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# A FUZZY MULTI-CRITERIA DECISION APPROACH FOR MEASURING TECHNOLOGY COMPETENCY PERFORMANCE OF SMEs

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## ABSTRACT

This paper researches on the technology competency, management capability and firm performance. Technology competency and strategic management becomes more and more important for enterprises to keep their competitive power in the sector. Technology and management competency determines capabilities of enterprises to compete in the sector and has a critical importance for the innovative researches and development. The development of the research model is based on the empirical studies of the management from technology literature. Data were collected from a sample of 450 Turkish manufacturing firms which was obtained by stratified sampling from the registered firm database of Istanbul Chamber of Industry. A hierarchical performance evaluation model is structured based on the six main competency dimensions that are determined by expert evaluation and based on the literature review. In this study, a fuzzy multi-criteria decision making approach is proposed to evaluate technology competency performance of the manufacturing firms in Istanbul, Turkey. Small and medium-sized enterprises (SMEs) are analyzed and evaluated with respect to technology survey responses in which processes management, products, information and communication technology, marketing strategy, innovation and entrepreneurial activities and research and developments (R&D) issues are investigated. Fuzzy analytic hierarchy process (FAHP) method is used to determine the weights of the decision criteria. These criteria weights and responses of survey analysis (data) related with the enterprises are input for the VIKOR method to rank the firms.
**Keywords:** Technology competency, multi criteria decision making (MCDM), small and medium-sized enterprises (SMEs).

## 1. INTRODUCTION

Countries in globalizing world are divided into two parts: those producing technology and those using technology. Enterprises recognize technology as a nature of driver for the growth and development, most managers are aware of deploying technology to support strategic business objectives by using technology as an interface.

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Technology is vitally important not only for competitive advantages of firms and sectors but also for the competency of countries, thus, it plays a decisive role on development and underdevelopment level in terms of the effects it creates. Determining the most appropriate technology from different alternatives, selecting among alternatives and performing the best one initiates the value creation and a competitive advantage in a serious decision-making process. Enterprises need to implement technology-oriented investment projects to pass by competitors in the global competitive environment.

The manufacturing industry is one of the main drivers of the Turkish economy. A number of manufacturing sub-sectors in Turkey have been growing in recent years [1], [2]. Nowadays, one of the most important subjects for the companies which are profitable and have continuous management principles, is the fact of having targets [3]. Small to medium sized enterprises (SMEs) are considered to be the backbone of any economy as they play a major role in the economic development of a country [4].

Hsieh et al. [5] presents a fuzzy multi-criteria analysis approach for selecting of planning and design (P&D) alternatives in public office building. The aim of the MCDM is to obtain the optimum choice that has the highest degree of satisfaction for all of the relevant attributes [6], [7]. Yalcin et al. [7] evaluated financial performance of Turkish manufacturing companies based on the method which are integrated with FAHP, VIKOR and TOPSIS. FAHP and balanced scorecard (BSC) hybrid approach is proposed by Lee et al. [8] for evaluating an information technology department in the manufacturing industry. Ertugrul and Karakasoglu [9] presented a fuzzy model to evaluate the financial performance of Turkish cement companies by using FAHP and TOPSIS method. Grey based Taguchi method is used for simulation optimization in the stage of grade relational calculation weighting then fuzzy AHP method is adopted to determine the weights of grey relational coefficients [10].

Liao [11] analyzes the technology management methodologies and applications as a literature review from 1995 to 2003. Hameed et al. [12] suggest a conceptual model for the process of information technology (IT) innovation adoption in organizations based on the engineering and technology management. Ashrafi and Murtaza [13] show the use and impact of ICT on SMEs in Oman. Kalkan et al. [14] show the relationships between firm size, prospector strategy, architecture of information technology and firm performance. Oliveira et al. [15] present a method called decision making based on knowledge (DeBK) which is designed to analyze the knowledge of project information at the front end of innovation and its impact on decisions. Cetindamar et al. [16] show a framework for technology management activities for understanding technology management as a dynamic capability. Pretorius and Benade [17] suggest a systems dynamics approach to competing technologies for exploring uncertainty of interaction and market parameters.

The reminder of paper is organized as follows: In Section 2, technology performance criteria used for technology competency evaluation of SMEs are briefly explained. Section 3 presents the applied approaches and their steps. In Section 4, criteria weights and an application for technology competency evaluation of the manufacturing firms are given. Finally, results of the application and explanations are presented and suggestions for further research are given.

## 2. PERFORMANCE CRITERIA OF TECHNOLOGY COMPETENCY

Drawing on a structured questionnaire, data of the study were collected from a sample of 450 manufacturing firms that are listed in the database of the Istanbul Chamber of Industry. A questionnaire with 44 questions about technology management issues were investigated on SMEs operating in a sub-sector of manufacturing sector in Istanbul. The data were obtained by the survey from six dimensions and twenty sub-criteria for machine sub-sector. Thirty firms are randomly selected from machine sub-sector to define the best-performing firm by the technology competency analysis.

The proposed list of dimensions, sub-criteria and the data used in technology competency analysis are based on literature review and expert evaluation. Six dimensions of the technology and management competency are defined to evaluate the levels of the firms;

-*Process Management:* It considers the economic and ecological efficiency, the presence of technology management process, quality assurance, working culture, productivity or its contribution to corporate or business strategies and objectives. This main criteria includes three sub-criteria; Cleaner production and productivity applications, Technology management, Quality and assurance systems [1], [11], [13].

-*Product competitiveness:* It considers innovative and technological products development capability, advertising and promotional activities and the product potential to compete with its competitors in terms of technical performance or in any other dimension seen as important by customers. This main criteria has three sub-criteria; Technology working group, Innovative and technological products, e-commerce and marketing activity [2], [15], [16].

-*Information and Communication Technologies (ICT):* It considers the computerized technologies, technology investments, barrier to ICT, enterprise software applications, expertise, ICT budgets and database usage, hardware and software infrastructure and collaborations for infrastructure projects. This main criteria includes four sub-criteria; Knowledge based systems, Technology utilization, Operations expertise and Technology investments [13], [16].

-*Marketing Strategies*: It considers project cooperation, gaining a competitive advantage in the market and the probability of the commercialization model and of the product benefits to reach market requirements as commercial risks, marketing and positioning strategies. The main criteria includes two sub-criteria; Business strategy, Strategic and technological cooperation [1], [2], [15].

-*Innovation and Entrepreneurship*: It considers technological innovations and news, management activities, technological developments, expert staff, knowledge acquisition, and new product development. The main criteria includes four sub-criteria; Open innovation, New product and service development, Innovative workforce, Social media and communication tools [1], [13], [16].

-*Research and Development*: It considers research collaboration, financial capabilities, the average annual budget allocated to R&D activities, research and development projects, intellectual and industrial property rights and research activities for new products. The main criteria includes four sub-criteria; R&D activities, Organizational competencies, Technological projects, Intellectual and industrial property rights [2], [15], [16].

## 3. THE MATHEMATICAL APPROACHES

The main objective of this paper is to evaluate the firms of machine sub-sector of the Turkish manufacturing sector. A hierarchical performance evaluation model is structured to evaluate technology competency level of the firms based on the six main dimensions and criteria.

For this purpose, we use fuzzy analytic hierarchy process to determine the weights of all criteria, sub-criteria and then choose the best firm in Turkish manufacturing sector by VIKOR approach with respect to machine industry. In this section, the basic definitions and steps of the applied approach is presented. Fuzzy analytic hierarchy process method is used to determine the weights of the criteria and sub-criteria. These criteria weights and responses of survey analysis related with firm profile are input data to rank the firms by the VIKOR method.

### 3.1. Fuzzy Analytic Hierarchy Process

In this study, Buckley's [18] extension FAHP approach is used to obtain the weights of the financial performance criteria since it is easy to extend to the fuzzy case and guarantees a unique solution to the reciprocal comparison matrix and the steps of this approach are relatively easier than the other Fuzzy-AHP approaches. The steps used for the Buckley's FAHP algorithm can be summarized as follows [18], [19] and [20];

*Step 1.* Construct pairwise comparison matrices among all the criteria in the hierarchical structure (equation 1). Assign linguistic terms shown in equation (2), to the pairwise comparisons by asking which is the more important of each two criteria, such as

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

Where

$$\tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9} & \text{criterion } i \text{ has relative} \\ & \text{importance to criterion } j \\ 1. & i = j \\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1} & \text{criterion } i \text{ has less} \\ & \text{importance to criterion j} \end{cases} \tag{2}$$

*Step 2.* Use geometric mean technique to define the fuzzy geometric mean as follows:

$$\tilde{r}_i = \left( \tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in} \right)^{1/n} \tag{3}$$

Where $\tilde{a}_{in}$ fuzzy comparison value of criterion $i$ to criterion $n$ , thus, is geometric mean of fuzzy comparison value of criterion $i$ to each criterion.

*Step 3.* Calculate the fuzzy weights of each criterion using

$$\tilde{w}_i = \tilde{r}_i \otimes \left( \tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n \right)^{-1} \tag{4}$$

Where $\tilde{w}_i$ is the fuzzy weight of the *i*th criterion, can be indicated by $\tilde{w}_i = (lw_i, mw_i, uw_i)$. Here $lw_i, mw_i, uw_i$ and stand for the lower, middle and upper values of the fuzzy weight of the *i*th criterion.

*Step 4.* Utilize center of area (COA) method to find out the best non-fuzzy performance (BNP) value (crisp weights) of each criterion by the following equation:

$$BNP\tilde{w}_i = [(uw_i - lw_i) + (mw_i - lw_i)]/3 + lw_i \tag{5}$$

According to the value of the derived BNP for each of the alternatives, the ranking of the each alternative can then proceed.

### 3.2. VIKOR Approach

Yu [21] and Zeleny [22] proposed the VIKOR method. This method is based on an aggregating function representing closeness to the reference point(s). Yalcin et al. [7] introduced the VIKOR method as an aggregating function, representing the distance from the ideal solution. The main steps of the VIKOR method are described as follows:

*Step 1*. Determine the best and the worst value of all criterion functions assuming that *i*th function represents a benefit:

$$f_i^* = \max_j f_{ij} \qquad f_i^- = \min_j f_{ij} \tag{6}$$

*Step 2*. Compute the values $S_j$ and $R_j$ ; $j = 1,...,J$ , by the relations

$$S_j = \sum_{i=1}^{n} w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-) \tag{7}$$

$$R_j = \max \left[ w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-) \right] \tag{8}$$

where $w_i$ are the weights of criteria, expressing their relative importance.

*Step 3*. Compute the values, $Q_j$ $j = 1,...,J,$ by the relation

$$Q_j = v(S_j - S^*)/(S^- - S^*) + (1-v)(R_j - R^*)/(R^- - R^*) \tag{9}$$

Where $S^* = \min_j S_j$ ; $S^- = \max_j S_j$ and, $R^* = \min_j R_j$ ; $R^- = \max_j R_j$ .

$v$ is introduced as weight of the strategy of "the majority of criteria" (or "the maximum group utility") and usually v= 0,5.

*Step 4*. Rank the alternatives, sorting by the values $S$ , $R$ and $Q$ , in decreasing order. The results are three ranking lists.

*Step 5*. Propose as a compromise solution, for given criteria weights, the alternative ( $a^{'}$ ), which is the best ranked by the measure $Q$ if the following two conditions are satisfied:

C1. "Acceptable advantage"; $Q(a^{''}) - Q(a^{'}) \geq DQ$, where $a^{''}$ is the alternative with second position in the ranking list by $Q$ ; $DQ = 1/(J-1)$ ; $J$ is the number of alternatives.

C2. "Acceptable stability in decision making": Alternative must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be: "voting by majority rule" ( $v > 0.5$ is needed), or "by consensus" $v \approx 0.5$ , or "with veto" ( $v < 0.5$ ). Here, $v$ is the weight of the decision making strategy "the majority of criteria" (or "the maximum group utility"). If one of the conditions is not satisfied, then the set of compromise solutions is proposed, which consists of:

- Alternatives, $a^{'}$ and $a^{''}$ if only the conditions C2 are not satisfied.
- Alternatives, $a^{'}$ ; $a^{''}$ ; . . . ; $a^{(k)}$ if the conditions C1 are not satisfied,

$a^{(k)}$ is determined by the relation $Q(a^{(k)}) - Q(a^{'}) \approx DQ$ , the positions of these alternatives are "in closeness".

## 4. APPLICATION

The evaluation procedure in this paper consists of three main steps as summarized in three steps;

*Step 1*. Identify the evaluation criteria considered as the most important criteria for the manufacturing industry. Survey questions was prepared associated with these criteria and database were was created.

*Step 2*. Construct the hierarchy of the evaluation criteria and calculate the weights of these criteria using FAHP method.

*Step 3*. Conduct the VIKOR methods to achieve the final ranking results in the machine sub-sector for the 2015 year.

### 4.1. Fuzzy Weights of The Criteria

Considering these steps; technology competency criteria are evaluated by two experts from the Technology Transfer Office and one academic expert from Industrial Engineering Department. In the opinion of three experts, fuzzy weights of dimensions and criteria, BNP value of them and normalized weights of the criteria can be found as shown in Table 1;

**Table 1.** Weights of the Dimensions and Criteria

| Dimensions and Criteria | BNP | Normalized |
|---|---|---|
| **1. Process Management** | 0.046 | *3.42%* |
| *1.1. Cleaner production and productivity applications* | 0.019 | *21.22%* |
| *1.2. Technology management* | 0.028 | *31.34%* |
| *1.3. Quality and assurance systems* | 0.043 | *47.44%* |
| **2. Product competitiveness** | 0.123 | *9.12%* |
| *2.1. Technology working group* | 0.060 | *26.70%* |
| *2.2. Innovative and technological products* | 0.122 | *54.06%* |
| *2.3. E-commerce and marketing activity* | 0.044 | *19.23%* |
| **3. Information and Communication Technologies** | 0.306 | *22.78%* |
| *3.1. Knowledge based systems* | 0.250 | *43.16%* |
| *3.2. Technology utilization* | 0.135 | *23.25%* |
| *3.3. Operations expertise* | 0.052 | *9.06%* |
| *3.4. Technology investments* | 0.142 | *24.53%* |
| **4. Marketing Strategies** | 0.187 | *13.88%* |
| *4.1. Business strategy* | 0.190 | *56.97%* |
| *4.2. Strategic and technological cooperation* | 0.144 | *43.03%* |
| **5. Innovation and Entrepreneurship** | 0.209 | *15.58%* |
| *5.1. Open innovation* | 0.082 | *18.97%* |
| *5.2. New product and service development* | 0.223 | *51.52%* |
| *5.3. Innovative workforce* | 0.060 | *13.73%* |
| *5.4. Social media and communication tools* | 0.068 | *15.78%* |
| **6. Research and Development** | 0.473 | *35.22%* |
| *6.1. Research and development activities* | 0.220 | *23.99%* |
| *6.2. Technological projects* | 0.142 | *15.49%* |
| *6.3. Organizational competencies* | 0.130 | *14.19%* |
| *6.4. Intellectual and industrial property rights* | 0.425 | *46.33%* |

According to evaluations, most important dimension is Research and Development (%35.22). Under this dimension most important three criteria are respectively; Intellectual and Industrial Property Rights (%46.33), Research and Development Activities (%23.99) and Technological Projects (%15.49). Second important dimensions is Information and Communication Technologies-ICT (%22.78). Under this dimension most important three criteria are respectively; Knowledge based systems (%43.16), Technology investments (%24.53) and Technology utilization (%23.25). Third important dimension is Innovation and Entrepreneurship (%15.58). Under this dimension most important three criteria are respectively; New product and service development (%51.52), Open innovation (%18.97) and Social media and communication tools (%15.78).

### 4.2. Ranking the Firms By VIKOR Approach

Weights of the dimensions and the evaluation criteria are calculated by using FAHP method. Consequently, VIKOR methods is conducted to achieve the final ranking results in the machine sub-sector for the 2015 year. Calculation steps of the VIKOR method are applied to firm's data and the alternatives are ranked by sorting S, R and Q values in an increasing order. Finally, the rankings are obtained by the Q distance in the VIKOR method, increasingly in Table 2;

Firm names in the rankings were not disclosed, the names of the manufacturing firms are kept secret because of privacy and confidentiality in the field of research. Given these results in Table 2, the best ranked firm by the Q value for the machine sub-sector of manufacturing is the firm, F340. V is introduced as weight of the strategy of "the majority of criteria" is used as 0.5 (by consensus) in this study. J is the number of alternatives, and $DQ = 1/(30-1) = 0.034$. It can be observed that the ratings of F340 and F85 alternatives are not very close to each other. F340 has an acceptable advantage, in other words;

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$$Q(F85) - Q(F340) \geq DQ \text{ and, } Q(F85) - Q(F340) = 0.083 \geq 0.034$$

F340 is also stable within the decision-making process; in other words it is also the best ranked in $S_j$ and/or $R_j$. First firm, F340 is proposed as a compromise solution because the two conditions (C1 and C2) are satisfied between each other.

Second ranked firm, F85 has an acceptable advantage on the third ranked firm (F118); in other words, $Q(F118) - Q(F85) = 0.105 \geq 0.034$. It can be observed that the ratings of F85 and F118 alternatives are not very close to each other. F85 is also stable within the decision-making process; in other words it is also the ranked same position in $R_j$. Because the two conditions are satisfied together, the alternative F85 is proposed as a compromise solution.

**Table 2.** Results of the VIKOR method for v = 0.5

| Firms | S Distance | R Distance | Q Distance | Ranking |
|---|---|---|---|---|
| F340 | 1.915 | 0.313 | 0.096 | 1 |
| F85 | 1.348 | 0.405 | 0.180 | 2 |
| F118 | 1.669 | 0.432 | 0.285 | 3 |
| F131 | 1.921 | 0.463 | 0.389 | 4 |
| F426 | 2.484 | 0.430 | 0.420 | 5 |
| F428 | 2.496 | 0.430 | 0.422 | 6 |
| F93 | 2.173 | 0.463 | 0.432 | 7 |
| F17 | 2.210 | 0.463 | 0.438 | 8 |
| F46 | 2.247 | 0.463 | 0.444 | 9 |
| F117 | 2.375 | 0.463 | 0.466 | 10 |
| F441 | 2.828 | 0.430 | 0.478 | 11 |
| F221 | 2.560 | 0.463 | 0.497 | 12 |
| F134 | 2.568 | 0.463 | 0.498 | 13 |
| F445 | 3.158 | 0.430 | 0.533 | 14 |
| F277 | 2.866 | 0.474 | 0.570 | 15 |
| F232 | 3.005 | 0.474 | 0.593 | 16 |
| F263 | 2.663 | 0.515 | 0.615 | 17 |
| F111 | 2.070 | 0.570 | 0.622 | 18 |
| F347 | 3.215 | 0.474 | 0.629 | 19 |
| F444 | 3.368 | 0.463 | 0.633 | 20 |
| F139 | 3.449 | 0.463 | 0.647 | 21 |
| F446 | 3.492 | 0.463 | 0.654 | 22 |
| F430 | 3.422 | 0.474 | 0.664 | 23 |
| F442 | 3.625 | 0.463 | 0.676 | 24 |
| F237 | 3.523 | 0.474 | 0.681 | 25 |
| F409 | 3.557 | 0.474 | 0.687 | 26 |
| F168 | 3.968 | 0.474 | 0.756 | 27 |
| F281 | 3.983 | 0.474 | 0.758 | 28 |
| F77 | 4.313 | 0.541 | 0.943 | 29 |
| F413 | 3.979 | 0.570 | 0.944 | 30 |

## 5. CONCLUSION

According to the evaluation results, the firm F340, survey no:1064, presents the best performance with the some important features; it is a medium sized firm with 10-49 number of employees and has been working for 11-15 years. The firm allocated 2% of the annual budget to Information and Communication Technologies (ICT). The firm generally cooperates in the production development field with the other private sector firms. Technological innovations and news are followed by the firm and it has ability to create new products and services well. F340 is always engaged in research and development activities with the private sector's firms by the collaborations. Firm has not yet received government funds for the projects, probably due to unawareness about financial possibilities because it is seen from firm's responses that they complains from the cost of financial accession. F340 has important Intellectual and Industrial Property Rights; three utility models that are lack of inventive step, three industrial designs and three trademark registrations for the product.

The approach integrated by FAHP and VIKOR method is proposed for technology competency evaluation of Turkish manufacturing firms take into consideration 2015 year data. FAHP approach is utilized to determine the weights of the criteria and sub-criteria and VIKOR is used to rank the firm based on the technology evaluation model.

To the best of our knowledge, it is one of the top studies on the technology competency evaluation area for the SMEs. Multi-criteria decision making methods can be used as comparatively to rank the firms from different sub-sectors as various metal, electrical and electronics, automotive, textile, paper, food, plastic product, construction and furniture. However, for limitation of paper space, we omitted overall and local fuzzy weights of dimensions, criteria and other sub sector's results obtained by the VIKOR method. Also various different kinds of MCDM approaches as ELECTRE, PROMETHEE, TOPSIS and DEMATEL under fuzzy environment can be used regarding performance evaluation which can consider other sectors.

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**REFERENCES / KAYNAKLAR**

[1] Istanbul Chamber of Industry. Management Approach for the SMEs, Istanbul Chamber of Industry Committee of Quality and Technology, Issue: 2007-06, ISBN: 975-512-870-0, Improved third edition, İstanbul, 2007.

[2] Istanbul Chamber of Industry. Product Development of the SMEs, Istanbul Chamber of Industry Committee of Quality and Technology, Issue: 2007-08, ISBN: 975-512-866-2, Improved third edition, İstanbul, 2007.

[3] Tosun, S., Önüt, S., "A Supplier Selection Model For Project Portfolios", *Sigma: Journal of Engineering & Natural Sciences*, 32(3), 2014.

[4] Ayanda, A.M., Laraba, A.S., "Small and Medium Scale Enterprises as a Survival Strategy for Employment Generation in Nigeria", *Journal of Sustainable Development*, 4(1):200-206, 2011.

[5] Hsieh, T. Y., Lu, S. T., Tzeng, G. H., "Fuzzy MCDM approach for planning and design tenders selection in public office buildings", *International journal of project management*, 22(7), 573-584, 2004.

[6] Yang, T., Chen, M., Hung, C., "Multiple attribute decision-making methods for the dynamic operator allocation problem", *Mathematics and Computers in Simulation*, 73, 285–299, 2007.

[7] Yalcin, N., Bayrakdaroglu, A., Kahraman, C., "Application of fuzzy multi-criteria decision making methods for financial performance evaluation of Turkish manufacturing industries", *Expert System with Application*, 39, 350-364, 2012.

[8] Lee, A.H.I., Chen, W.C., Chang, C.J., "A fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan", *Expert System with Applications*, 34, 96–107, 2008.

[9] Ertugrul, I., Karakasoglu, N., "Performance evaluation of Turkish cement companies with fuzzy analytic hierarchy process and TOPSIS methods", *Expert Systems with Applications*, 36 (1), 702–715, 2009.

[10] Belgin, Ö., "Multi-Objective Simulation Optimization Using Grey-Based Taguchi Method With Fuzzy AHP Weighting", *Sigma: Journal of Engineering & Natural Sciences*, 33(3), 341-350, 2015.

[11] Liao, S. H., "Technology management methodologies and applications: A literature review from 1995 to 2003", *Technovation*, 25(4):381-393, 2005.

[12] Hameed, M.A., Counsell S., Swift S., "A conceptual model for the process of IT innovation adoption in organizations", *Journal of Engineering and Technology Management,* 29(3):358-390, 2012.

[13] Ashrafi, R., Murtaza, M., "Use and Impact of ICT on SMEs in Oman", *The Electronic Journal of Information Systems Evaluation,* 11(3):125-138, 2008.

[14] Kalkan, A., Erdil, O., Çetinkaya, Ö., "The relationships between firm size, prospector strategy, architecture of information technology and firm performance", *Procedia-Social and Behavioral Sciences*, 24:854-869, 2011.

[15] Oliveira, M. G., Rozenfeld, H., Phaal, R., Probert, D., "Decision making at the front end of innovation: the hidden influence of knowledge and decision criteria", *R&D Management,* 45(2), 161-180, 2015.

[16] Cetindamar, D., Phaal, R., Probert, D., "Understanding technology management as a dynamic capability: A framework for technology management activities", *Technovation*, 29(4), 237-246, 2009.

[17] Pretorius, L., Benade, S.J., "A systems dynamics approach to competing technologies: Exploring uncertainty of interaction and market parameters", *South African Journal of Industrial Engineering*, 22(2):27-39, 2011.

[18] Buckley, J.J., "Fuzzy hierarchical analysis," *Fuzzy Sets and Systems*, 17(1), 233–47, 1985.

[19] Demirel, T., Demirel, N.C., Kahraman, C., "Fuzzy Analytic Hierarchy Process and its Application", *Fuzzy Multi-Criteria Decision Making: Springer Optimization and Its Applications*, 16, 53-83, 2008.

[20] Gumus, A. T., Yayla, A. Y., Çelik, E., Yildiz, A., "A Combined Fuzzy-AHP and Fuzzy-GRA Methodology for Hydrogen Energy Storage Method Selection in Turkey", *Energies*, 6(6), 3017-3032, 2013.

[21] Yu, P.L., "A class of solutions for group decision problems", *Management Science*, 19 (8), 936–946, 1973.

[22] Zeleny, M., Multiple criteria decision making, McGraw-Hill, New York, 1982.