$

$$i = 1,2,\ldots,m \,; j = 1,2,\ldots,n$$

$$\tilde{x}_{ij} = {}^{1}/_{k} \left(\tilde{x}_{ij}{}^{1} \oplus \ldots \oplus \tilde{x}_{ij}{}^{k} \oplus \ldots \oplus \tilde{x}_{ij}{}^{k}\right)$$

Where $\tilde{x}_{ij}{}^{k}$ is the performance rating of alternative A_i with respect to criterion C_j evaluated by kth expert and $\tilde{x}_{ij}{}^{k} = \left(l_{ij}{}^{k}, m_{ij}{}^{k}, u_{ij}{}^{k}\right)$.

Normalizing the fuzzy-decision matrix

The normalized fuzzy-decision matrix denoted by $\tilde{R}$ is shown as the following formula:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n}, i = 1,2,\ldots,m,\ j = 1,2,\ldots,n \tag{10}$$

Then, the normalization process can be performed by following formula:

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^{+}}, \frac{m_{ij}}{u_j^{+}}, \frac{u_{ij}}{u_j^{+}}\right), u_j^{+} = \max_i \{u_{ij} | i = 1,2,\ldots,n\} \tag{11}$$

Or we can set the best aspired level u_j^{+} and $j = 1,2,\ldots,n$ is equal to one; otherwise, the worst is zero. The normalized $\tilde{r}_{ij}$ is still triangular fuzzy numbers. The weighted fuzzy normalized decision matrix is shown as the following matrix $\tilde{V}$:

$$\tilde{V} = [\tilde{V}_{ij}]_{n \times n}\ ,\quad i = 1,2,\ldots,m \quad j = 1,2,\ldots,n \tag{12}$$

Where:

$$\tilde{V}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j.$$

Determining the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS)

According to the weighted normalized fuzzy-decision matrix, we know that the elements $\tilde{v}_{ij}$ are normalized positive TFN and their ranges belong to the closed interval [0, 1]. Then, we can define the

Table 2. Linguistic terms for the fuzzy ratings.

Absolutely appropriate	**(9, 10, 10)**
Appropriate	(7, 9, 10)
Slightly appropriate	(5, 7, 9)
Neutral	(3, 5, 7)
Slightly inappropriate	(1, 3, 5)
Inappropriate	(0, 1, 3)
Absolutely inappropriate	(0, 0, 1)

Table 3. Linguistic variables for importance of each criterion.

Extremely strong	(9, 9, 9)
Intermediate	(7, 8, 9)
Very strong	(6, 7, 8)
Intermediate	(5, 6, 7)
Strong	(4, 5, 6)
Intermediate	(3, 4, 5)
Moderately strong	(2, 3, 4)
Intermediate	(1, 2, 3)
Equally strong	(1, 1, 1)

FPIS A^{*} (aspiration levels) and FNIS A^{-} (the worst levels) as the following formula:

$$A^{*} = \left(\tilde{v}_1^{*}, \dots ,\ \tilde{v}_j^{*}, \dots, \tilde{v}_n^{*}\right) \tag{13}$$

$$A^{-} = \left(\tilde{v}_1^{-}, \dots, \tilde{v}_j^{-}, \dots, \tilde{v}_n^{-}\right) \tag{14}$$

Where $\tilde{v}_j^{*} = (1,1,1) \otimes \tilde{w}_j = \left(lw_j, mw_j, uw_j\right)$ and $\tilde{v}_n^{-} = (0.0.0), j = 1,2,\dots,n.$

Calculating the distance of each alternative from FPIS and FNIS

The distances ($\tilde{d}_i^{*}$ and $\tilde{d}_i^{-}$) of each alternative from A^{*} and A^{-} can be currently calculated by the area compensation method:

$$\tilde{d}_i^{*} = \sum_{j=1}^{n} d\left(\widetilde{v_{ij}}, \tilde{v}_j^{*}\right), i = 1,2,\dots,m,\ j = 1,2,\dots,n \tag{15}$$

$$\tilde{d}_i^{-} = \sum_{j=1}^{n} d\left(\widetilde{v_{ij}}, \tilde{v}_j^{-}\right), i = 1,2,\dots,m,\ j = 1,2,\dots,n \tag{16}$$

Obtaining the closeness coefficients (relative gaps-degree) and improving alternatives for achieving aspiration levels in each criterion

Obviously, an alternative Ai is closer to the FPIS (A^{*}) and farther from FNIS (A^{-}) as CC_i approaches to 1. Therefore, according to the closeness coefficient we can determine the ranking order of all alternatives and select the best one from a set of feasible alternatives. The chosen alternative should have the shortest distance from the positive-ideal solution (that is, achieving the minimal gaps in each criterion) and the farthest distance from the negative-ideal solution (that is, achieving the maximal levels in each criterion). The $\widetilde{CC}_i$ is defined to determine the fuzzy gaps-degree based on fuzzy closeness coefficients for improving alternatives; once the $\tilde{d}_i^{+}$ and $\tilde{d}_i^{-}$ of each alternative have been calculated. This step solves the similarities to an ideal solution by the following formula:

$$\widetilde{CC}_i = \frac{\tilde{d}_i^{-}}{\tilde{d}_i^{-} + \tilde{d}_i^{*}} = 1 - \frac{\tilde{d}_i^{*}}{\tilde{d}_i^{-} + \tilde{d}_i^{*}} \tag{17}$$

CASE STUDY

Our study was conducted in CROUSE Company, established in 1986 in Iran. The company, with about 4000 employees produces automotive parts and is one of the major suppliers of the two largest automotive complexes in Iran; that is IRANKHODRO and SAIPA. It's financial flow and purchasing costs amount to nearly 8 billion dollars and 900 million dollars respectively. The company is currently procuring ABS sensor parts from European countries, but it wants to explore other options. In its search for different ways of procuring ABS sensor parts, our case study company has come up with five alternatives which follow (Table 5).

STEPS TAKEN AND DATA ANALYSIS

1) Having reviewed the relevant literature of technology selection criteria, 25 criteria were selected to work on.
2) Fuzzy Delphi method was applied to screen the criteria in the following procedure: first an FDM interview table with respect to Table 2 was setup and then interviews were made with ten experts from CROUSE Company. As a result, seven criteria were extracted from this stage (Table 6).
3) Determining the weights of evaluation criteria, we adopted fuzzy AHP method to evaluate the weights of different criteria for the performance of technology selection. Following the construction of fuzzy AHP model, it is extremely important that experts fill the judgment matrix.

According to the views presented by the committee with ten representatives about the relative importance of criteria, the pair wise comparison matrices of criteria were formed. We applied the fuzzy numbers defined in Table 3. We transformed the linguistic scales to the corresponding fuzzy numbers. Computing the elements of synthetic pair wise comparison matrix by using the geometric mean method suggested by Buckley (1985) that is:

Table 4. Linguistic variables for the ratings.

Very good (VG)	(9, 10, 10)
Good (G)	(7, 9, 10)
Medium good (MG)	(5, 7, 9)
Fair (F)	(3, 5, 7)
Medium poor (MP)	(1, 3, 5)
Poor (P)	(0, 1, 3)
Very poor (VP)	(0, 0, 1)

$$\tilde{a}_{ij} = \left(\tilde{a}_{ij}^{1} \otimes \tilde{a}_{ij}^{2} \otimes \ldots \otimes \tilde{a}_{ij}^{10}\right)^{1/10}$$

For example:

$$\tilde{a}_{12} = \left((2,3,4) \otimes (1,1,1) \otimes (2,3,4) \otimes (2,3,4) \otimes (1/4,1/3,1/2) \otimes (2,3,4) \otimes (5,6,7) \otimes (1,2,3) \otimes (1/4,1/3,1/2) \otimes (1,2,3)\right)^{1/10} = (1.175,1.712,2.294)$$

Other matrix elements can be obtained by the same computational procedure, therefore, the synthetic pair wise comparison matrices of the ten representatives will be constructed as follows matrix A:

$$A = \left[\begin{array}{c|ccccccc} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 \\ C_1 & (1,1,1) & (1.175,1.712,2.294) & (0.896,1.335,1.888) & (3.294,4.117,5.016) & (4.558,5.609,6.642) & (4.253,5.304,6.337) & (2.548,3.66,4.716) \\ C_2 & (0.436,0.584,0.851) & (1,1,1) & (0.699,0.95,1.282) & (2.377,3.18,3.968) & (3.174,4.246,5.291) & (3.099,4.151,5.181) & (1.473,2.011,5.548) \\ C_3 & (0.53,0.749,1.116) & (0.78,1.052,1.431) & (1,1,1) & (3.392,4.225,5.02) & (4.799,5.769,6.716) & (3.796,4.822,5.806) & (2.285,3.128,4.012) \\ C_4 & (0.199,0.244,0.304) & (0.212,0.337,0.461) & (0.195,0.23,0.283) & (1,1,1) & (0.96,1.317,1.866) & (0.568,0.792,1.231) & (0.338,0.426,0.591) \\ C_5 & (0.151,00.178,0.219) & (0.181,0.224,0.294) & (0.149,0.173.208) & (0.536,0.759.1.041) & (1,1,1) & (0.404,0.508,0.728) & (0.207,0.262,0.36) \\ C_6 & (0.158,0.188,0.235) & (0.193,0.241,0.322) & (0.172,0.207,0.263) & (0.812,1.263,1.762) & (1.374,1.966,2.475) & (1,1,1) & (0.281,0.364,0.536) \\ C_7 & (0.212,0.273,0.392) & (0.392,0.497.0.679) & (0.249,0.32,0.438) & (1.692,2.345,2.961) & (2.781,3.812,4.83) & (1.866,2.745,3.565) & (1,1,1) \end{array}\right]$$

To calculate the fuzzy weights of criteria, the computational procedures were performed as follows:

$$\tilde{r}_1 = \left(\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \tilde{a}_{13} \otimes \tilde{a}_{14} \otimes \tilde{a}_{15} \otimes \tilde{a}_{16} \otimes \tilde{a}_{17}\right)^{1/7}$$

$$\begin{aligned} \tilde{r}_1 &= \big((1,1,1) \otimes (1.175,1.712,2.294) \otimes (0.896,1.335,1.888) \otimes (3.294,4.117,5.016) \\ &\quad \otimes (4.558,5.609,6.642) \otimes (4.253,5.304,6.337) \otimes (2.548,3.66,4.716)\big)^{1/7} \\ &= (2.085,2.692,3.564) \end{aligned}$$

$$\tilde{r}_2 = (1.339,1.805,2.527),$$
$$\tilde{r}_3 = (1.788,2.247,2.771),$$
$$\tilde{r}_4 = (0.395,0.505,0.659)$$

$$\tilde{r}_5 = (0.292,0.354,0.448), \quad \tilde{r}_6 = (0.4,0.506,0.645),$$
$$\tilde{r}_7 = (0.784,1.01,1.29)$$

For the weight of each criterion, they can be done as follows:

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5 \oplus \tilde{r}_6 \oplus \tilde{r}_7)^{-1}$$

$$\tilde{w}_1 = \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5 \oplus \tilde{r}_6 \oplus \tilde{r}_7)^{-1}$$

$$\begin{aligned} \tilde{w}_1 &= (2.085,2.692,3.564) \\ &\quad \otimes \big(1/(3.564+2.527+2.771+0.659+0.448+0.645+1.29),1/(2.692 \\ &\quad +1.805+2.247+0.505+0.354+0.506+1.01),1/(2.085+1.339 \\ &\quad +1.788+0.395+0.292+0.4+0.784)\big) = (0.175,0.295,0.499) \end{aligned}$$

We then calculated the remaining $\tilde{w}_i$ (Table 7). They are:

$$\tilde{w}_2 = (0.117,0.198,0.354),$$
$$\tilde{w}_3 = (0.15,0.246,0.388),$$
$$\tilde{w}_4 = (0.033,0.055,0.092)$$

$$\tilde{w}_5 = (0.024,0.039,0.063),$$
$$\tilde{w}_6 = (0.034,0.055,0.09), \quad \tilde{w}_7 = (0.066,0.111,0.18)$$

EVALUATING ALTERNATIVES BY FUZZY TOPSIS

In this step, we adopted fuzzy TOPSIS to evaluate the performance of the technology alternatives. This paper focuses on evaluating the performance of five potential ABS sensor technologies. First we constructed the fuzzy-decision matrix and chose the appropriate linguistic variables for the alternatives with respect to criteria. The evaluator has his own range for the linguistic variables employed in this study according to his subjective judgments (Table 8). The evaluator then adopted linguistic terms (Table 4) including “very good”, ‘‘good”, ‘‘medium good”, ‘‘fair”, ‘‘medium poor”, “poor” and “very poor” to express his opinion about the rating of every technology regarding each capability criteria based on the data of the five technologies listed in Table 5. Using Equation 12, we then normalized the fuzzy-decision matrix as Table 9. In the next step we established the weighted normalized fuzzy-decision matrix. The resulted fuzzy-weighted decision matrix is shown as Table 10. At this step, we defined the fuzzy positive-ideal solution (FPIS) and the fuzzy negative-ideal solution (FNIS) as: A^{+} and A^{-}.

$$\begin{aligned} A^{+} &= [(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1)] \otimes \tilde{w}_j \\ &= [(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1)] \\ &\otimes [(0.175,0.295,0.499),(0.117,0.198,0.354),(0.15,0.246,0.388),(0.15,0.246,0.388),(0.033,0.055,0.092), \\ &(0.024,0.039,0.063),(0.034,0.055,0.09),(0.066,0.111,0.18)] = \end{aligned}$$

$$\begin{aligned} &(0.175,0.295,0.499),(0.117,0.198,0.354),(0.15,0.246,0.388),(0.15,0.246,0.388),(0.033,0.055,0.092), \\ &(0.024,0.039,0.063),(0.034,0.055,0.09),(0.066,0.111,0.18) \end{aligned}$$

$$A^{-} = [(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0)]$$

Table 5. ABS sensor parts procurement alternatives.

Alternative	description
A_1	Importing the whole ABS sensor from another country.
A_2	Importing the ABS sensor parts from another country and assembling the terminal internally within the company.
A_3	Importing all ABS sensor parts from another country and doing the assembly internally within the company.
A_4	Importing just the internal pivot of the sensor from another country and having the production of other parts and assembly done internally within the company.
A_5	Producing the whole ABS sensor internally within the company.

Table 6. Derived criteria and their definitions.

Criterion	Definition
C_1: Political effect	How political sanctions and limitations affect the growth and development of the selected technology.
C_2: Impact on employment	How the selected technology affects employment.
C_3: Economic attractiveness	How the selected technology affects the sales volume.
C_4: Innovation	How the selected technology affects innovation.
C_5: Technical knowledge and learning	The technical knowledge transferred and learning occurred with the selected technology.
C_6: Value creation for customers	The value of the technology core product and its supplementary functions to customers.
C_7: Usability	The importance of the needs satisfied by the technology products to customers.

Table 7. Weights of criteria.

$\tilde{w}_i$	Weight	Rank
$\tilde{w}_1$	$(0.175, 0.295, 0.499)$	1
$\tilde{w}_2$	$(0.117, 0.198, 0.354)$	3
$\tilde{w}_3$	$(0.15, 0.246, 0.388)$	2
$\tilde{w}_4$	$(0.033, 0.055, 0.092)$	5
$\tilde{w}_5$	$(0.024, 0.039, 0.063)$	7
$\tilde{w}_6$	$(0.034, 0.055, 0.09)$	6
$\tilde{w}_7$	$(0.066, 0.111, 0.18)$	4

Table 8. Subjective cognition result of evaluator towards the seven levels of linguistic variables.

		C_1	C_2	C_3	C_4	C_5	C_6	C_7
$D =$	A_1	(1, 3, 5)	(1, 3, 5)	(7, 9, 10)	(7, 9, 10)	(7, 9, 10)	(7, 9, 10)	(7, 9, 10)
	A_2	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(7, 9, 10)	(5, 7, 9)	(7, 9, 10)	(5, 7, 9)
	A_3	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(9, 10, 10)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	A_4	(7, 9, 10)	(7, 9, 10)	(5, 7, 9)	(9, 10, 10)	(5,7, 9)	(3, 5, 7)	(3, 5, 7)
	A_5	(7, 9, 10)	(9, 10, 10)	(5, 7, 9)	(9, 10, 10)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)

Table 9. Normalized fuzzy-decision matrix.

		C_1	C_2	C_3	C_4	C_5	C_6	C_7
$ND =$	A_1	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)	(0.7,0.9,1)
	A_2	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.7,0.9,1)	(0.5,0.7,0.9)	(0.7,0.9,1)	(0.5,0.7,0.9)
	A_3	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.9,1,1)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)
	A_4	(0.7,0.9,1)	(0.7,0.9,1)	(0.5,0.7,0.9)	(0.9,1,1)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
	A_5	(0.7,0.9,1)	(0.9,1,1)	(0.5,0.7,0.9)	(0.9,1,1)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)

Table 10. Weighted normalized fuzzy-decision matrix.

		C_1	C_2	C_3	C_4	C_5	C_6	C_7
V=	A_1	(0.0175, 0.0885, 0.2495)	(0.0117, 0.0594, 0.1725)	(0.105, 0.2214, 0.388)	(0.0231, 0.0495, 0.092)	(0.0168, 0.0351, 0.063)	(0.0238, 0.0495, 0.09)	(0.0462, 0.099, 0.18)
	A_2	(0.0525, 0.1475, 0.3493)	(0.0351, 0.099, 0.2415)	(0.075, 0.1722, 0.3492)	(0.0231, 0.0495, 0.092)	(0.012, 0.0273, 0.0567)	(0.0238, 0.0495, 0.09)	(0.033, 0.0777, 0.162)
	A_3	(0.0875, 0.2065, 0.4491)	(0.0585, 0.1386, 0.3105)	(0.075, 0.1722, 0.3492)	(0.0297, 0.055, 0.092)	(0.012, 0.0273, 0.0567)	(0.017, 0.0385, 0.081)	(0.033, 0.0777, 0.162)
	A_4	(0.1225, 0.2655, 0.499)	(0.0819, 0.1782, 0.345)	(0.075, 0.1722, 0.3492)	(0.0297, 0.055, 0.092)	(0.012, 0.0273, 0.0567)	(0.0102, 0.0275, 0.063)	(0.0198, 0.0555, 0.126)
	A_5	(0.1225, 0.2655, 0.499)	(0.1053, 0.198, 0.345)	(0.075, 0.1722, 0.3492)	(0.0297, 0.055, 0.092)	(0.012, 0.0273, 0.0567)	(0.017, 0.0385, 0.081)	(0.033, 0.0777, 0.162))

Table 11. Closeness coefficients to aspired level among different alternatives.

	d^+	d^-	Satisfaction degree of cc_i^-	Gaps degree of cc_i^+	Rank
A_1	1.7133	0.8108	0.3212	0.6788	5
A_2	1.7583	0.8670	0.3271	0.6729	4
A_3	1.8385	0.9773	0.3470	0.653	3
A_4	1.8545	1.0135	0.3533	0.6467	2
A_5	1.8806	1.0597	0.3604	0.6396	1

We define $\widetilde{CC}_i^+$ as satisfaction degree in ith alternative and $\widetilde{CC}_i^-$ as gap degree in ith alternative. We can know which and how gaps should be improved for achieving aspiration levels and getting the best win–win strategy from among a fuzzy set of feasible alternatives. The aspired/desired satisfaction degree of fuzzy TOPSIS is 1.00. From the results of Table 11, we can find out the satisfaction degrees and gap degrees of each technology selection.

CONCLUSION

This research aims to apply a fuzzy Delphi, fuzzy AHP and fuzzy TOPSIS model to evaluate ABS sensor technology alternatives for CROUSE Company. The integrated evaluation system provides practitioners with a fuzzy point of view to traditional performance evaluation model for dealing with imprecision. The proposed method enables decision analysts to better understand the complete evaluation process. This approach provides a more accurate, effective and systematic decision support tool. The importance of the criteria is evaluated by experts and the uncertainty of human decision making is taken into account through the fuzzy concept in fuzzy environment. Applying fuzzy AHP revealed that of the many criteria found in literature for technology selection, seven were very important and that two criteria, political issues and impact of technology on employment were the most important. One major value of our research was extracting these criteria showing that effective factors for technology selection are not only financial indicators but also other indicators such as political issues or the impacts of technology on employment are influential. We used our method to evaluate the five potential ABS sensor technologies against these criteria and our finding was that performing all processes of producing the ABS sensor in our country is the most appropriate technology for CROUSE Company.

REFERENCES

Achilladelis B, Antonakis N (2001). The dynamics of technological innovation: the case of the pharmaceutical industry. *Res. Policy*, pp. 535-588.

Awazu Y (2006). Managing technology alliances: The case for knowledge management. *Int. J. Inf. Manage.*, 484-493.

Bellman R, Zadeh L (1970). Decision-making in a fuzzy environment management. *Science, 17*: 141-164.

Bevilacqua M, Ciarapica F, Giacchetta G (2006). A fuzzy-QFD approach to supplier selection. *J. Purchas. Supply Manage.*, pp.14-27.

Brown S, Dennis A, Venkatesh V (2010). Predicting Collaboration Technology Use: Integrating Technology Adoption and Collaboration Research. *J. Manage. Inf. Syst.*, pp. 9-53.

Buckley JJ (1985). Fuzzy hierarchical analysis. *Fuzzy Sets Syst., 17*: 233-247.

Büyüközkan G, Feyziog˘lu O, Nebol E (2007). Selection of the strategic alliance partner in logistics value chain. *Int. J. Prod. Econ., 113*: 148-158.

Cantwell J (1992). *The internalization of technological activity and its implications for competitiveness, in: O. Grandstrand, L. HakanSon, S. Sjolander (Eds.), Technology Management and International Business: Internationalisation of R&D and Technology.* New York: Wiley.

Carlson J, Zmud R (1999). Channel expansion theory and the experiential nature of media richness perceptions. *Acad. Manage. J.*, pp.153-170.

Chan F, Kumar N (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. *Omega, 35*: 417-431.

Chiesa V (1998). R&D Strategy and Organization. *Series Technol. Manage.*, pp.107-188.

Choudhury A, Shankar R, Tiwari M (2006). Consensus-based intelligent group decision-making model for the selection of advanced technology. *Decision Support Syst., 42*: 1776-1799.

Clark K (1989). what strategy can do for technology. *Harv. Bus. Rev.*, pp. 94-98.

Coldrick S, Longhurst P, Ivey P, Hannis J (2005). An R&D options selection model for investment decisions. *Technovation*, pp.185-193.

Da Silveira G, Cagliano R (2006). The relationship between interorganizational information systems and operations performance. *Int. J. Operat. Prod. Manage.*, 232-281.

Daft R, Lengel R (1986). Organizational information requirements, media richness and structural design. *Manage. Sci.*, pp. 554-571.

Daim T, Kocaoglu D (2008). Exploring technology acquisition in Oregon, Turkey and in the U.S. electronics manufacturing companies. *J. High Technol. Manage. Res.*, pp. 45-58.

Dussauge P, Hart S, Ramanatsoa B (1992). *Strategic technology management.* New York: Wiley.

Evans A, Strezov V, Evans T (2009). Assessment of sustainability indicators for renewable energy technologies. *Renew. Sustainab. Energy Rev.*, pp. 1082-1088.

Farooq S, O'Brien C (2010). Risk calculations in the manufacturing technology selection process. *J. Manuf. Technol. Manage.*, pp. 28-49.

Fichman R, Kemerer C (1999). The illusory diffusion of innovation: an examination of assimilation gaps. *Inf. Syst. Res.*, pp.123-139.

Gimenez G (2006). Investment in new technology: modeling the decision process. *Technovation*, pp. 345-350.

Granstrand O (2004). The economics and management of technology trade: Towards a pro-licensing era? *Int. J. Technol. Manage.*, 209-240.

Gregory M (1995). Technology management: a process approach. *Proceed. Institut. Mech. Eng., 209*: pp. 347-355.

Hänninen S, Kauranen I (2007). Product innovation as micro strategy. *Int. J. Innov. Learn.*, pp. 425-443.

Hemmert M (2004). The Influence of Institutional Factors on the Technology Acquisition Performance of High-Tech Firms: Survey Results from Germany and Japan. *Res. Policy*, pp. 1019-1039.

Hemphill T (2006). Economic considerations in cooperative research and development agreements (CRADA): The case of Taxol, NIH, and technology transfer. *Technol. Soc.*, 321-331.

Hsieh TY, Lu ST, Tzeng GH (2004). Fuzzy MCDM approach for planning and design tenders selection in public office buildings. *Int. J. Project Manage., 22*: 573-584.

Hsu Y, Lee C, Kreng V (2010). The application of Fuzzy Delphi Method and Fuzzy AHP in lubricant regenerative technology selection. *Expert Syst. Appl.*, pp. 419-425.

Husain ZS, Pathak R (2002). A technology management perspective on collaborations in the Indian automobile industry: a case study. *J. Eng. Technol. Manage*, pp.167-201.

Hwang C, Yoon K (1981). *Multiple attribute decision making-methods and applications: A state of the art survey.* Springer-Verlag.

Ishikawa A, Amagasa M, Shiga T, Tomizawa G, Tatsuta R, Mieno H (1993). The max–min Delphi method and fuzzy Delphi method via fuzzy integration. *Fuzzy Sets Syst., 55*: 241-253.

Kahraman C, Cebeci U, Ruan D (2004). Multi-attribute comparison of catering service companies using fuzzy AHP: The case of Turkey. *Int. J. Prod. Econ., 87*: 171-184.

Kahraman C, Cebeci U, Ulukan Z (2003). Multi-criteria supplier selection using fuzzy AHP. *Logist. Inf. Manage., 16*: 382-394.

Kasvi J, Vartiainen M, Hailikari M (2003). Managing knowledge and knowledge competences in projects and project organisations. *Int. J. Project Manage.*, pp. 571-582.

Keogh W, Stewart V, Taylor J (2001). *Developing strategies for growth in HTSFs: looking beyond survival in an increasingly competitive marketplace, in: During, W., Oakey, R. (Eds.), New Technology-Based Firms in the New Millenium.* London: Pergamon Press.

Kim B (2003). Managing the transition of technology life cycle. *Technovation*, pp. 372-381.

Klir G, Yuan B (1995). *Fuzzy sets and fuzzy logic – Theory and application.* New Jersey: Prentice-Hall Inc.

Kulak O, Kahraman C, Öztayşi B, Tanyaş M (2005). Multi-attribute information technology project selection using fuzzy axiomatic design. *J. Enterprise Inf.*, pp. 275-288.

Kuo MS, Tzeng GH, Huang WC (2007). Group decision making based on concepts of ideal and anti-ideal points in fuzzy environment. *Math. Comput. model., 45*: 324-339.

Laarhoven P, Pedrycz W (1983). A fuzzy extension of Sati's priority theory. *Fuzzy Sets Syst., 11*: 229-241.

Landeta J (2006). Current validity of the Delphi method in social sciences. *Technological Forecast., Social Change*, pp. 467-482.

Langley A, Mintzberg H, Pitcher P, Posada E, Saint-Macary J (1995). Opening up decision making: the view from the black stool. *Organiz. Sci.*, pp. 260-279.

Laurie D (2001). *Venture Catalyst.* New York: McGraw-Hill.

Lee H, Kim C, Cho H, Park Y (2009). An ANP-based technology network for identification of core technologies: A case of telecommunication technologies. *Expert Syst. Appl.*, pp. 894-908.

Lee J, Kim S (2001). An integrated approach for interdependent information system project selection. *Int. J. Proj. Manage*, pp. 111-118.

Lee Y, Song Y (2007). Selecting the key research areas in nano-technology field using technology cluster analysis: a case study based on national R&D programs in South Korea. *Technovation*, 57-64.

Lefebvre L, Langley A, Harvey J, Lefebvre E (1992). Exploring the strategy–technology connection in small manufacturing firms. *Prod. Operat.*, pp. 269-285.

Lehtimäki T, Simula H, Salo J (2009). Applying knowledge management to project marketing in a demanding technology transfer project: Convincing the industrial customer over the knowledge gap. *Ind. Market. Manage.*, pp. 228-236.

Leseure M, Brookes N (2004). Knowledge management benchmarks for project management. *J. Knowl. Manage.*, pp.103-116.

Liu H, Jiang Y (2001). Technology transfer from higher education institutions to industry in China: nature and implications. *Technovation*, pp. 175-188.

Lucheng H, Xin L, Wenguang L (2010). Research on emerging technology selection and assessment by technology foresight and fuzzy consistent matrix, pp. 77-89.

McAdam R, Keogh W, Galbraith B, Laurie D (2005). Defining and improving technology transfer business and management processes in university innovation centres. *Technovation*, pp. 1418-1429.

Murray T, Pipino L, Gigch J (1985). A pilot study of fuzzy set modification of Delphi. *Human. Syst. Manage.*, pp. 6-80.

Murry T, Pipino L, & Gigch J (1985). A pilot study of fuzzy set modification of Delphi. *Human Systems Manage., 5*: 76-80.

Noorderhaben N (1995). *Strategic decision making.* UK: Addison-Wesley.

Patterson K, Grimm C, Corsi T (2003). Adopting new technologies for supply chain management. *Transport. Res. Part E*, pp. 95-121.

Peças P, Ribeiro I, Folgado R, Henriques E (2009). A Life Cycle Engineering model for technology selection: a case study on plastic injection moulds for low production volumes. *J. Cleaner Prod.*, pp. 846-856.

Phaal R, Farrukh C, Probert D (2001). Technology management process assessment: A case study. *Int. J. Operat. Prod. Manage.*, pp. 1116-1132.

Piipo P, Tuominen M (1990). *Promoting innovation management by decision support systems: Facilitating new products' relevance to the corporate objectives. In J. Allesch (Ed.), Consulting in innovation: Practice—methods— perspectives.* Holland: Elsevier Science Publishers.

Prajogo D, Sohal A (2006). The integration ofTQMand technology/R&D management in determining quality and innovation performance. *J. J. manage. sci.*, pp. 296-312.

Reinsch N, Beswick R (1990). Voice mail versus conventional channels: A cost minimization analysis of individuals' preferences. *Acad. Manage. J.*, pp. 801-816.

Ronde P (2003). Delphi analysis of national specificities in selected innovative areas in Germany and France. *Technol. Forecast. Soc. Change*, pp. 419-448.

Sarami M, Mousavi S, Sanayei A (2009). TQM consultant selection in SMEs with TOPSIS under fuzzy environment. *Expert Syst. Appl., 36*: 2742-2749.

Schweizer L (2005). Knowledge transfer and R&D in pharmaceutical companies: A case study. *J. Eng. Technol. Manage.*, 315-331.

Shehabuddeen N, Probert D, Phaal R (2006). From theory to practice: challenges in operationalising a technology selection framework. *Technovation*, pp. 324-335.

Shen Y, Lin G, Tzeng G (2011). Combined DEMATEL techniques with novel MCDM for the organic light emitting diode technology selection. *Expert Syst. Appl., 38*: 1468-1481.

Shen YC, Chang SH, Lin, G, Yu HC (2010). A hybrid selection model for emerging technology. *Technol. Forecast. Soc. Change*, 151-166.

Short J, Williams E, Christie B (1976). *The Social Psychology of Telecommunications.* London: John Wiley.

Siegel D, Waldman D, Atwater L, Link A (2004). Toward a model of the effective transfer of scientific knowledge from academicians to practitioners: qualitative evidence from the commercialization of university technologies. *J. Eng. Technol. Manage.*, pp.115-142.

Siriram R, Snaddon D (2005). Verifying links in technology management, transaction processes and governance structures. *Technovation*, pp.321-337.

Stacey G, Ashton W (1990). A structured approach to corporate technology strategy. *Int. J. Technol. Manage.*, pp. 389-1407.

Stewart RA (2008). A framework for the life cycle management of information technology projects: ProjectIT. *Int. J. Project Manage.*, pp. 203-212.

Sung T (2009). Technology transfer in the IT industry: A Korean perspective. *Technol. Forecast. Soc. Change*, pp. 700-708.

Swamidass P, Kotha S (1998). Explaining manufacturing technology use, firm size and performance using a multidimensional view of technology. *J. Operat. Manage.*, pp. 23-37.

Takayama M, Watanabe C (2002). Myth of market needs and technology seeds as a source of product innovation — an analysis of pharmaceutical new product development in an anti-hypertensive product innovation. *Technovation*, pp. 353-362.

Tingling P, Parent M (2004). An exploration of enterprise technology selection and evaluation. *Journal of Strategic Inf. Syst.*, pp. 329-354.

torkkeli m, tuominen m (2002). The contribution of technology selection to core competencies. *Int. J. Prod. Econ.*, pp. 271-284.

Venanzi D (1996). A new approach to the identification and selection of international technology transfer modes: logical framework and empirical evidence. *Technovation*, pp. 287-300.

Walsh S, Linton J (2011). The Strategy-Technology Firm Fit Audit: A guide to opportunity assessment and selection. *Technol. Forecast. Soc. Change.*, pp.199-216.

Wang TC, Chang TH (2007). Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment. *Expert Syst. Appl., 33*: 870-880.

Wu L, Ong C (2008). Management of information technology investment: A framework based on a Real Options and Mean–Variance theory perspective. *Technovation*, pp. 122-134.

Yang T, Hung CC (2007). Multiple-attribute decision making methods for plant layout design problem. *Robot. Comput. Integr. Manuf., 23*: 126-137.

Yu O, Hsu G, Chen T (1998). *Introduction to technological management: Technological forecast and planning.* Taipei: Wu Nan Publishing Company.

Zadeh LA (1965). Fuzzy sets. *Inf. Control, 8*: 338-353.

Zaidmanand B, Gevidalli G (1989). TEQ–a methodology for comparative evaluation of technologies. *Eng. Costs Prod. Econ.*, pp. 131-138.

Zhang J, Daim T, Choi BC, Phan K (2008). A multiple-perspective model for technology assessment Case of mobile broadband technologies selection in China. *J. Technol. Manage. china*, pp. 264-278.