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A Hybrid MCDM Approach Based on Fuzzy ANP and Fuzzy TOPSIS for Technology Selection

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Abstract. In order to compete in the global environment, a manufacturing company has to keep developing new technologies. Selection of a right technology is a critical stage in a successful technology transfer process. However, technology selection is a complex multi-dimensional problem including both qualitative and quantitative factors, such as human resources, operational and financial dimensions, which may be in conflict and may also be uncertain. In addition, interdependent relationships exist among various dimensions as well as criteria of technology selection. The identified problems could be solved by combining multiple criteria decision making (MCDM) methods of different nature and fuzzy set theory. The objective of the current paper is to develop a complex approach to evaluate technologies and to rank their appropriateness for a company. A hybrid model is proposed, based on Fuzzy Analytic Network Process (FANP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS). A real-life case study is presented to validate the proposed model.

Key words: Multiple Criteria Decision Making (MCDM); Fuzzy Analytic Network Process (FANP); Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS); technology selection; Advanced Manufacturing Technology (AMT).

1. Introduction

New or advanced manufacturing technology (AMT) provides both tangible and intangible benefit for companies. It is an important factor in allowing surviving in competitive environment. New innovative products can be presented or performance of existing products can be improved by introducing new technologies (Säfsten *et al.*, 2014). However, AMTs are different and do not provide the same benefits. As Anand and Kodali (2009) mentioned, in most of the industries, managers tend to adopt a new technology because of the

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benefits reported by other companies across the world or because of their customers have demanded it. It is believed that only few managers could make a decision of implementing such advanced technologies in their organizations, based on their own assessment. It is a crucial question, because selection of inappropriate technology could have destructive outcome both strategically and financially (Farooq and O'Brien, 2015). Accordingly, the aim of the presented study is to propose a complex model for evaluating the appropriateness of technologies for a company and to demonstrate the validity and the applicability of the approach in a real-life case study.

Various techniques have been applied for justification of investment in a new technology in literature. Small (2006) identified that the published literature on AMT investment appraisal techniques can be grouped into three categories: the economic approach (appraisal through the use of standard financial mechanisms); the strategic approach (analysis of such issues as business objectives and competitive advantages of a company, also technical importance of investment); and the analytic approach (utilizing such techniques as value, portfolio and risk analysis). The approaches include traditional investment performance measurement criteria such as net present value (NPV), internal rate of return (IRR), payback period (PB), also attempts to incorporate intangible and qualitative factors are observed (Ordoobadi, 2012).

Indeed, for the purpose of considering and selecting new technologies in real-life cases, both quantitative and qualitative factors should be involved in the evaluation. Accordingly, manufacturing technology selection can be considered as a multiple criteria decision making (MCDM) problem in uncertain environment. The first attempts of using some type of MCDM methods for a problem under consideration appeared. Subramanian and Ramanathan (2012) summarized applications of Analytical Hierarchy Process (AHP) in operations management, including applications for evaluating technology investments, starting from the last decade. In the latter decade Shyjith *et al.* (2008) used combination of AHP and TOPSIS to select an optimum maintenance strategy for a textile industry. Considering the uncertainty of the problem, fuzzy AHP was used for evaluating information technology projects by Thomaidis *et al.* (2006). Fu *et al.* (2006) applied FAHP to prioritize factors affecting the adoption of electronic marketplaces. Anand and Kodali (2008) used the PROMETHEE method, also an Analytical Network Process (ANP) for selection of lean manufacturing systems (Anand and Kodali, 2009). Ordoobadi (2012) also suggested an ANP model to solve the advanced technology selection problem. Tavana *et al.* (2013) presented a hybrid fuzzy group decision support framework for a specific complex task, i.e. prioritizing advanced technology at NASA. Stanujkic *et al.* (2014) used MOORA method for grinding circuit selection, while Liu *et al.* (2014) used 2-tuple linguistic MULTIMOORA method for healthcare waste treatment technology evaluation and selection. A multiple criteria group decision making models under fuzzy environment were presented by Yazdani-Chamzini (2014) for handling equipment selection and by Chuu (2014) for the best radio frequency identification technology selection to enhance supply chain competitiveness. Recent concepts in the development of advanced technologies are based on automation and information sciences (Skibniewski and Zavadskas, 2013). Several decision models have applied different MCDM methods for evaluating new technologies (Zavadskas *et al.*, 2013; Kildiene *et al.*, 2014).

To be succeeded in the field of technology selection, combination of scientific methodology and personal experience of the field is the vital point. Complex multidimensional nature of the problem can be handled by applying multiple criteria decision making (MCDM) methods. The interdependent relationships of factors can be taken into account by Analytic Network Process (ANP) (Saaty, 1996). To rank alternatives and to select the best solution, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981) can be used, based on the idea of selecting the ideal technology assuring the success of a company. In order to encounter the uncertainty among factors of technology selection, crisp MCDM methods are combined with fuzzy sets theory (Zadeh, 1965).

Quite a lot of works on fuzzy ANP and fuzzy TOPSIS approaches can be observed in a literature, but there are a few researches that combine these methods together. There is a lack of models ready for real-life applications for advanced manufacturing technology selection. Accordingly, the current paper proposes hybrid approach that is able to deal with the interdependencies of factors in an uncertain environment and to select the best alternative that is the closest to the possible ideal one.

The paper is organized as follows. The literature review on a topic is presented firstly. Then, a proposed approach for AMT evaluation is described. Finally, a case study of the application of the proposed model is presented in the last section.

2. Literature Review on AMT: Concept, Benefits and Criteria of Selection

The object of the research is defined according to Walters *et al.* (2006): advanced manufacturing technology is "a group of integrated hardware-based and software-based technologies, which if properly implemented, monitored and evaluated, lead to improving the efficiency and effectiveness of the firm in manufacturing a product or providing a service".

AMT includes: Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computerized Numeric Control (CNC) machines, Manufacturing (or enterprise) Resource Planning (MRP or ERP), Flexible Manufacturing Systems (FMS), Computerized Maintenance Management System (CMMS), Computer-Integrated Manufacturing (CIM) systems, Optimized Production Technology (OPT), Just-In-Time (JIT), industrial robots, and automation.

Improving organization operation by AMT adoption has become an extremely important issue in recent years. The advantages of a company arising from application of a proper advanced manufacturing technology include both tangible profit and intangible benefits. Tangible profit can be measured by inventory savings, reduced unit costs and improved return on equity. Increased companies flexibility and fast response to changes in a market, improving product quality and enhancing competitive advantages can be called as intangible benefits (Small, 2006). Burcher and Lee (2000) indicate that companies invest in AMT to get financial, i.e. tangible benefits, also to enhance intangible advantages –

company image and competitiveness. Strategic and managerial benefits are also emphasized by Roh *et al.* (2014). As a result, selection of a right technology is very essential for a company.

To assess AMT proposals carefully, evaluation of both qualitative and quantitative factors is necessary. There are several studies for justification of investment in an advanced technology in the literature. Justification methods for technologies are summarized by Raafat (2002). Tonge *et al.* (2000) justified investment to information systems at fast growing medium-sized enterprises. The required factors for evaluating information systems were indicated as financial threshold, competitive advantage, internal efficiency, productivity, and delivery improvement. The criteria of Kocaglu *et al.* (2001) for technology selection were effectiveness, practicality, implementation time, cost, and risk. Bernoider and Koch (2001) developed a selection model of enterprise resource planning variants in large and middle size companies. Criteria for justification of technologies included adaptability, flexibility, process improvement, customer satisfaction, and implementation time. Yurdakul (2002) measured manufacturing system performance using dependability, flexibility, time, quality, and cost as evaluation criteria. Wu *et al.* (2014) applied the following attributes for evaluation of strategies: resources and capabilities, social responsibility, stakeholder management, also demand and supply uncertainty.

Bayazit (2005) applied AHP for evaluating flexible manufacturing systems. The study used nine criteria for decision making, i.e. usual criteria as cost and quality, also productivity and customer satisfaction as well as competitive power, dependability, compatibility, commitment, and top management. Braglia *et al.* (2006) adopted AHP method for evaluating Computerized Maintenance Management System (CMMS) software. The evaluation criteria of their study were cost, also performance, system's implementation, its reliability, efficiency, and maintainability. In technology selection framework of Shehabuddeen *et al.* (2006) reliability, quality, cost of capital, and cost of operation, compatibility, usability, and strategy alignment were mentioned as critical factors. Anand and Kodali (2008) used the PROMETHEE method for selection of lean manufacturing systems. The required factors for evaluating the systems were indicated as financial factors, organizational factors, top management role, impact on employees, suppliers, customers and shareholder, also perceived benefits. Tan *et al.* (2011) applied flexibility, compatibility, cost, vendor, and strategic fit as criteria of technology evaluation and selection. Percin (2008) adopted the ANP method for comparative analysis and selecting ERP systems. The critical factors of system selection were oriented to strategic relevance, also suitability for use, measured by user friendliness, functionality and flexibility. It is also proposed necessarily to evaluate total costs, systems' implementation time, and system's reliability. The determined criteria of Kodali *et al.* (2009) for justification of maintenance systems included commonly applied criteria as cost, quality and productivity, systems reliability, also, some criteria covering a wider approach to environment, morale, and safety. Anand and Kodali (2009) developed an ANP model for selecting lean manufacturing systems. The determined criteria were productivity, quality, cost, delivery, flexibility, innovation, and morale. The study of Ordoobadi (2012) applied usual measurements of cost, quality, productivity etc. that were used as evaluation criteria in the suggested an ANP model to solve the advanced

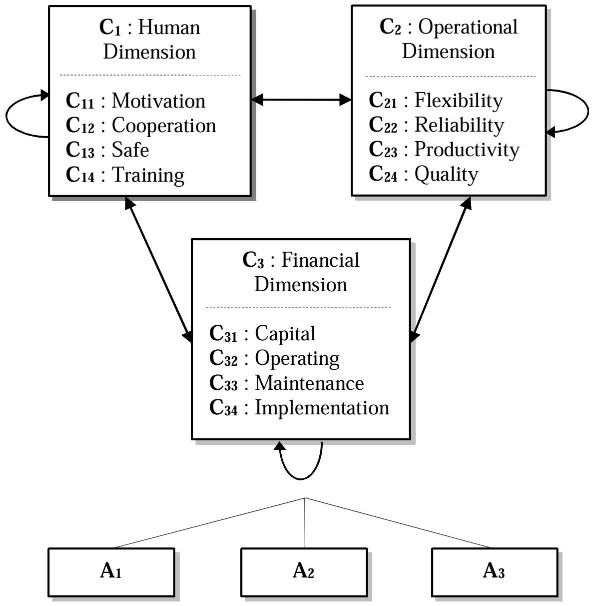

Fig. 1. The ANP – TOPSIS model for technology selection.

technology selection problem. Hashemkhani Zolfani and Bahrami (2014) combined two methods for ranking investment in high technologies industries, i.e. SWARA for criteria weights and COPRAS for ranking of alternatives. SWARA and COPRAS with grey numbers were applied for machine tool selection by Aghdaie *et al.* (2013). In order to enhance an accuracy of evaluation, Chakraborty and Zavadskas (2014) applied WASPAS method in several manufacturing decision making problems. Dejus and Antucheviciene (2013) applied WASPAS for multiple criteria assessment of safety technologies at a construction site. Cheng (2013) made a comparison of technologies for the new materials development by applying fuzzy AHP.

3. Proposed Approach for Technology Evaluation

The structure of the proposed AMT evaluation task is presented in Fig. 1. It is proposed to evaluate alternative technologies considering human, operational and financial dimensions and applying MCDM methodology under fuzzy environment for selecting the most suitable solution for a company. Accordingly, the next sections shortly present the main components of the proposed approach, including identification of appropriate criteria for technology selection and multiple criteria methodology for ranking of technologies.

3.1. *Fuzzy ANP*

ANP was developed by Saaty (1996) as a tool for multiple criteria decision making. ANP is selected for the proposed approach due to its advantages comparing with initial method of Saaty (1980) for analytical multiple criteria tasks (AHP). AHP analyzes hierarchical relations among different decision levels without considering interrelations among criteria or alternatives, while the ANP evaluates interrelationships among the criteria and the decision levels by the means of network relations. As in mostly real-world cases of AMT evaluation and selection interdependences are inevitable, ANP is considered to be the most suitable tool when modeling the analyzed problem.

Moreover, ATM provides both tangible and intangible benefit, also human dimensions are involved and evaluation of their preferences is subjective and hard to estimate by exact numerical values. In that case an extension of crisp analytic instrument by fuzzy sets theory is proposed for handling problems under uncertainty.

Recently, researchers applied FANP in many research areas, such as R&D project selection (Mohanty *et al.*, 2005), transportation-mode selection (Tuzkaya and Onut, 2008), environmental impact assessment (Liu and Lai, 2009), evaluating technology transfer of new equipment (Lee *et al.*, 2010), measurement of the sectorial competition level (Dağdeviren and Yuksel, 2010), performance evaluation of virtual research center (Luo *et al.*, 2010), supplier selection (Vinodh *et al.*, 2011), competitive-strategy evaluation (Lee, 2013), location selection (Tolga *et al.*, 2013), inventory classification (Kiris, 2013), new product development (Chyu and Fang, 2014; Parameshwaran *et al.*, 2015), also development of product with emphasis on green and low-carbon products (Lin *et al.*, 2015), other production planning and production control activities of manufacturing company (Rafiei and Rabbani, 2014), evaluating visibility (Banerjee, 2014) or financial performance (Khalili Esbouei *et al.*, 2014) of companies, and etc.

3.2. *Fuzzy TOPSIS*

The main idea of the TOPSIS method (Hwang and Yoon, 1981) is that the best alternative should be not only the closest to the ideal solution, but also the farthest from the negative solution. Ideal solution can be reached by maximizing the benefit criteria and minimizing the cost criteria, whereas the cost criteria are maximized and the benefit criteria are minimized in the negative solution.

As mentioned before, crisp and quantitative data is often unsuitable to model real-life cases of AMT selection. Therefore, the fuzzy TOPSIS method is proposed to be applied in a hybrid approach. There the ratings of alternatives respect to criteria are evaluated by linguistic variables. Next, the linguistic variables are represented by fuzzy numbers that are subject to further calculations.

There are a number of recent crisp and fuzzy TOPSIS applications in different areas, including selection information and communication technology projects (Samadi *et al.*, 2014; Li and Chou, 2014), companies' competence or financial performances evaluation (Amiri *et al.*, 2009; Çelen, 2014), analyzing investment projects, business competition and other strategic decisions (Torlak *et al.*, 2010; Antucheviciene *et al.*, 2011; Kahraman *et al.*, 2013; Onar *et al.*, 2014; Yazdani-Chamzini *et al.*, 2014; Kilic and Kaya, 2015; Akhavan *et al.*, 2015), project's risk evaluation (Tamosaitiene *et al.*, 2013), supplier selection (Roghanian *et al.*, 2010; Lee *et al.*, 2015), assessment of intelligent building (Kaya and Kahraman, 2014), location selection (Chung and Kim, 2014; Cebi and Otay, 2015), and etc.

The relative importance of each fuzzified criterion is determined by fuzzy ANP and is involved in selection of the most effective technology by applying the fuzzy TOPSIS approach. However, very few of the models in the literature combine ANP and TOPSIS in fuzzy environment. One of these few models is the approach proposed by Buyukozkan and Cifci (2012) for evaluating green suppliers.

The purpose of the current research is to develop an integrated approach ready for real-life applications for advanced manufacturing technology selection considering the interdependencies among criteria in uncertain environment.

3.3. *Identification of Technology Selection Criteria*

A lot of important factors that can be used by experts to evaluate new technologies are mentioned in the literature. However, there is a need for general criteria system, to be more flexible and applicable to various organizations (Ordoobadi, 2012).

The suggested critical factors for measuring new technology can be grouped into three dimensions: financial dimension, operational dimension, and human dimension. The major criteria of financial dimension include: cost of capital, cost of implementation, cost of operating, and cost of maintenance. The criteria of operational dimension include: flexibility, quality, reliability, and productivity. The criteria of human dimension are motivation, cooperation, safe working practices, and training requirements.

Figure 1 presents the network structure of this evaluation framework, involving interrelated criteria as well as considered technology alternatives.

4. Case Study

The computation of the proposed integrated framework can be pursued using the following steps:

Step 1: *Determination of the evaluation model.*

A medium sized manufacturing company in Iran has been chosen as an example to illustrate the application of the proposed model.

The list of critical criteria adopted from literature is modified by experts. Experts express their attitude to the problem by choosing criteria from the list they think are important to the problem. Also they have a possibility to add the criteria that they consider to be also important but missing in the initial list. The decision committee includes six operations managers. The confirmed factors for measuring new technology are: cost of capital, cost of implementation, cost of operating, and cost of maintenance, flexibility, quality, reliability, productivity, motivation, cooperation, safe working practices, and training requirements. The evaluation model is shown in Fig. 1.

Some possible technology alternatives are identified for achieving the goals of the company. To improve product reliability, this company wants to adopt a new advanced technology. The firm is faced with three alternatives: Materials Requirement Planning

Table 1
Fuzzy linguistic scale for relative importance of criteria.

Linguistic terms	Equal	Equally important	Weakly important	Strongly more important	Very strongly more important	Absolutely more important
Triangular fuzzy numbers	(1, 1, 1)	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)

(MRP), Computer Aided Design (CAD), and Automated Storage and Retrieval Systems (ASRS).

Step 2: *Selecting fuzzy linguistic scale*.

The scale was selected as presented by Parsaei *et al.* (2012). The linguistic variables for evaluation of relative importance of criteria are shown in Table 1.

Step 3: *Determine the dimensions and criteria weights using the fuzzy ANP*.

Step 3.1: *Pairwise comparison*.

The dimensions and the criteria in each level are subject to pair wise comparisons. Comparisons are performed considering their relative importance to the control criterion of the dimension. The fuzzy pairwise comparison matrix $\tilde{A}$ is constructed by using triangular fuzzy numbers (see Table 1) to indicate the relative preferences of dimensions and criteria:

$$\tilde{A} = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & \tilde{a}_{nn} \end{bmatrix}, \tag{1}$$

where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ shows the relative importance of criteria compared in pairs, i.e. importance of i item over the j item, where $i, j = 1, 2, \dots, n$.

If there are k experts, by employing geometric average approach, the aggregate fuzzy judgment matrix $\tilde{A}^*$ is:

$$\tilde{A}^* = [\tilde{a}^*_{ij}], \tag{2}$$

where $\tilde{a}^*_{ij} = (\tilde{a}^1_{ij} \otimes \tilde{a}^2_{ij} \otimes \dots \otimes \tilde{a}^k_{ij})^{1/k}$. $\tilde{a}^k_{ij}$ is the pairwise comparison between two criteria evaluated by kth expert, and $\tilde{a}^k_{ij} = (l^k_{ij}, m^k_{ij}, u^k_{ij})$. The fuzzy arithmetic operations of triangular fuzzy numbers are defined following Wang *et al.* (2009) with reference to Dubois and Prade (1980), also Chutia *et al.* (2011) and provided in Appendix A.

Consistency of the pairwise comparisons should be checked before applying them to further calculations. In order to check the consistency of the matrix, the Consistency Ratio (CR) is used. For calculating CR, the Random Indices (R^m and R^g) are presented by Gogus and Boucher (1998). If both CR^m and CR^g of a given pairwise comparisons matrix are less than 0.10, then pairwise comparisons are sufficiently consistent and can be applied for further steps of the problem.

Step 3.2: *Calculate the relative importance.*

To compose the supermatrix at first we need to calculate the priority vectors for each pairwise comparison matrix. To estimate triangular fuzzy priorities $\tilde{w}_k$, $k = 1, 2, \ldots, n$, the logarithmic least-squares method is used following Buyukozkan and Cifci (2012) and Sevkli *et al.* (2012) with reference to Önüt *et al.* (2009):

$$\tilde{w}_k = \left(w_k^l, w_k^m, w_k^u\right), \quad k = 1, 2, \ldots, n, \tag{3}$$

where

$$w_k^s = \frac{(\prod_{j=1}^n a_{kj}^s)^{1/n}}{\sum_{i=1}^n (\prod_{j=1}^n a_{ij}^m)^{1/n}}, \quad s \in \{l, m, u\},$$

for all i, j, where $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, n$.

Step 3.3: Defuzzify the weights.

Defuzzification of the weights obtained from fuzzy matrices is made as follows Buyukozkan and Cifci (2012):

$$F(\tilde{a}_{ij}) = 1/2 \int_0^1 \left(\inf_{x \in \Re} \tilde{a}_{ij}^x + \sup_{x \in \Re} \tilde{a}_{ij}^x \right) dx. \tag{4}$$

Next, an example of priority assessment of the dimensions with respect to Operational dimension is presented. Using data of pairwise comparisons of dimensions (as presented in three columns of Table 2) and applying Eq. (3), the fuzzy weight of human dimension with respect to operational dimension is calculated as follows:

$$w^l = \frac{(1 \times 0.51 \times 0.47)^{1/3}}{(1 \times 0.64 \times 0.58)^{1/3} + (1.55 \times 1 \times 0.86)^{1/3} + (1.73 \times 1.16 \times 1)^{1/3}} = 0.202;$$

$$w^m = \frac{(1 \times 0.64 \times 0.58)^{1/3}}{(1 \times 0.64 \times 0.58)^{1/3} + (1.55 \times 1 \times 0.86)^{1/3} + (1.73 \times 1.16 \times 1)^{1/3}} = 0.233;$$

$$w^u = \frac{(1 \times 0.89 \times 0.74)^{1/3}}{(1 \times 0.64 \times 0.58)^{1/3} + (1.55 \times 1 \times 0.86)^{1/3} + (1.73 \times 1.16 \times 1)^{1/3}} = 0.282.$$

Then, the defuzzified weight is obtained by using Eq. (4) and also presented in Table 2.

Table 2
The pairwise comparison of dimensions with respect to operational dimension.

	Human	Financial	Operational	Fuzzy weight	Defuzzified weight	Normalized weight
Human	(1 1 1)	(0.5 0.6 0.89)	(0.47 0.58 0.74)	(0.202 0.233 0.282)	0.242	0.239
Financial	(1.12 1.55 1.94)	(1 1 1)	(0.68 0.86 1.26)	(0.296 0.357 0.437)	0.367	0.363
Operational	(1.36 1.73 2.12)	(0.79 1.16 1.47)	(1 1 1)	(0.332 0.410 0.474)	0.403	0.398
$CR^m = 0.0001$	$CR^g = 0.0008$					

Table 3
The priority weights of dimensions.

	Human	Financial	Operational
Human	0.235	0.218	0.239
Financial	0.332	0.372	0.363
Operational	0.433	0.410	0.398

Table 4
The pairwise comparisons of operational dimension with respect to motivation.

	Flexibility	Reliability	Productivity	Quality	Normalized weight
Flexibility	(1 11)	(1.10 1.71 2.50)	(1.32 2.24 3.46)	(0.64 0.99 1.66)	0.331
Reliability	(0.40 0.58 0.91)	(1 1 1)	(1 2.72 4.04)	(0.53 1.09 1.71)	0.256
Productivity	(0.29 0.45 0.75)	(0.25 0.37 1)	(1 1 1)	(0.66 1 1.51)	0.170
Quality	(0.60 1.01 1.57)	(0.58 0.92 1.89)	(0.66 1 1.51)	(1 1 1)	0.243
$CR^m = 0.0491$	$CR^g = 0.0891$				

Table 5
The unweighted supermatrix.

	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}
C_{11}	0.247	0.276	0.191	0.236	0.287	0.263	0.256	0.231	0.244	0.256	0.221	0.239
C_{12}	0.298	0.284	0.246	0.283	0.231	0.270	0.251	0.242	0.241	0.255	0.214	0.240
C_{13}	0.139	0.175	0.274	0.251	0.232	0.205	0.247	0.237	0.250	0.243	0.245	0.236
C_{14}	0.316	0.265	0.289	0.230	0.250	0.262	0.246	0.290	0.265	0.246	0.320	0.285
C_{21}	0.331	0.317	0.259	0.244	0.390	0.311	0.322	0.295	0.227	0.263	0.300	0.331
C_{22}	0.256	0.251	0.228	0.229	0.325	0.321	0.325	0.367	0.224	0.252	0.213	0.205
C_{23}	0.170	0.203	0.258	0.258	0.150	0.187	0.199	0.160	0.285	0.241	0.247	0.230
C_{24}	0.243	0.229	0.255	0.269	0.135	0.181	0.154	0.178	0.264	0.244	0.240	0.234
C_{31}	0.244	0.254	0.258	0.250	0.280	0.311	0.279	0.238	0.261	0.252	0.290	0.276
C_{32}	0.249	0.260	0.257	0.234	0.223	0.296	0.256	0.418	0.205	0.254	0.258	0.263
C_{33}	0.254	0.229	0.244	0.255	0.280	0.224	0.256	0.163	0.253	0.243	0.230	0.229
C_{34}	0.253	0.257	0.241	0.261	0.217	0.169	0.209	0.181	0.236	0.251	0.222	0.232

After performing analogous comparisons with respect to every dimension, the priority weights of dimensions are summarized in Table 3.

To compare the criteria significance within each dimension, pairwise comparisons are applied again. The eigenvector of the comparison matrix provides the criteria that will be applied further in the supermatrix. An example of pairwise comparison within the Operational dimension with respect to Motivation is presented in Table 4. Weight of each criterion is obtained in the analogous way. These weights will be used in an unweighted supermatrix (Table 5).

Step 4*: Construct and solve the supermatrix.*

ANP is capable to assume the interdependence between the items within the network by using a supermatrix (Table 5). The results of previous stages are used and a supermatrix is composed when the weights of the criteria are multiplied by the weight of its own dimension.

Table 6
The weighted supermatrix.

	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}
C_{11}	0.058	0.065	0.045	0.056	0.069	0.063	0.061	0.055	0.053	0.056	0.048	0.052
C_{12}	0.070	0.067	0.058	0.067	0.055	0.065	0.060	0.058	0.053	0.056	0.047	0.052
C_{13}	0.033	0.041	0.064	0.059	0.056	0.049	0.059	0.057	0.055	0.053	0.053	0.052
C_{14}	0.074	0.062	0.068	0.054	0.060	0.063	0.059	0.069	0.058	0.054	0.070	0.062
C_{21}	0.143	0.137	0.112	0.106	0.155	0.124	0.128	0.117	0.093	0.108	0.123	0.136
C_{22}	0.111	0.109	0.099	0.099	0.129	0.128	0.129	0.146	0.092	0.103	0.087	0.084
C_{23}	0.074	0.088	0.112	0.112	0.060	0.074	0.079	0.064	0.117	0.099	0.101	0.094
C_{24}	0.105	0.099	0.110	0.117	0.054	0.072	0.061	0.071	0.108	0.100	0.098	0.096
C_{31}	0.081	0.084	0.086	0.083	0.102	0.113	0.101	0.086	0.097	0.094	0.108	0.103
C_{32}	0.083	0.086	0.085	0.078	0.081	0.108	0.093	0.152	0.093	0.095	0.096	0.098
C_{33}	0.084	0.076	0.081	0.085	0.102	0.081	0.093	0.059	0.094	0.090	0.086	0.085
C_{34}	0.084	0.085	0.080	0.087	0.079	0.061	0.076	0.066	0.088	0.093	0.082	0.086

Table 7
The weights of criteria.

Criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}
Weights	0.058	0.058	0.053	0.062	0.124	0.112	0.088	0.087	0.097	0.097	0.086	0.080

Table 8
Linguistic variables for the ratings of alternatives.

Linguistic terms	Very poor	Poor	Medium poor	Medium	Medium good	Good	Very good
Triangular fuzzy numbers	(0, 0, 1)	(0, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 10)	(9, 10, 10)

Table 6 presents the weighted supermatrix of the case study, i.e. unweighted values are multiplied by the corresponding weights. For example, weighted criteria of human dimension with respect to motivation are calculated as $(0.247,\ 0.298,\ 0.139,\ 0.316) \times 0.235 = (0.058,\ 0.070,\ 0.033,\ 0.074)$.

Eventually the system solution is obtained by successively raising the weighted supermatrix by large powers, usually $2k + 1$ (where k is a large arbitrarily number), until the supermatrix converges into a stable supermatrix ($\tilde{W} = \lim_{k\to\infty} W^k$). So, the final solution is obtained by multiplying the weighted supermatrix by itself and it reflects the cumulative interactions of elements (Buyukozkan and Cifci, 2012; Zhou *et al.*, 2013; Bardhan *et al.*, 2011).

The final weights of the criteria of the presented case study are shown in Table 7. They are used in fuzzy TOPSIS steps later.

Step 5*: Rank the alternative technologies applying fuzzy TOPSIS.*

The sub-steps are presented according to Chen (2000).

Step 5.1: *Compose an initial fuzzy decision making matrix for evaluation of analyzed advanced manufacture technologies.*

Linguistic variables for the ratings are presented in Table 8.

Table 9
Normalized fuzzy-decision matrix.

	C_{11}	C_{12}	C_{13}	C_{14}
MRP	(0.80, 0.95, 1)	(0.66, 0.86, 1)	(0.52, 0.76, 1)	(0.06, 0.04, 0.04)
CAD	(0.37, 0.57, 0.77)	(0.34, 0.55, 0.76)	(0.44, 0.68, 0.92)	(0.07, 0.05, 0.04)
ASRS	(0.02, 0.08, 0.23)	(0.02, 0.07, 0.21)	(0.38, 0.60, 0.84)	(1, 0.25, 0.11)
Weights	0.0575	0.0581	0.0529	0.0621
	C_{21}	C_{22}	C_{23}	C_{24}
MRP	(0.40, 0.60, 0.8)	(0.40, 0.60, 0.80)	(0.80, 0.95, 1)	(0.37, 0.58, 0.78)
CAD	(0.12, 0.3, 0.5)	(0.87, 0.98, 1)	(0.18, 0.35, 0.53)	(0.75, 0.92, 1)
ASRS	(0.87, 0.98, 1)	(0.07, 0.23, 0.43)	(0.57, 0.77, 0.92)	(0.07, 0.17, 0.34)
Weights	0.124	0.1115	0.0875	0.0874
	C_{31}	C_{32}	C_{33}	C_{34}
MRP	(0.33, 0.27, 0.25)	(0.35, 0.30, 0.28)	(0.46, 0.40, 0.39)	(0.46, 0.40, 0.38)
CAD	(1, 0.58, 0.39)	(1, 0.61, 0.44)	(1, 0.70, 0.53)	(1, 0.68, 0.51)
ASRS	(0.58, 0.39, 0.31)	(0.57, 0.41, 0.33)	(0.82, 0.59, 0.47)	(0.82, 0.58, 0.45)
Weights	0.0968	0.0967	0.0858	0.0799

The fuzzy decision matrix with m alternatives and n criteria is composed as:

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \end{array}. \tag{5}$$

Step 5.2: *Normalize the initial decision making matrix.*

Normalized fuzzy decision making matrix $\tilde{R}$ is calculated by using a linear normalization method:

$$\tilde{R} = [r_{ij}]_{m\times n}, \quad i = 1, 2, \dots .m, \; j = 1, 2, \dots n,$$

$$r_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right), \quad \text{if } j \in B, \; c_j^+ = \max c_{ij}, \tag{6}$$

$$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \quad \text{if } j \in C, \; a_j^- = \min a_{ij}, \tag{7}$$

where B and C are sets of benefit criteria and cost criteria, respectively.

The normalized fuzzy decision making matrix is shown in Table 9.

Step 5.3: *Calculate the weighted normalized fuzzy decision making matrix.*

The case matrix is calculated applying the Eq. (8) and presented in Table 10:

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes w_j, \tag{8}$$

Table 10
Weighted normalized fuzzy-decision matrix.

	C_{11}	C_{12}	C_{13}	C_{14}
MRP	(0.05, 0.05, 0.06)	(0.04, 0.05, 0.06)	(0.03, 0.04, 0.05)	(0, 0, 0)
CAD	(0.02, 0.03, 0.04)	(0.02, 0.03, 0.04)	(0.02, 0.04, 0.05)	(0, 0, 0)
ASRS	(0, 0, 0.01)	(0, 0, 0.01)	(0.02, 0.03, 0.04)	(0.06, 0.02, 0.01)
	C_{21}	C_{22}	C_{23}	C_{24}
MRP	(0.05, 0.07, 0.01)	(0.04, 0.07, 0.09)	(0.07, 0.08, 0.09)	(0.03, 0.05, 0.07)
CAD	(0.01, 0.04, 0.06)	(0.01, 0.11, 0.11)	(0.02, 0.03, 0.05)	(0.07, 0.08, 0.09)
ASRS	(0.11, 0.12, 0.12)	(0.01, 0.03, 0.05)	(0.05, 0.07, 0.08)	(0.01, 0.01, 0.03)
	C_{31}	C_{32}	C_{33}	C_{34}
MRP	(0.03, 0.03, 0.02)	(0.03, 0.03, 0.03)	(0.04, 0.03, 0.03)	(0.04, 0.03, 0.03)
CAD	(0.01, 0.06, 0.04)	(0.01, 0.06, 0.04)	(0.09, 0.06, 0.05)	(0.08, 0.05, 0.04)
ASRS	(0.06, 0.04, 0.03)	(0.05, 0.04, 0.03)	(0.07, 0.05, 0.04)	(0.07, 0.05, 0.04)

where $\tilde{V} = [\tilde{v}_{ij}]_{m\times n}$, $i = 1, 2, \dots, m$; $j = 1, 2, \dots, n$; w_j is the weight for the criterion j obtained from supermatrix.

Step 5.4: *Calculate the relative distances from ideal and negative ideal alternatives.*

The elements $\tilde{v}_{ij}$ in the weighted normalized fuzzy decision making matrix are normalized positive triangular fuzzy numbers. They range in the interval of [0, 1]. Then, we can define the aspiration levels (fuzzy positive ideal solution, A^+) and the worst levels (fuzzy negative ideal solution, A^-) as follows (Sun, 2010):

$$A^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_n^+), \tag{9}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-), \tag{10}$$

where $\tilde{v}_j^+ = (1, 1, 1) \times w_j = (w_j, w_j, w_j)$ and $\tilde{v}_j^- = (0, 0, 0)$, $j = 1, 2, \dots, n$.

The distance of every alternative from fuzzy positive and negative ideal solutions (d_i^+ and d_i^-, respectively) is calculated as presented in Eqs. (11)–(12) and the defuzzified distance is calculated by Eq. (13):

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+), \quad i = 1, 2, \dots, m;\ j = 1, 2, \dots, n, \tag{11}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1, 2, \dots, m;\ j = 1, 2, \dots, n, \tag{12}$$

$$d(\tilde{A}, \tilde{B}) = \sqrt{\frac{1}{3}\big[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\big]}. \tag{13}$$

Step 5.5: *Rank the alternatives.*

Alternatives can be ranked according to the closeness coefficient (or relative distance), that can be calculated by formula:

$$CC_i^- = \frac{d_i^-}{d_i^- + d_i^+} = 1 - \frac{d_i^+}{d_i^- + d_i^+}. \tag{14}$$

Table 11
Closeness coefficients to aspired level among different AMT.

Alternatives	d_i^+	d_i^-	Satisfaction degree of CC_i^-
MRP	0.691	0.879	0.560
CAD	0.648	0.950	0.594*
ASRS	0.818	0.768	0.484

The ranking results of each AMT of the case study are presented in Table 11. We can conclude, that according to the described hybrid fuzzy multiple criteria methodology, the best AMT is CAD with the biggest degree of satisfaction (i.e. $CC_i^- = 0.594$).

5. Conclusions

A hybrid fuzzy MCDM approach is proposed to evaluate and select advanced manufacturing technologies.

A complex hierarchical evaluation model is suggested, based on technology evaluation dimensions and criteria derived both on the literature analysis and on the survey of experts.

An integrated approach of fuzzy ANP and fuzzy TOPSIS is suggested for ranking of technology alternatives due to their capabilities of handling interrelated and uncertain information.

The proposed model was applied in a medium sized manufacturing company in Iran. The application of robust MCDM methodology ascertained the reliability of evaluation results, on the other hand the case study showed the model to be valuable and easily applicable tool in such situations.

In real-life, especially in discussed problems where strong interactions between criteria observed, always there is a need of techniques that could take into account these aspects. When considering interrelations between criteria using supermatrix method in ANP and fuzzy ANP, the cumulative interactions of elements are reflected, as well as in a novel DANP (DEMATEL based ANP) approach (Hsu *et al.*, 2012) that can be used in further studies too.

Appendix A

Let $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$ be two positive triangular fuzzy numbers. Then basic fuzzy arithmetic operations on these fuzzy numbers are defined as:
Addition: $\tilde{A} + \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$;
Subtraction: $\tilde{A} - \tilde{B} = (a_1 - b_1, a_2 - b_2, a_3 - b_3)$;
Multiplication: $\tilde{A} \times \tilde{B} = (a_1 b_1, a_2 b_2, a_3 b_3)$;
Division:

$$\tilde{A} \div \tilde{B} = \left(\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}\right);$$

Exponentiation:

$$\tilde{A}^k = \left(a_1{}^k, a_2{}^k, a_3{}^k\right);$$

Root:

$$\sqrt[k]{\tilde{A}} = \left(\sqrt[k]{a_1}, \sqrt[k]{a_2}, \sqrt[k]{a_3}\right).$$

The fuzzy weighted geometric mean of n fuzzy numbers can be expressed as:

$$\begin{aligned}\tilde{y}_G &= f_G(\tilde{x}_1, \ldots, \tilde{x}_n; \tilde{w}_1, \ldots, \tilde{w}_n)\\ &= (\tilde{x}_1)^{\frac{\tilde{w}_1}{\tilde{w}_1+\tilde{w}_2+\cdots+\tilde{w}_n}} (\tilde{x}_2)^{\frac{\tilde{w}_2}{\tilde{w}_1+\tilde{w}_2+\cdots+\tilde{w}_n}} \ldots (\tilde{x}_n)^{\frac{\tilde{w}_n}{\tilde{w}_1+\tilde{w}_2+\cdots+\tilde{w}_n}}\\ &= \prod_{i=1}^{n} (\tilde{x}i)^{\frac{\tilde{w}_i}{\sum_{j=1}^{n} \tilde{w}_j}},\end{aligned}$$

where $\tilde{x}_1, \ldots, \tilde{x}_n$ are the n positive fuzzy numbers to be weighted and $\tilde{w}_1, \ldots, \tilde{w}_n$ are their fuzzy weights. Obviously, $\tilde{y}_G$ also is a fuzzy number.

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Mišrus daugiakriteris technologijų atrankos būdas, taikant ANP ir TOPSIS metodus neraiškioje aplinkoje

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Norėdama išlikti konkurencinga globalioje aplinkoje, gamybos įmonė turi diegti naujas technologijas. Tinkamiausių technologijų atranka yra sudėtinga įvairialypė problema, apimanti kiekybinius ir kokybinius veiksnius, tokius kaip žmogiškųjų išteklių, veiklos efektyvumo ir finansiniai aspektai, kurie gali būti prieštaringi bei neretai sudėtingai įvertinami. Be to, tarp technologijų tinkamumą apibūdinančių veiksnių bei kriterijų egzistuoja tarpusavio priklausomybės, į kurias reikia atsižvelgti, renkantis veiklos strategiją. Išvardintas problemas galima išspręsti derinant kelis įvairaus pobūdžio daugiakriterius sprendimų priėmimo (*MCDM*) metodus ir neraiškiųjų aibių (*Fuzzy Set*) teoriją. Pristatomo tyrimo tikslas – parengti kompleksinę technologijų tinkamumo vertinimo ir atrankos metodiką. Siūlomas mišrus modelis, pagrįstas analitinio tinklo proceso ir artumo idealiam taškui metodais neraiškioje aplinkoje (*FANP* ir *FTOPSIS*). Pateiktas pavyzdys, iliustruojantis siūlomo modelio taikymą vidutinio dydžio gamybos įmonėje.