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Analytic network process: An overview of applications

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ABSTRACT

The analytic network process is one of the multi-criteria decision-making methods widely used to solve various issues in the real-world due to the consideration of complex and interrelated relationships between decision elements and the ability to apply quantitative and qualitative attributes simultaneously. The purpose of this paper is to review and categorize ANP studies previously conducted. For this purpose, 456 valid scientific papers are reviewed from 2000 to 2017 (in May 2017). The articles are classified in nine application areas: (1) *health, safety and environmental management*; (2) *hydrology and water management*; (3) *business and financial management;* (4) *human resources management;* (5) *tourism;* (6) *logistics and supply chain management;* (7) *design, engineering and manufacturing systems;* (8) *energy management* and (9) *other topics*. After reviewing the papers in the nine application areas, some suggestions for future research are presented. This article provides useful information on ANP for scholarly researchers.

1. Introduction

Recently, MCDM[1] methods have been widely considered by researchers and scientists. These methods have great application in various fields of science, including management, engineering, science and business, to help decision makers make good choices [1]. Evaluating, selecting, ranking and sorting alternatives are the purposes of using such methods.

Several studies have been carried out on MCDM methods. Vaidya and Kumar [2] reviewed articles published in connection with AHP. Ho [3] conducted a study to examine applied papers in the field of integrated AHP. In this study, papers published in the years 1997–2006 were examined. Emrouznejad et al. [4] analyzed applied descriptions of DEA in 1978 to 2008. Behzadian et al. [1] classified and interpreted articles related to the PROMETHEE technique. Hatami-Marbini et al. [5] analyzed studies published in the fuzzy DEA literature for 20 years. Zavadskas and Turskis [6] examined the most important results and applications of MCDM over the course of 5 years. Behzadian et al. [7] studied other applied articles related to the TOPSIS technique. Yin [8] reviewed papers published between 1996 and 2010 about the theory of gray systems. Baležentis and Baležentis [9] reviewed papers on the multiMOORA method. Yazdani and Graeml [10] reviewed 198 applied studies in the field of VIKOR, which were published in more than 100 scientific journals and conferences. Kahraman et al. [11] classified fuzzy multi criteria decision-making methods into two categories of MADM and MODM methods. They reviewed papers published in the field of engineering, computer science and management for their classification. Mardani et al. [12] examined published papers related to MCDM methods in 150 valid scientific journals for the period 1994–2014 in

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[1] Note: All abbreviations presented in this paper are explained in Table A in the appendix.

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order to review fuzzy multi criteria decision-making methods systematically. Celik et al. [13] reviewed 82 articles on interval type-2 fuzzy sets. Govindan and Jepsen [14] analyzed studies conducted on ELECTERE. Gul et al. [15] examined 343 papers published on the development and application of VIKOR.

The review of the MCDM literature reveals that there has been no extensive study on the application of ANP in different fields so far. ANP is the generalized from of AHP. In addition to the hierarchical structure, the relationship among criteria is also considered in ANP. Indeed, ANP provides a network of relationships among criteria, which leads to more reliable results [16]. Any review articles on ANP can provide researchers a deep insight into different applications of this method. Furthermore, the categories provided in the current review paper can be highly valuable for researchers who aim at conducting a study on a particular topic using ANP. The purpose of the current study is to review studies carried out on the ANP technique. In this regard, 456 papers published from 2000 to 2017 (in May 2017) were reviewed. We particularly target library databases including Elsevier, Springer, Taylor and Francis, Emerald, IOS Press and IEEExplore, covering major journals in operation research and management sciences. The published papers are reviewed based on specific areas of application and also in terms of ANP composition or comparison with other MCDM methods.

The rest of the paper is organized as follows. In Section 2, ANP steps are explained. The paper's methodology is discussed in Section 3. In Section 4, results of the reviewed papers categorized into nine groups are discussed. Some statistic results about the reviewed papers are discussed in Section 5. In Section 6, directions of future research about the ANP are presented in terms of both theory and practice. Finally, some concluding remarks are given in Section 7.

2. The analytic network process

ANP computes complex relationships between decision elements through replacement of a hierarchical structure with a network structure [17]. ANP has all the positive features of AHP, including simplicity, flexibility, simultaneous use of quantitative and qualitative criteria and ability to review consistency in judgments. ANP considers each issue as a network of criteria, sub-criteria and alternatives. All elements in a network can communicate with each other in any way. In other words, in a network, feedback and interconnection are possible between clusters [18]. ANP can be summarized in four steps as follows:

Step 1. Building a model and converting a problem into a topic network structure
A problem must be transformed into a logical system, such as a network, openly. This network structure can be obtained through brainstorming or any other suitable methods, such as the Delphi or nominal group method. At this point, the problem is converted into a network structure, where all elements can communicate with each other.

Step 2. Formulating a pairwise comparison matrix and determining priority vectors
Similar to pairwise comparison performed in AHP, decision elements in each cluster are compared pairwise. Clusters themselves are also compared based on their role and effect on achieving goals as well as interdependencies between criteria of each cluster. The effect of criteria on each other can be provided through the eigenvector. The relative importance of the elements is measured according to the Saaty nine-point scale (where 1 is "equally important" and 9 is "extremely more important"). In this step, the internal importance vector, which represents the relative importance of elements or clusters, is calculated using Eq. (1).

$$Aw = \lambda_{max} w \tag{1}$$

where A is the pairwise comparison matrix of the criteria, w is the eigenvector and λ_{max} is the largest eigenvalue. Geometric mean approximation is usually used to calculate the eigenvector w.

Step 3. Generating a super-matrix and converting it to a weighted super-matrix
To achieve overall priorities in a system with interactions, internal importance internal importance vectors need to enter into specific columns of a matrix called the super-matrix. The super matrix is actually a partition matrix, which shows the relationship between two clusters in a system. A three-level structure of the goal, criteria and alternatives is presented in two forms: a. hierarchy and b. network, as presented in Fig. 1.
The super-matrix of the hierarchy can be represented as follows:

$$W_h = \begin{bmatrix} 0 & 0 & 0 \\ w_{21} & 0 & 0 \\ 0 & w_{32} & I \end{bmatrix} \tag{2}$$

In this super matrix, w_{21} is a vector that shows the effects of the goal on criteria, w_{32} shows the effects of criteria on alternatives and I is the unit matrix. If criteria have interactions, AHP will be converted to ANP. Interactions of criteria are through inserting w_{22} in the super matrix w_h as the w_n matrix.

$$W_n = \begin{bmatrix} 0 & 0 & 0 \\ w_{21} & w_{22} & 0 \\ 0 & w_{32} & I \end{bmatrix} \tag{3}$$

This matrix is called the primary super-matrix. By replacing the vectors of internal priorities, elements and matrices in the primary super-matrix, an un-weighted super-matrix is obtained. The weighted super-matrix is computed by multiplication of the un-weighted super-matrix values in the cluster matrix. In the final stage using

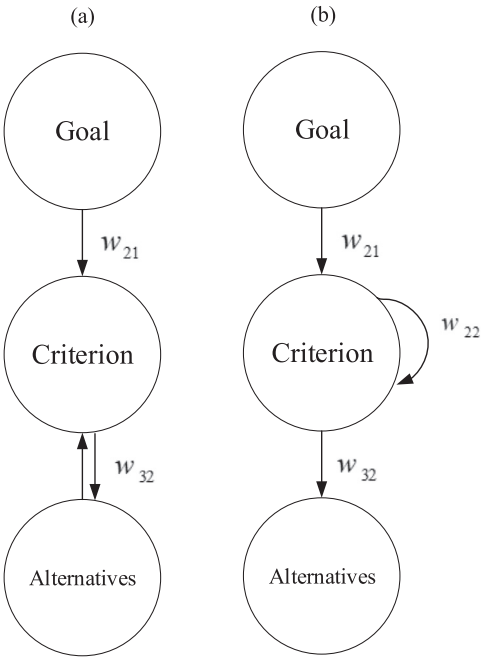

Fig. 1. The three-level structure of the goals, criteria and alternatives.

Eq. (4), a limited super-matrix is calculated to bring all the weighted super-matrix elements. As long as all the super-matrix elements are identical, operations continue to work.

$$\lim_{k\to\infty} W^k \tag{4}$$

Step 4. Selecting the best option
The final weight of alternatives under consideration is accessible from the alternatives' column in the limited super-matrix. An alternative with the highest weight in this matrix is considered as the top choice.

3. Methodology

As presented in Fig. 2, the process of this literature review is summarized in six steps. The first step is to identify ANP articles. To do this, an extensive search was carried out in the title, abstract and keywords of various articles. Since this review of literature considered high-ranking articles which provided the most valuable information to researchers, conference papers, master's theses, doctoral dissertations, textbooks and unpublished articles were excluded from the review phase. It should be noted that, since most studies on the use of ANP have been conducted since 2000, this year was chosen as the source year for the search for articles. According to the searches, out of the six library databases, 509 articles were identified, of which 53 were deleted in the second step because they did not use ANP as an applied method. In the third step, the 456 papers are coded based on paper name, authors' nationality, publication year, journal title, version of fuzzy sets, and other methods used for completing the article or comparing the results on an Excel sheet. The fourth step is about categorizing the articles in terms of application areas and identifying gaps of each category. In this regard, the categorizing methods presented by Behzadian et al. [7] and Gul et al. [15] were followed. Application areas identified in this article are: (1) health, safety and environmental management; (2) hydrology and water management; (3) business and financial management; (4) human resources management; (5) tourism; (6) logistics and supply chain management; (7) design, engineering and manufacturing systems; (8) energy management and (9) other topics. The last category covered articles published in several different fields, which included medicine, agriculture, education, government and sports. Based on the topic, each article is classified in one of the nine categories. Having categorized the articles, we identified practical issues according to each category, which were not reviewed, and introduced them to be investigated using ANP in future research. In analyzing each category, methods, which are good complement to ANP but have not been used until then, are also introduced. In the fifth step, based on the information presented in the second step, the papers are analyzed from statistical point of view. Finally, in the last step, some future directions are presented, covering both theoretical and applied dimensions.

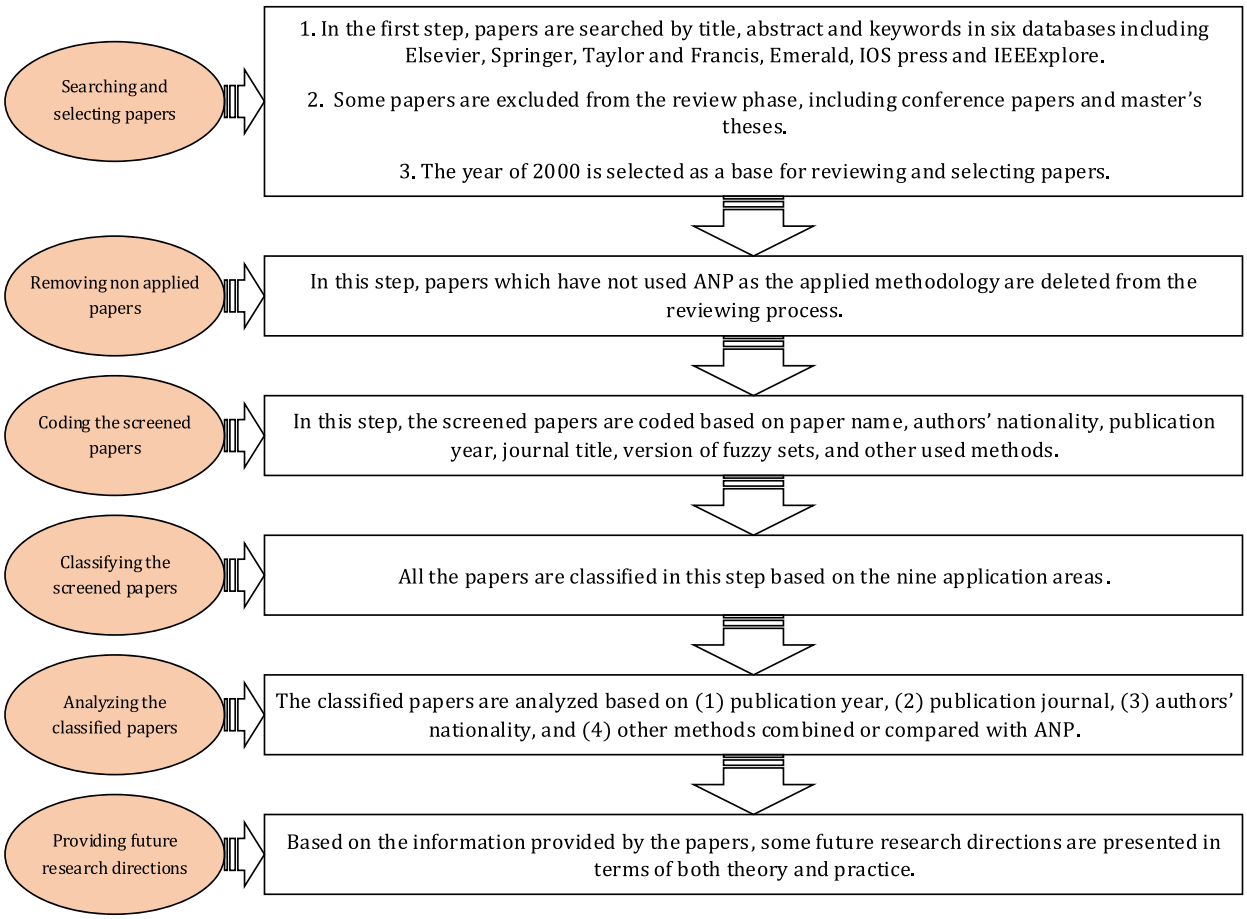

Fig. 2. The research methodology flow of the literature review.

4. Analysis of the application areas of the analytic network process method

The papers reviewed in this study are classified into nine different categories based on the appropriate fields. It was extremely difficult to determine the correct category for each article in a fraction of the time. Sometimes, the articles showed potential to fall into several categories. Nevertheless, in this study, we attempted to select the best category according to the main issue raised in the text of each article. Due to the large number of the articles, all the papers identified in each category is presented in separate tables in alphabetical order.

4.1. Health, safety and environmental management

This category covered articles presented in the field of waste management LCA, EIA and land-use planning. For better analysis, articles in this category are divided into four sub-categories including (1) *safety and risk*, (2) *waste management*, (3) *clean air* and (4) *other applications in this area*. Tables 1–3 summarize the research in this category.

Thirty-four percent of studies in the *health, safety and environmental management* category are categorized into the *safety and risk* subcategory (see Table 1). Preventing air, sea, rail and factory events is the most frequent topic in this subcategory. Ranking causes of road and job accidents due to their irreparable consequences and determining the importance of criteria affecting the occurrence of earthquakes, floods and volcanoes are among issues for future studies using ANP. Furthermore, applying the combination of HRA methods such as CREAM and ATHEANA with ANP in order to enhance the accuracy of manpower reliability calculations is a hybrid methodology suggested for future research.

In the *waste management* subcategory, most of the research carried out is related to waste disposal location selection problems (see Table 2). Although there are many criteria which have effect on the location selection problem of waste disposal centers from economic, social and environmental aspects, there is no comprehensive sustainable framework that covers all of them. By reviewing papers in this subcategory, it is revealed that the combination of ANP with a ranking method (e.g., VIKOR) could improve the flexibility and accuracy of location selection problems. Therefore, creating a

Table 1
The papers in the *safety and risk* subcategory.

Author(s)	Specific area	Other techniques combined or compared
Akyuz [19]	Investigating human factors causing accidents in the maritime transportation industry	AcciMapp
Akyuz [20]	Investigating factors affecting incidents in the marine industry	HFACS
Bahurmoz [21]	Selecting the best strategy for the safety of pilgrims	BOCR
Chang et al. [22]	Examining certificates of occupational safety	FANP, VIKOR
Chang et al. [23]	Assessing and examining the performance of the safety management system in the air industry	FTOPSIS
Chen et al. [24]	Identifying important indices in the design and production of clothing to meet needs of users' health and safety	Compared by AHP
Dağdeviren [25]	Investigating work system safety and evaluating faulty behavior risk in facility production	FANP
Hsu et al. [26]	Assessing the safety management system in airlines	GRA, DEMATEL
Huang et al. [27]	Providing an assessment model for equipment risk management in the petrochemical industry	–
Ilangkumaran et al. [28]	Assessing the safety of the working environment in the casting industry	FST
Lam and Lai [29]	Assessing safety indices in airlines	QFD
Liou et al. [30]	Assessing safety indices in airlines	DEMATEL
Liu and Tsai [31]	Risk assessment to reduce or prevent occupational accidents in the construction industry	FANP, QFD, FMEA
Peng et al. [32]	Weighting factors affecting fire	ANP, FST
Wu et al. [33]	Determining the weight of disaster factors and providing a model for the hillslope prediction	*K*-means, WSN
Wang et al. [34]	Assessing risk factors and failure modes in hospital services	FMEA, COPRAS
Yucel et al. [35]	Providing a model for assessing the risk of implementing information systems in hospitals	FIS
Zhan et al. [36]	Analyzing human and organizational factors affecting the occurrence of accidents in the railway industry	FDEMATEL, HFACS-RAs
Zhou et al. [37]	Assessing the safety management of hydropower construction projects	HFACS, DEMATEL

Table 2
The applied papers on *waste management* and *clean air* subcategories.

Subcategories	Author(s)	Specific area	Other techniques combined or compared
Waste management	Afzali et al. [38]	Selecting the most suitable place for waste disposal	BL, FL
	Aragonés-Beltrán et al. [39]	Determining a suitable location for the solid waste disposal of the city	Compared by AHP
	Bottero et al. [40]	Prioritizing various wastewater treatment technologies	AHP
	Hsu et al. [41]	Selecting the best seller of recycled materials	DEMATEL, VIKOR
	Khadivi and Ghomi [42]	Selecting a proper place for waste disposal	DEA
	Khan and faisal [43]	Providing a model for waste disposal management	–
	Lami and Abastante [44]	Selecting the most suitable method to recycling magnesium waste	–
	Motlagh and Sayadi [45]	Selecting the most suitable place for waste disposal	WLC, GIS
	Promentilla et al. [46]	Identifying and evaluating counter measures to develop a site remediation strategy	LGP
	Ren et al [47]	Evaluating different concentrations of citric acid and ethylene diamine tetra-acetic acid for safe sewage sludge disposal by removing toxins and maintaining nutrients	FANP
	Tuzkaya et al. [48]	Selecting a proper place for undesirable facilities (such as a waste disposal site)	–
	Zhao et al. [49]	Selecting the method of thick residual coal re-mining	FANP
Clean air	Liou [50]	Identifying effective attributes and strategies for managing and reducing production of carbon	DEMATEL
	Promentilla et al. [51]	Prioritizing measures to combat irreparable infiltration	FANP
	Promentilla et al. [52]	Identifying a proper location for establishing co2 capture and a storage technology	–
	Teng et al [53]	Determining the relative importance of indicators of energy conservation and carbon reduction in the hotel industry in Taiwan	
	Zhang [54]	Selecting low-carbon tourism strategies along with identifying effective attributes in this field	DM, FANP

comprehensive sustainable framework of criteria and evaluating candidate places using the combination of ANP and VIKOR are subjects, which can be considered for future research.

As presented in Table 2, *clean air* has the minimum number of articles among studies classified into the *health, safety and environmental management* category**.** In this regard, ranking effective actions to deal with air pollution and micro fluids, along with choosing the best method to diminish greenhouse gases, recycle the waste and increase green products, is among subjects recommended to be investigated using ANP in future research. In order to evaluate these issues, taking into consideration the combination of smart grade systems with ANP is a useful methodology. Since data analyzed in the context of safety and health should have maximum accuracy, utilization of different versions of fuzzy sets such as interval type-2 fuzzy sets, hesitant fuzzy sets and intuitionistic fuzzy sets is also suggested as future research for subjects discussed in this subcategory. Other papers investigating problems in the context of *health, safety and environmental management* are presented in Table 3.

Table 3
Other applied papers in the category of *health, safety and environmental management*.

Author(s)	Specific area	Other techniques combined or compared
Bobylev [55]	Assessing the effects of the underground construction technology on urban environment	–
Celik [56]	Providing an integrated process management system based on quality aspects, environmental concerns, occupational safety and health requirements	FAD
Chang et al. [57]	Assessing revitalization strategies to construct a forest railway in Taiwan	FDM, GP, BOCR
Chuang and Yang [58]	Identifying key success factors in implementation of green-manufacturing systems	
Eakin et al. [59]	Identifying drivers of social-ecological change and appropriate methods for reducing vulnerability in the coffee industry	–
Gopinath et al. [60]	Prioritizing watershed areas for soil conservation	–
Govindan et al. [61]	Selecting the best green manufacturing method in the pipe and plastic industry	DEMATEL, PROMETHEE
Grošelj and Strin [62]	Selecting the best strategy to maintain and promote natural and protected areas	SWOT
Kengpol and Boonkanit [63]	Selecting the best eco-design idea to produce environmentally-friendly products	TRIZ
Khoshnava et al. [64]	Selecting green building materials according to sustainable factors	FANP, DEMATEL
Liu and Lai [65]	Environmental impact assessment in construction projects	FANP, FL, SAT
Mohammadfam et al. [66]	Evaluating and promoting the standard OHSAS 18001	TOPSIS
Nekhay et al. [67]	Determining the importance of factors affecting soil erosion based on objective and subjective information	GIS
Nilashi et al. [68]	Determining the relative importance of factors affecting the acceptance of the hospital information system technology at Malaysian government hospitals	FANP
Shi et al. [69]	Providing a corporate sustainability model in supply chain networks of a Chinese athletic company to reduce environmental impacts	EFA, FDM
Topaloglu et al. [70]	Identifying the relationships between functionality factors in electronic health websites and determining the importance of each one of them	–
Tseng [71]	Evaluating and developing the environmental practice in knowledge management capability	DEMATEL, FST
Tseng et al [72]	Assessing the implementation of green innovation in Taiwanese printed circuit board manufacturing firms	FST
Wolfslehner and Vacik [73]	Assessing sustainable forest management strategies based on the pressure-state response framework	–
Wang et al. [74]	Selecting eco-designs at the stage of new product development by considering environmental impacts	LCA, FANP

Table 4
The papers in the *hydrology and water management* category.

Author(s)	Specific area	Other techniques combined or compared
Abed-Elmdoust and Kerachian [75]	Assessing water users in inter-basin water transfer systems	ER, TOPSIS, PROMETHEE II, Compared by AHP
Chen et al [76]	Evaluating effective attributes on watershed plans	DEMATEL
RazaviToosi and Samani [77]	Prioritizing watershed plans with respect to different development strategies in environmental, social and economic sectors	FANP, TOPSIS, FMMSM
RazaviToosi and Samani [78]	Prioritizing water transfer projects in the Karoon River	FMMSM, FTOPSIS
RazaviToosi and Samani [79]	Prioritizing watershed plans to implement human and financial resource development strategies in the area of watershed management	FANP, FDEMATEL, FVIKOR
Toosi and Samani [80]	Ranking and selecting water transfer projects due to unusual distribution and water scarcity	–
Zhang et al [81]	Assessing the vulnerability of water supply systems	GCE

4.2. Hydrology and water management

Most articles on sustainable water resource planning, water management strategy assessment and irrigation planning belong to the *hydrology and water management* category. Table 4 contains a summary of the reviewed articles related to this category.

Few numbers of articles conducted using ANP are related to the *hydrology and water management* category. Articles in this category deal with assessing and prioritizing watershed projects and water transferring projects, as well as with evaluating the vulnerability of water supply systems. Some recommended research studies in this category are assessment of water quality monitoring networks, assessment of water demand management strategies, and selection of best projects for water resources and water resource planning. Along with these studies, some studies can be performed using the FISM and FDEMATEL methods in order to examine the relationship among parameters for watershed plans.

4.3. Business and financial management

Articles in this category have focused on the main aspects of management such as performance measurement, portfolio management, investment analysis, customer satisfaction and competitive advantages. Due to diversity and for a better anal-

Table 5
The applied papers on *function evaluation* subcategory.

Author(s)	Specific area	Other techniques combined or compared
Chen and Lee [82]	Evaluating the performance of project managers in an air-conditioned engineering design and construction company	–
Chen et al. [83]	Evaluating the performance of knowledge management in universities	BSC
Dinçer et al. [84]	Assessing airline performance	BSC, FANP, DEMATEL, MOORA
Hsu et al. [85]	Providing a framework for evaluating the performance of the semiconductor industry	BSC, FDM
Hung et al. [86]	Evaluating the performance of internet marketing services	DEMATEL
Isfahani et al. [87]	Assessing the performance of organizations from the aspect of customer relationship management in the MAPNA Group	FANP
Jatoth et al. [88]	Assessing the performance of cloud services and ranking them based on the quality features of the services	AHP, DEA, SDEA
Kahraman [89]	Evaluating the performance of services in hospital	DEMATEL
Lin and Pan [90]	Assessing the performance of site property management and ranking sites	FDM, TOPSIS
Lin et al. [91]	Evaluating the performance of business intelligence systems in order to select the most effective attribute	–
Luo et al. [92]	Evaluating the performance of virtual research centers	TFNANP
Öztayşi et al. [93]	Evaluating the performance of the CRM sector in e-commerce companies	–
Piltan and Sowlati [94]	Evaluating the performance of partners in the wood factory	ISM, FL
Poveda-Bautista et al. [95]	Evaluating the competitive performance of companies engaged in the plastic industry	BSC, PM
Rashvand et al. [96]	Evaluating the performance of construction companies	–
Shen and Tzeng [97]	Assessing and improving the financial performance of the banking industry	DEMATEL, VIKOR
Tohumcu and Karasakal [98]	Evaluating the performance of research and development projects in an R&D institution	DEA
Varmazyar et al. [99]	Evaluating the performance of research centers of the research and technology organization in Iran	DEMATEL, TOPSIS, COPRAS, MOORA, ARAS, BSC, UIT
Wu et al. [100]	Evaluating the performance of hospitals	BSC, CA
Yang et al. [101]	Evaluating the performance of production systems in the wafer fabricating industry	AHP
Yurdakul [102]	Evaluating the performance of manufacturing companies	AHP

Table 6
The papers in the *project selection* subcategory.

Author(s)	Specific area	Other techniques combined or compared
Altuntas and Dereli [103]	Developing an evaluation system for investment projects in terms of commercialization potential in a technological field	FANP, FDEMATEL
Büyüközkan and Öztürkcan [104]	Selecting six sigma projects in logistics companies	DEMATEL
Chen et al. [105]	Selecting the most suitable feeder management system in power companies	BOCR
Ebrahimnejad [106]	Selecting construction projects for residential and office units	FANP, FVIKOR
García-Melón and Poveda-Bautista [107]	Prioritizing the Venezuela Power Company's projects by taking into account the strategic goals of the company	–
Grady and Peeta [108]	Selecting international development projects	SNA
Jeng and Huang [109]	Selecting and evaluating research and development projects in the electronic industry	DM, DEMATEL
Lee and Kim [110]	Selecting information system projects	GP
Lee and Kim [111]	Selecting information system projects	DM, ZOGP
Liang and Li [112]	Selecting company information system projects in an undershirt manufacturing factory in China	BOCR
Meade and Presley [113]	Selecting the best R&D project in companies to gain competitive advantages	–
Mohanty et al. [114]	Selecting R and D projects in the iron and steel industry	FANP
Šimelytė et al. [115]	Selecting the best foreign direct investing policy	BOCR
Tavana et al. [116]	Assessing NASA's advanced-technology projects	TOPSIS
Yuen and Lau [117]	Selecting research and development projects	LPPAM

ysis, the articles of this category are divided into five sub-categories including (1) *function evaluation,* (2) *project selection,* (3) *strategy selection,* (4) *risk assessment* and (5) *other applications in this area.* A summary of the research carried out in this category is presented in Tables 5–8.

As presented in Table 5, the subject of performance evaluation using ANP has the most application in plastics and banking industries, construction companies, hospital and research and development projects. Since the DEA method is not sensitive to the measurement unit of criteria and also provides optimal combination of input and output for an efficient unit, combination of ANP with DEA, which is suggested for future research, can provide more reliable results for problems in the context of performance assessment.

Table 7
The applied papers on *strategy selection* and *risk assessment* subcategories.

Subcategories	Author(s)	Specific area	Other techniques combined or compared
Strategy selection	Azimi et al. [118]	Prioritizing mining strategies in the light of the SWOT framework	SWOT, TOPSIS
	Chen and Cheng [119]	Evaluating strategies presented by cell phone providers	–
	Chiu et al. [120]	Evaluating performance improvement strategies for e-commerce in e-stores	DEMATEL, VIKOR, INRM
	Lee and Lee [121]	Selecting the best competitive strategy for the multinational pharmaceutical companies	–
	Lin et al. [122]	Selecting the best marketing strategy in the service industry	FANP
	Raisinghani et al. [123]	Selecting an e-business strategy	–
	Valipour et al. [124]	Selecting a right strategy to evaluate the risk of property management in Iranian public-private partnership projects	FCANP
	Wu and Lee [125]	Selecting a knowledge management strategy for Internet services	–
	Wu [126]	Assessing knowledge management strategies in an active company in the field of manufacturing, designing and selling semiconductor components	DEMATE
	Wu et al. [127]	Selecting the most appropriate marketing strategy	TOPSIS
	Yang and Huang [128]	Assessing factors affecting the success of online clothes sales and providing effective strategies	
	Yüksel and Dagdeviren [129]	Evaluating SWOT strategies in a textile company	SWOT, Compared by AHP
Risk assessment	Cao and Song [130]	Assessing risk in co-creating value with customers in a manufacturing company	RST
	Chang et al. [131]	Assessing the risk of ERP systems	FANP
	Chemweno et al. [132]	Selecting appropriate risk assessment methods in the European process industry and an automated guided vehicle assembler	–
	Chen [133]	Ranking risk dimensions in the laptop industry	FISM, DEMATEL
	Chen et al. [134]	Presenting a risk assessment model with respect to environmental criteria and factors related to natural phenomena to select an appropriate site for airport construction projects	–
	Jia et al. [135]	Presenting the maturity of a risk management model for construction projects	–
	Liu et al. [136]	Evaluating risk projects of scientific drilling	AHP, FSE
	Lo and Chen [137]	Evaluating information security risks	DEMATEL, FLQMEOWA
	Silvestri et al. [138]	Identifying the most appropriate risk assessment model in manufacturing companies with the goal of reducing operating costs and improving productivity	–
	Yang et al. [139]	Evaluating the risk of information security systems	NRM, DEMATEL, VIKOR

According to Table 6, approximately 12% of the articles on *business and financial management* are dedicated to the *project selection* subcategory. The most important issues in this subcategory are related to information systems and R and D projects. Evaluation of investment projects of power plants, renewable energy projects as well as outsourcing projects is another topic for future research using ANP. Furthermore, application of FANP-GP as a methodology is also suggested for future research. One of the significant features of GP is simultaneous access to several target functions based on priorities, which has an important role in project selection. In FANP-GP, the FANP technique can be utilized in two ways. First to (*i*) determine the relative importance of criteria and (*ii*) focus on interactions among criteria in uncertainty conditions, and second to prioritize goals based on existing constraints. ARAS is also a useful method in project selection, which is recommended to be combined with the ANP technique for the problems discussed in Table 6. ARAS not only can rank options, but also compute the rank of each option based on the ideal alternative.

The subcategory of *strategy selection* with 12 articles is the third most common subject reviewed in the *business and financial management* category (see Table 7). The issues related to marketing strategies in service industries, assessing knowledge management strategies, SWOT and assessing online trading strategies are among the topics investigated in the reviewed papers. Furthermore, topics such as assessing repair and maintenance strategies and higher education systems are recommended to be addressed using ANP in future research.

Based on information presented in Table 7, the *risk assessment* subcategory has the lowest number of studies. Laptop industry, construction projects, information safety, airports, and manufacturing companies are among the topics with the maximum frequency in the *risk assessment* subcategory. The literature review reveals that the combination of error analysis methods such as FMEA with ANP in fuzzy environments for ranking error modes is among the methodologies that were not considered in the *risk assessment* subcategory. The application of FANP-FMEA as a methodology is suggested for industries where the risk issue is highly important. Other papers in the context of *business and financial management* are presented in Table 8.

Table 8
Other applied papers in the category of *business and financial management.*

Author(s)	Specific area	Other techniques combined or compared
Aragonés-Beltrán et al. [140]	Evaluating urban industrial lands	–
Asan and Soyer [141]	Identifying and selecting an organization's strategic management concepts in the industrial engineering department	TDBU, Clustering
Carlucci and Schiuma [142]	Assessing the role of knowledge assets in generating profits in an engineering company	–
Chang et al. [143]	Evaluating digital video recorder systems	FANP
Chen [144]	Identifying key factors for evaluating the performance of a hypermarket	DEMATEL, VIKOR
Chen [145]	Identifying service quality improvement criteria aimed at increasing the competitive advantage of airlines	DEMATEL
Chiang et al. [146]	Assessing and prioritizing customer needs and design strategies	TDM
Chou and Cheng [147]	Evaluating the quality and ranking of certified public accountant firms' websites and improving their design	FANP, FVIKOR
Dağdeviren and Yüksel [148]	Evaluating sectoral competititon level in a manufacturing company in the Porter's diamond model framework	FANP
Dangol et al. [149]	Determining best management practices to improve the performance of a company based on performance prediction outcomes	SEM, SE
Erdoğmuş et al. [150]	Evaluating transportation processing systems in high-tech industries	BOCR
Feglar et al. [151]	Assessing the survey of the business motivation model in the information and communication technology	SWOT, BOCR
Fiala [152]	Analyzing factors affecting the network economy	DNP*
Grilo et al. [153]	Evaluating construction collaborative networks in construction projects	–
He et al. [154]	Evaluating factors affecting the complexity of mega construction projects	Delphi, FANP
Hu et al. [155]	Selecting a proper solution to improve the performance of smart phones	DEMATEL, VIKOR
Huang et al. [156]	Ranking critical infrastructures in public welfare	DEMATEL
Hsu et al. [157]	Determining the relative importance of the performance of drivers in commercializing technology from universities to industries	FDM, ISM
Jun et al. [158]	Evaluating and ranking business models in bottom-of-the-pyramid markets	–
Karpak and Topcu [159]	Identifying and ranking factors affecting the success of SMEs	–
Kengpol and Tuominen [160]	Ranking attributes affecting optimal investment in IT	MAH, DM
Keramati and Salehi [161]	Identifying factors affecting the success of electronic employment websites	
Kim et al. [162]	Identifying key technologies in an IT company	ARM
Koyuncu et al. [163]	Identifying factors affecting the work system design in order to optimize the decision-making process	FANP
Kumar and Claudio [164]	Selecting the best online ecommerce website to buy cookware, perfumes and watches	FAHP, FANP
Kwon et al. [165]	Prioritizing promotional policies for the big data industry	–
Lee and Tu [166]	Examining the relationship between factors affecting a company's value	DEMATEL, VIKOR, MMT
Lee et al. [167]	Providing an identification approach for vulnerability of organizational plans in achieving organizational goals	FRA
Lee et al. [168]	Evaluating new service concepts for mobile information and entertainment services	–
Lee et al. [169]	Identifying and ranking the five force model and determining the status of competition in the web industry	SICI
Lee et al. [170]	Evaluating product-service systems according to customer preferences	FANP
Lee et al. [171]	Investigating factors affecting stock prices based on different investment methods	DEMATEL
Lee et al. [172]	Selecting appropriate stocks for investment to maximize returns	MG
Levy and Taji [173]	Prioritizing effective measures for crisis management	DSS
Lin and Hsu [174]	Evaluating attributes affecting brand images	FANP
Lin et al. [175]	Identifying important criteria for evaluating and selecting digital music service platforms	NRM, PCA, DEMATEL, VIKOR
Lin et al. [176]	Evaluating fashion design schemes in the fashion industry	DEMATEL, VIKOR
Lin et al. [177]	Assessing strategic competition in the field of green business innovation capabilities	FST, IPA
Monarko et al. [178]	Making proper decisions for the construction of an arena	–
Mu [179]	Selecting the most suitable city for holding conferences and predicting the number of participants	BCR
Niemira and Saaty [180]	Presenting a model for financial crisis prediction	–
Palmisano et al. [181]	Selecting the most appropriate method of requalification for rural sustainable development	DRSA
Peris et al. [182]	Prioritizing Local Agenda 21 programs in one of the Spanish cities	–
Piltan and Sowlati [183]	Identifying factors affecting the performance of partners in the wood factory	WA
Sarkis and Sundarraj [184]	Evaluating enterprise information technologies	–
Sarkis et al. [185]	Selecting sustainable subcontractors	AHP
Shen et al. [186]	Selecting stocks and improving their performance due to changes in financial variables	DEMATEL, VIKOR
Shih et al. [187]	Estimating the sales volume of printers in recycling industries	Compared by AHP

(*continued on next page*)

Table 8 (*continued*)

Author(s)	Specific area	Other techniques combined or compared
Taşkin et al. [188]	Assessing the quality of hospital services	FANP, FDEMATEL, VIKOR
Tavana et al. [189]	Selecting the right media for marketing	COPRASG, FANP
Tosun et al. [190]	Determining the importance of factors affecting operator market share and investigating the market share of telecom operators	–
Tsai and Chou [191]	Selecting an appropriate management system to improve the business of paper and packaging production	DEMATEL, ZOGP
Tsai et al. [192]	Evaluating the effectiveness of web-based marketing in the airline industry	DEMATEL, VIKOR, 4P, WVA
Tsai and Hsu [193]	Selecting corporate social responsibility programs in the aviation industry	DEMATEL, ZOGP, ABC
Tsai et al. [194]	Selecting corporate social responsibility programs with respect to cost and profitability criteria in the hotel industry	
Tsai and Kuo [195]	Evaluating entrepreneurial policies with regard to budget constraints in SMEs	DEMATEL, ZOGP
Tsai et al. [196]	Evaluating encouraging entrepreneurship policies in SMEs	
Tsai et al. [197]	Prioritizing activities and allocating proper resources in IT projects	DEMATEL, ZOGP
Tsai et al. [198]	Providing a model for corporate finance decisions	DEMATEL, GP
Tseng et al. [199]	Assessing sustainable production attributes in a healthcare service company	FST
Uygun et al. [200]	Measuring the institutionalization level of SMEs	FANP, FDEMATEL, TOPSIS
Valmohammadi and Dashti [201]	Evaluating obstacles and implementing challenges of electronic commerce in the Iran Khodro Industrial Group	ISM, FANP
Verdecho et al. [202]	Identifying and evaluating inter-enterprise collaboration management to improve the performance of a company	–
Wang and Tzeng [203]	Evaluating brands in marketing by taking different criteria into account	IRM, DEMATEL, VIKOR
Wenbo [204]	Investigating factors affecting the economic performance of eco-industrial parks	Compared by AHP
Wu et al. [205]	Evaluating bancassurance alliance models	DM
Yüksel and Dağdeviren [206]	Assessing the BSC dimension in determining the performance level of a manufacturing company	FANP, BSC
Zammori [207]	Designing a model for predicting results in terms of the importance and impact level of input attributes	–
Zutshi et al. [208]	Identifying factors affecting corporate cooperation in business processes using a business interoperability quotient measurement model	–

Table 9
The applied papers on the topic of *Tourism*.

Author(s)	Specific area	Other techniques combined or compared
Bies and Zacharia [209]	Identifying factors influencing the development of medical tourism	BOCR
Chen et al. [210]	Evaluating the performance of hot spring hotels in Taiwan	BSC, DEMATEL
Horng et al. [211]	Identifying main factors and designing features in an indoor restaurant	DEMATEL
Hsieh et al. [212]	Quality assessment of hotel services according to customers' expectations	–
Hsu et al. [213]	Identifying the most important criteria for improving electronic service quality in online traveling websites	FPP
Lin and Huang [214]	Evaluating and prioritizing factors determining the passenger choice of low-cost carriers	
Liu and Chou [215]	Identifying major factors in the tourism strategy in the Kinmen tourism industry	FDM, DEMATEL
Lin and Lu [216]	Evaluating an ecotourism site	ISM, FDM, FANP
Lin et al. [217]	Evaluating the operation of travel intermediaries in a travel industry	–
Lin et al. [218]	Evaluating experiential values using tourists' experiences in the 2010 Taipei International Flora Exposition	ISM, FANP
Liu et al. [219]	Providing a model for evaluating tourism policies aimed at improving them In Taiwan	DEMATEL, VIKOR
Liu et al. [220]	Evaluating the performance of a metro–airport connection service to improve tourism policies in Taiwan	DEMATEL, DNP, VIKOR
Padhi and Aggarwal [221]	Providing a method to manage earning in the hotel industry and optimizing quota and price of hotel commodities	ANN, FGP
Peng and Tzeng [222]	Identifying the most effective methods to improve the performance of the tourism industry	DEMATEL, VIKOR
Tsai et al. [223]	Evaluating national park websites and ranking them	DEMATEL, VIKOR

4.4. Tourism

The articles in this category have focused on the main aspects of tourism and hotel in terms of tourism, pilgrimage and medicine. Improving policies related to tourism and hotel industries, evaluating tourist attractions, improving informational and promotional strategies, as well as becoming aware of tourists' expectations are features of this category. Table 9 summarizes all articles in this category.

Articles in this category are related to the evaluation of tourism policies and strategies, evaluation of hotels and traveling websites, and so on. As it is shown, these evaluations were performed in a crisp environment and thus using FANP can

contribute to the results. To identify influential parameters in evaluations, the use of the BOCR-ANP model is recommended. The FANP-FDEA method is proper to assess the performance of hotels and websites. In addition to the above-mentioned issues, it is recommended to evaluate and prioritize the tourism developing infrastructure and rank improvement service quality strategies using ANP as future studies.

4.5. Logistics and supply chain management

This categorization relates to articles on location problems, outsourcing and supplier selection in various fields. For better analysis, articles in this category are divided into five sub-categories including (1) *supplier and distributor selection,* (2) *outsourcing,* (3) *location,* (4) *transportation,* (5) *supply chain function's assessment* and (6) *other applications in this area*. Tables 10–12 provide an overview of articles in this category.

Reviewing 108 studies in the *logistics and supply chain management* category indicates that supplier selection is a hot topic in the articles (see Table 10). Moreover, artificial intelligence and computer-based models (such as CBR) integrated with ANP are among methodologies neglected in the literature of supplier and distributor selection. In addition to the points mentioned, ranking requirements for lean-agile manufacturing as well as just-in-time production in various industries are among topics suggested for future research in the supply chain performance assessment.

Studies in the *outsourcing* subcategory are often related to partner selection in the supply chain of electronic and airline industries (see Table 11). Most of the studies used ANP-DEMATEL as the methodology. In order to achieve more reliable results, the application of the hybrid methodology in fuzzy environment for outsourcing information systems is suggested for future studies.

According to Table 11, studies categorized into the *location finding* subcategory were more conducted in the context of the location selection problem of hospital, logistics and distribution centers. The combination of meta-heuristic algorithms (such as GA) and GIS with ANP due to having high ability in analyzing spatial data is suggested as methodologies for future research in this subcategory. Furthermore, application of GIS-FANP-FWOD as a decision support system is also suggested to be employed in the location selection problems.

The least number of articles reviewed in the category *of logistics and supply chain management* is related to *supply chain function assessment* (see Table 11). To improve the result of subjects reviewed in this subcategory, application of ANP-DEA is also suggested. Other studies in the category of *logistics and supply chain management* are presented in Table 12.

4.6. Design, engineering and manufacturing systems

This category refers to the articles on modern manufacturing systems, automation, material engineering, product design, quality engineering, repair, maintenance and assembly. Articles of this category are divided into four subcategories of (1) *product design*, (2) *machinery selection*, (3) *maintenance* and (4) *other applications in this area.* A summary of the reviewed articles related to this category is presented in Tables 13–15.

Of the 88 studies categorized into the *design, engineering and manufacturing systems* category, 23 articles were carried out in the field of *product design*. By reviewing the papers, it is revealed that the application of ANP was far more popular in the automotive industry than in other industries in the *product design* subcategory (see Table 13). Product reconstruction, redesign and risk assessment of new product development in different industries are suggested topics to be examined using ANP in future research.

Machine tool selection and maintenance have the minimum number of articles in the category of *design, engineering and manufacturing systems* (see Table 14). In this regard, application of DEMATEL-ANP or ISM-ANP is suggested as methodologies to solve the most subjects presented in Table 14 in future research. The reason is that determining the interaction among the criteria by DEMATEL or ISM not only facilitated the process of problem solving, but also improved the accuracy of the obtained result. Combination of ANP-GP or ANP with other rating methods such as VIKOR is recommended to select an appropriate maintenance and repair strategy. It is noteworthy that the fuzzy combination of these methods can result in better outcomes. If there is no complete and obvious information, using the ANP-GRA combined method can be helpful.

Other articles reviewed in the category of *design, engineering and manufacturing systems* are presented in Table 15. Evaluation of production strategies and production systems, manufacturing technologies selection and prioritization of ERP modules are among the issues classified in this subcategory.

4.7. Energy management

These articles refer to the evaluation and selection of energy generation methods and technologies, as well as the performance of the energy system. A summary of the reviewed articles related to this category is presented in Table 16.

Based on Table 16, it is indicated that renewable energy sources are the most widely used subject in this category. Considering the importance of this issue in various researches, topics such as locating energy generating plants from renewable energy sources, assessing the performance of these power plants, selecting production technologies, and evaluating renewable energy sources using the ANP is suggested for further research. Moreover, evaluation and selection of energy production

Table 10
The applied papers on the *supplier and distributor selection* subcategory.

Author(s)	Specific area	Other techniques combined or compared
Abdollahi et al. [224]	Assessing and selecting suppliers based on lean and agile criteria	FDEMATEL, DEA
Ayağ and Samanlioglu [225]	Selecting a supplier in the automotive industry	FANP
Bakeshlou et al. [226]	Providing a fuzzy multi-objective linear programming model to select the best green supplier	FANP, ELA
Boran and Goztepe [227]	Providing a commodity acquisition model to select the appropriate merchant	FANP
Büyüközkan and Çifçi [228]	Selecting a sustainable supplier for a manufacturing company to improve supply chain management activities	FANP
Chen and Lee [229]	Selecting a proper supplier according to different patterns of collaboration such as strategic alliance, financial situation and so on in a manufacturing company	Markov Process
Demirtas and Üstün [230]	Choosing a supplier and order allocation for a refrigerator manufacturing company	MOMILP
Gencer and Gürpinar [231]	Selecting a supplier in an electronic company	–
Geng and Liu [232]	Selecting a proper supplier to develop the PSS service system in a mechanical shovel company	SERVQUAL, VIKOR
Govindan et al. [233]	Selecting a responsible supplier for an access control hardware manufacturing company in India based on social responsibility practices	DEMATEL, PROMETHEE
Hashemi et al. [234]	Selecting a green supplier based on economic and environmental attributes	GRA
Hsu and Hu [235]	Selecting the best supplier for hazardous substance management according to environmental regulations	–
Huang and Hu [236]	Selecting a supplier in the automotive industry	FANP, GP, DNP
Kang et al. [237]	Selecting a supplier in the semiconductor industry	FANP
Kasirian and Yusuff [238]	Selecting a supplier in a Malaysian automotive company	TOPSIS
Kuo and Lin [239]	Selecting a supplier with respect to environmental factors and environmental compliance rules	DEA
Kuo et al. [240]	Selecting a supplier in the green supply chain of an electronic company	ANN, DEA
Lin [241]	Selecting a supplier in the absence of accurate information and assigning the optimum order value to suppliers	FPP, FMOLP
Lin et al. [242]	Selecting a supplier in an electronics company using the triple bottom line framework	FANP
Lin et al. [243]	Selecting a supplier in a motherboard manufacturing company using the ERP system	TOPSIS, LP
Lin et al. [244]	Selecting a proper supplier to develop the PSS service system	ISM
Liou et al. [245]	Selecting a supplier to improve their services in the airline industry	DEMATEL, FI
Liou et al. [246]	Selecting a supplier based on environmental factors in electronics company	DEMATEL
Önüt et al. [247]	Selecting a supplier in a communication company	FANP, TOPSIS
Pang and Bai [248]	Identifying important criteria in the assessment of suppliers and selecting the most appropriate supplier for a high-technology manufacturing company	FSEU, FANP
Rai and Bolia [249]	Selecting a supplier of weapons in the air force	AHP
Rajesh and Ravi [250]	Selecting a supplier in the resilient supply chain of an electronic manufacturing company in India	GRA
Razmi and Rafiei [251]	Selecting suppliers and assigning orders to them	MINLP
Razmi et al. [252]	Selecting a supplier with respect to vendor important factors	FANP, NLP
Tadić et al. [253]	Providing a framework for assessing and selecting the city logistics concept in Belgrade with respect to stakeholders' interests and their partners	FDEMATEL, FANP, FVIKOR
Tavana et al. [254]	Selecting third-party reverse logistics providers in a manufacturing company	–
Theißen and Spinler [255]	Selecting the most suitable supplier to manage the reduction of CO2 emissions in the fast-moving consumer good industry	–
Tseng et al. [256]	Selecting a supplier in the green supply chain of the largest professional printed circuit board manufacturing company in Taiwan	FANP
Tseng et al. [257]	Selecting the right supplier in the supply chain management of a printed circuit board manufacturing company in Taiwan	CI
Ustun and Demirtas [258]	Selecting suitable suppliers and shipment allocation to each supplier for a refrigerator manufacturing company	AGP, MGP
Vinodh et al. [259]	Selecting a supplier in a manufacturing organization	FANP
Wan et al. [260]	Selecting a supplier with respect to factors such as reducing costs and improving quality in an auto manufacturing company	TLANP, ELECTRE II
[261]	Selecting a supplier in a third-party logistics	FANP, PFIGP
Wu et al. [262]	Selecting suppliers and a proper partner for strategic alliances in the liquid crystal display industry	–
Wu et al. [263]	Selecting suppliers with the aims of reducing costs, keeping the quality of manufactured products and assigning the order to each of the suppliers	MIP
Xu et al. [264]	Selecting a product-service supplier in the absence of information on previous suppliers' performance	FANP
Yang and Tzeng [265]	Selecting a proper vendor in a company manufacturing computers and electronic products	DEMATEL
Yücenur et al. [266]	Selecting the most suitable supplier in logistics companies	FAHP, FANP
Zhu et al. [267]	Assessing and selecting a supplier in the green supply chain with respect to environmental factors	

Table 11
The applied papers on the outsourcing, location, transportation and supply chain function's assessment subcategories.

Subcategories	Author(s)	Specific area	Other techniques combined or compared
Outsourcing	Govindan et al. [268]	Selecting a third-party reverse logistic provider and evaluating criteria that affect its selection in an Indian automobile component manufacturing company	AHP
	Hsu and Liou [269]	Providing a decision model for outsourcing and selecting a supplier in the airline industry	DEMATEL
	Hsu et al. [270]	Selecting an appropriate outsourcing provider in the airline industry	DEMATEL, MGRT
	Kayakutlu and Buyukozkan [271]	Evaluating and selecting the most effective performance attributes in third party logistics companies	DM
	Liou and Chuang [272]	Selecting a provider for outsourcing airlines	DEMATEL, VIKOR
	Liou [273]	Selecting right partners for strategic alliances in the airline industry	FPP, DEMATEL
	Liou et al. [274]	Selecting partners for strategic alliances to meet the needs of customers in the aircraft industry	FPP
	Liou et al. [275]	Selecting an outsourcing provider in the airline	DEMATEL, FPP
	Tjader et al. [276]	Selecting the best outsourcing strategy in IT	BSC
	Uygun et al. [277]	Evaluating and selecting an outsourcing provider for a carrier company	DEMATEL, FANP
	Wu and Barnes [278]	Selecting the best partner in the green supply chain of Chinese electrical appliance and equipment manufacturing industries	MOP
	Wu and Barnes [279]	Selecting a partner in agile supply chains	Dempster-Shafer, RBF-ANN, MIMOP
	Zhu et al. [280]	Providing a strategy to determine the logistics partners in electrical appliances company	–
Location	Guneri et al. [281]	Selecting the right place to build a shipyard	FANP
	Kuo and Liang [282]	Selecting the right place for an international distribution center in Pacific Asia	TOPSIS, FANP, DEMATEL
	Kuo [283]	Locating an international distribution center in coastal cities (coastal ports)	FANP, FDEMATEL
	Lin and Tsai [284]	Evaluating effective factors on selecting the right place for hospital construction	NGT, TOPSIS
	Lin and Tsai [285]	Selecting the most suitable place to invest in medical services	TOPSIS
	Neumüller et al. [286]	Selecting the right place for distribution centers for groceries	PAM
	Özceylan et al. [287]	Evaluating and selecting the right place for the development of freight villages	GIS, TOPSIS
	Özdağoğlu [288]	Selecting the right place for equipment in the food industry	FANP
	Peker et al. [289]	Selecting the right place for logistics centers in Turkey	BOCR
	Rezaeiniya et al. [290]	Selecting the best place for greenhouse	–
	Sarkis and Sundarraj [291]	Locating equipment in a digital equipment corporation	TOM
	Wu et al. [292]	Selecting the right place to build a hospital using Porter's diamond model	FANP, PM
Transportation	Bugarinović et al. [293]	Ranking access charge principles in the transportation industry	
	Ozdemir and Basligil [294]	Selecting the most suitable aircraft for Turkish airlines	CI, Compared by AHP
	Özgen and Tanyas [295]	Selecting the best customs broker agency and international road transport company	FANP
	Shang et al. [296]	Selecting a shipping project	–
	Su et al. [297]	Selecting the best shipping project	DST
	Tuzkaya and Önüt [298]	Assessing transportation methods on the route between Turkey and Germany	FANP
	Wey and Wu [299]	Selecting the best transport infrastructure project in Taiwan	FDM, GP
Supply chain function's assessment	Agarwal et al. [300]	Investigating factors affecting supply chain performance and selecting the most appropriate paradigm for performance improvement	–
	Cabral et al. [301]	Evaluating supply chain performance using key performance indicators in the automobile industry	–
	Tseng et al. [302]	Evaluating the performance of sustainable supply chain management in a Taiwanese electronic manufacturing firm	BSC, FDM
	Tseng et al. [303]	Assessing the performance of sustainable service supply chain management with respect to environmental factors in electronic manufacturing firms	FDM
	Uygun and Dede [304]	Evaluating the performance of green supply chain management	FANP, FDEMATEL, FTOPSIS

Table 12
Other applied papers in the category of *logistics and supply chain management*.

Author(s)	Specific area	Other techniques combined or compared
Agarwal and Shankar [305]	Evaluating factors affecting trust in online commerce between a buyer and a supplier in an e-enabled supply chain	–
Büyüközkan and Berkol [306]	Determining design requirements of sustainable supply chain management in the fuel industry	QFD, ZOGP
Büyüközkan and Çifçi [307]	Evaluating activities of green supply chain management in the Ford Otosan Company in Turkey	FANP
Büyüközkan and Çifçi [308]	Assessing green suppliers to improve supply chain management activities in the Ford Motor Company	FDEMATEL, FANP, FTOPSIS
Chen et al. [309]	Selecting a strategy in green supply chain management and evaluating the most important activities in business functions	
Choudhury et al. [310]	Providing a model for strategic planning issues in a supply chain cell in a medicinal company	
Demirtas and Ustun [311]	Assessing suppliers and determining order allocation for them	AGP, MOMILP
Dou and Sarkis [312]	Assessing and selecting offshoring alternatives in terms of factors affecting supplier selection, location factors and sustainability factors	–
Dou et al. [313]	Identifying green supplier development programs aimed at improving supplier performance in the China's pivot irrigation equipment industry	GST
Hernandez et al. [314]	Identifying reverse logistics activities in the publishing industry	BOCR
Hung [315]	Presenting a divergent supply chain planning model in a mobile phone company to enhance competitive advantage	DEMATEL, FGP
Hussain et al. [316]	Evaluating alternatives for sustainable supply chain management	ISM
Joshi et al. [317]	Prioritizing supply chain competitiveness factors in the automotive industry	–
Kayakutlu and Büyüközkan [318]_ENREF_2	Analyzing factors affecting the effectiveness of supply value chain management by considering the dimensions of knowledge management in the textile industry	DM
Kirytopoulos et al. [319]	Providing a model for evaluating the supplier and assigning order value in multiple sourcing in the parapharmaceutical industry	AUGMECON, MOMP
Kusi-Sarpong et al. [320]	Identifying and evaluating factors affecting green supply chain management and its use for sustainable performance of mining industry companies	FDEMATEL
Lam and Dai [321]	Evaluating systematic criteria of logistics service providers (LSPs) to develop security design	QFD
Lee et al. [322]	Assessing the relationship between a buyer and a supplier in the high-tech industry	BOCR
Lin and Huang [323]	Identifying determinants in low cost carrier purchase	–
Raisinghani and Meade [324]	Selecting the right knowledge management system to develop an agile supply chain by examining the relationship between organization performance criteria and dimensions of agility, e-supply chain drivers	–
Ramkumar and Jenamani [325]	Evaluating sustainable purchasing in the supply chain of a ferroalloy manufacturing unit	DEMATEL
Ravi et al. [326]	Selecting reverse logistics operations for end-of-life computers	BSC
Ravi et al. [327]	Selecting the most suitable reverse logistics project in a computer hardware supply chain according to the available resources	ZOGP
Singh and Sharma [328]	Prioritizing flexibility alternatives in a supply chain of a spare part manufacturing company	–
Supeekit et al. [329]	Identifying the most important factors affecting the supply chain performance of a hospital	DEMATEL
Tuzkaya et al. [330]	Designing a model for a reverse logistics network for the Turkish white goods industry	FTOPSIS
Wu et al. [331]	Identifying key factors in supply chain agility to enhance its competitive advantage in the electronics industry	DEMATEL, FST
Xia and Chen [332]	Selecting the most appropriate risk management method in the supply chain	–

and storage strategies are next suggested topics for future studies. Use of meta-innovative methods such as GA and MINLP in combination with ANP is a suggested method for locating energy generating plants in future studies.

4.8. Human resources management

Articles of this class are related to evaluating and employing candidates for a professional job. Table 17 provides a summary of all the articles reviewed in this category.

Articles in this category take into account staff selection and employee performance assessment. Selection of management team members, selection of nurses, selection of consultants for organizations, selection of contractors, selection of university staff and selection of project managers are the topics in the personnel selection section, which are recommended for future research. Using intuitionistic fuzzy sets and hesitant intuitionistic fuzzy sets in combination with the ANP technique lead to the enhancement of the accuracy of personnel selection. Banking industry, information technology companies and evaluation of sales managers are good issues for future studies on employee performance assessment. Note that using

Table 13
The applied papers on the *product design* subcategory.

Author(s)	Specific area	Other techniques combined or compared
Ayağ et al. [333]	Selecting the most appropriate concept in the new product development process	TOPSIS
Büyüközkan et al. [334]	Determining the relative importance of design requirements for product planning	FANP, QFD
Chen et al. [335]	Identifying factors affecting the success of the new product development process in a small-sized home appliance manufacturing company	BSC
Ertay and Kahraman [336]	The design requirement in assessing the product development process for a PVC window system	FQFD, PROMETHEE I, PROMETHEE II, PROMETHEE III, FANP
Ertay et al. [337]	Prioritizing the design requirements in a car manufacturing company	FANP
Geng et al. [338]	Prioritizing engineering characteristics determined based on customers' demands	FST, QFD. DEA
Güngör et al. [339]	Determining requirements for product design and development based on the fuzzy decision-making system	FDMS, FANP
Kahraman et al. [340]	Presenting a fuzzy optimization model to solve the QFD problem in PVC door and window manufacturing company	MILP, FQFD, compared by AHP
Karsak et al. [341]	Prioritizing product technical requirements in the production planning process	QFD, ZOGP
Lee et al. [342]	Selecting the most appropriate new product development strategy and evaluating the effects of the selected strategy for 108 technology companies in China	BSC
Lee et al. [343]	Selecting technical requirements for designing a backlight unit in the thin film transistor liquid crystal display industry	FANP, QFD, GP
Lin [344]	Determining product position and improving vehicle telematics system services	DEMATEL, PCA, VIKOR, NRM
Lin et al. [345]	Identifying characteristics and requirements of customers in the field of automotive telematics systems	DEMATEL, TOPSIS
Liu and Hsiao [346]	Determining the most important product components at the design stage with regard to resource constraints in an electronic appliance manufacturing company	GP
Liu and Wang [347]	Production development and design planning according to customers' needs in a small-medium scale manufacturing company	QFD, FANP, DEMATEL
Liu et al. [348]	Optimizing a product family architecture tailored to customers' needs and company's budget constraints	GP
Liu [349]	Selecting the best prototype of the product at the design stage in a window design and production company	QFD, FANP, FLP
Ocampo and Seva [350]	Evaluating and prioritizing mobile text entry practices in smartphones	–
Parameshwaran et al. [351]	Prioritizing design requirements to develop new products	FDM، FISM، FANP، FQFD
Raharjo et al. [352]	Investigating the internal relationship between components of production design for consumer electronic products in European countries	QFD, FST
Shyur [353]	Evaluating commercial-off-the-self products in product development projects	TOPSIS
Younesi and Roghanian [354]	Providing a product design model to identify the best design criteria in Iran's transformer industry	QFDE, DEMATEL, FANP
Zaim et al. [355]	Identifying and ranking product technical characteristics	Combined by QFD and FQFD

fuzzy multi-objective optimization models and considering the effects of model objectives on each other can better solve the problem of allocation and optimal use of human resources.

4.9. Other topics

The final classification covers articles dealing with medicine, agriculture, education, government and sports. A summary of the reviewed papers related to this category is presented in Table 18.

5. Other classification schemes

In this section, the articles examined are studied from four perspectives including combined or comparative method used, year of publication, article publishing journals and nationality section of authors.

5.1. The combined or comparative method used in the articles

By reviewing various articles, it is found that combined ANP methods are far more useful than ANP. To consider different degrees of ambiguity in deciding, it is appropriate to use methods with the fuzzy method. FANP was used in 15.89% of the papers reviewed as a hybrid method. DEMATEL is among the other combined methods. Of the total reviewed articles, 13 articles compared the ANP performance with the performance of the other MCDM methods, such as AHP. The purpose of the comparison is to define ranking and weighing differences between the ANP method and the other MCDM methods. Table 19 shows the number and percentage of distribution of techniques combined or compared with ANP.

Table 14
The applied papers on the *machine tool selection and maintenance* subcategories.

Subcategories	Author(s)	Specific area	Other techniques combined or compared
Machine tool selection	Ayağ and Özdemir [356]	Selecting machinery in manufacturing companies	FANP, TOPSIS
	Chang et al. [357]	Selecting the best machine in terms of accuracy in the wafer slicing production process	DM
	Kumru and Kumru [358]	Prioritizing and selecting a three-dimensional coordinate-measuring machine	FANP
	Nguyen et al. [359]	Selecting the most suitable machine tool for the manufacturing company	Combined by COPRASG, Compared by TOPSIS, SAW and GRA
	[360]	Selecting a production car according to cost and risk criteria	FANP, PROMETHEE II
	Pal et al. [361]	Selecting a quick tooling route	QFD
	Paramasivam [362]	Selecting a suitable milling machine in a manufacturing company	DMA, Compared by AHP
	Sadeghian and Sadeghian [363]	Selecting machinery in a flexible production system	FANP, ANN
	Samanlioglu and Ayağ [364]	Selecting a proper machine tool for the manufacturing company	FANP, FPROMETHEE
	Yurdakul [365]	Selecting a machine tool based on its relationship with production strategies in a machinery manufacturing company	AHP
Maintenance	Aragonés-Beltrán et al. [366]	Providing an assessment model for stakeholders' influences on maintenance projects	–
	Cheng and Tsao [367]	Selecting a preventive maintenance strategy for rolling stock	–
	Kumar and Maiti [368]	Selecting an appropriate maintenance method for industrial units	FANP
	Mirabedini and Iranmanesh [369]	Providing a preventive repair scheduling method in machines performing multiple tasks simultaneously	MOGA
	Nazeri and Naderikia [370]	Selecting a suitable maintenance strategy in the railway industry with the goal of reducing costs	FDEMATEL, FANP, FFMEA
	Van Horenbeek and Pintelon [371]	Providing a framework for performance measurement maintenance in manufacturing companies	–
	Vujanović et al. [372]	Evaluating vehicle fleet maintenance attributes	DEMATEL

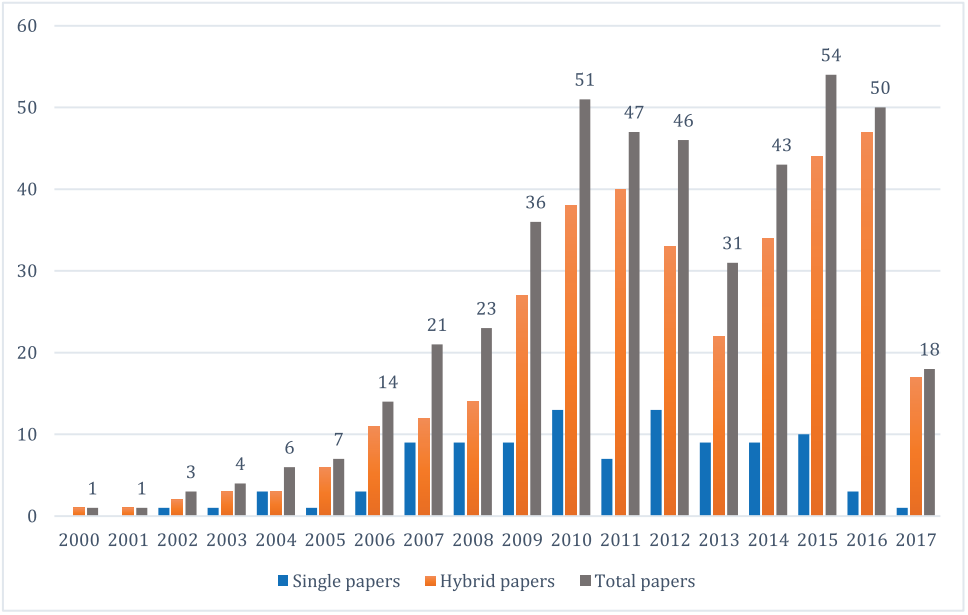

Fig. 3. Distribution of papers by publication year with respect to ANP used individually or in combination with other methods.

5.2. Year of publication

Fig. 3 shows the frequency of publication of the articles in different years. Based on this figure, since 2006, the number of articles published in the context of ANP has grown dramatically. As you can see, almost 88% of all the articles have been published since 2008.

Table 15
Other applied papers in the category of *design, engineering and manufacturing systems.*

Author(s)	Specific area	Other techniques combined or compared
Abdi [373]	Selecting a family product according to market requirements and production operations in a pharmaceutical manufacturing company	–
Abdi and Labib [374]	Evaluating the performance of reconfigurable manufacturing systems in a manufacturing company	–
Akyildiz et al. [375]	Prioritizing customers' orders due to capacity constraints in a steel production company	–
Aliakbari Nouri et al. [376]	Selecting the right production technology in a medium sized manufacturing company in Iran	FANP, FTOPSIS
Ayağ and Özdemir [377]	Selecting the best concept in new product development at the product engineering department of a hot runner system manufacturing company	FANP
Ayağ and Özdemir [378]	Selecting a proper ERP software for an electronics manufacturing company	FANP
Behnam et al. [379]	Prioritizing Mudas of production line in a cotton fabric manufacturing plant	VSM
Bayazit and Karpak [380]	Determining the impact of factors affecting the implementation of TQM and assessing the preparedness of manufacturing companies in adopting TQM practices	–
Chang et al. [381]	Identifying the most important agile factors when a product enters the mass production stage	ISM
Chang et al. [382]	Evaluating digital video recorder systems and selecting the best one	AHP
Chen and Chen [383]	Selecting the most appropriate model for assessing total quality management in the biotechnology industry	FANP
Chung et al. [384]	Selecting the best product mix to achieve optimal production in a semiconductor component manufacturing company	Compared by AHP
Cil and Turkan [385]	Identifying the relationship between business objectives and lean practices as well as stakeholder values	–
Dai et al. [386]	Modeling reliability of the manufacturing process in a valve–sleeve component manufacturing company	–
Govindan et al. [387]	Identifying factors and barriers against the reconstruction of automotive parts for clean production	ISM
Güngör [388]	Prioritizing connection types in assemblies	–
Hallikainen et al. [389]	Prioritizing ERP modules to be implemented in a global industrial manufacturing company	–
Hasan et al. [390]	Ranking product flow layouts on agility	–
Hemmati and Rabbani [391]	Determining a proper strategy to deliver products	–
Kang [392]	Selecting capacity allocation plans in semiconductor fabrication	FDM, FANP, CP, BOCR
Kilic et al. [393]	Selecting a proper ERP system for SMEs	PROMETHEE
Lee et al. [394]	Evaluating production strategies	FDM, FANP
Lee et al. [395]	Selecting a technology used in a software company	–
Lin et al. [396]	Selecting the most appropriate dispatching method in a manufacturing company	–
Lin et al. [397]	Identifying sustainable production indicators for an equipment manufacturing company	QFD, FST
Mei et al. [398]	Selecting best schemes for one-a-kind production interim products	FANP
Moalagh and Ravasan [399]	Evaluating success factors in implementation of ERP systems in a turbine manufacturing company	FANP
Onut et al. [400]	Selecting a proper equipment for a steel company	FANP, TOPSIS
Partovi [401]	Assessing the process choice for chemical production systems	QFD, AHP
Rafiei and Rabbani [402]	Determining the order penetration point of products produced using the hybrid strategy	FANP
Rafiei and Rabbani [403]	Checking levels of make to stock/make to order production strategies	FANP
Sarkis et al. [404]	Selecting agile virtual enterprises	–
Shen et al. [405]	Selecting a proper technology for organic light emitting diodes	DM, DEMATEL, PCA
Tesfamariam and Lindberg [406]	Prioritizing goals in manufacturing system design to exclude options not applicable at an early stage	SD, DLC
Tsai [407]	Selecting the best configuration of a flexible surface mount assembly system	CFPR
Tuzkaya et al. [408]	Selecting equipment in a manufacturing factory	FANP, PROMETHEE
Tzeng and Huang [409]	Selecting logistics and manufacturing strategies in the semiconductor industry	–
Vinodh et al. [410]	Selecting the best agile concept in a car spare parts manufacturing company	FANP, FDEMATEL, FTOPSIS
Vinodh et al. [411]	Selecting a concept in an agile design system in manufacturing plants	FANP
Wadhwa et al. [412]	Examining the concepts and strategies of virtual manufacturing	–
Wong and Wong [413]	Providing a lean-ecosphere management system to manage operations and people in a manufacturing company	ISM
Wong et al. [414]	Identifying key attributes in the evaluation of intelligent building systems	–
Wong et al. [415]	Determining the relationship between operational goals and intelligent attributes in building control systems	AHP
Wong et al. [416]	Assessing leanness level in a multination semiconductor component manufacturing company in Malaysia	–
Yang and Chang [417]	Prioritizing customer values in the cosmetics and toiletries industry	MEC, FANP
Yazgan [418]	Selecting an appropriate dispatching rule in a flexible production system	FANP, BOCR
Yazgan et al. [419]	Selecting ERP software	ANN
Yazgan et al. [420]	Evaluating and selecting a dispatching rule in flexible manufacturing systems	BOCR, CI

Table 16
The applied papers on the topic of *energy management*.

Author(s)	Specific area	Other techniques combined or compared
Büyüközkan and Güleryüz [421]	Selecting the most suitable renewable energy sources for investment	DEMATEL
Cannemi et al. [422]	Selecting investment projects in biomass power plants	–
Chen and Pang [423]	Assessing the distribution of the existing knowledge strategies in the solar energy industry	FANP
Gigović et al. [424]	Identifying installation sites for wind farms	DEMATEL, MABAC
Hu et al. [425]	Assessing the consumed energy performance of the campus building	FANP
Kabak et al. [426]	Ranking investment strategies in an energy field	SWOT, FANP
Köne and Büke [427]	Determining the best combination of fuel for generating electricity	–
Momoh and Zhu [428]	Prioritizing power generation units according to the appropriate price allocation	EQUIP, AHP
Promentilla et al. [429]	Prioritizing low carbon energy systems to reduce CO2 emissions in the electricity-generating sector	FANP
Rabbani et al. [430]	Assessing the performance of oil producing companies	FCOPRAS, SBSC
Sakthivel et al. [431]	Selecting an optimum biodiesel blend in an IC engine	TOPSIS
Shafiee [432]	Selecting a risk reduction strategy in the renewable energy industry	AHP, FST, FANP
Sittikruear and Bangviwat [433]	Evaluating measures to improve energy efficiency in a whiskey production plant	EV, Compared by AHP
Tahseen and Karney [434]	Assessing the potential of hydropower generated from the Niagara River and prioritizing energy recovery policies in terms of sustainability	SSWOT, AHP
Tavana et al. [435]	Assessing oil and gas pipeline routes	FST, Entropy
Xu et al. [436]	Prioritizing key performance indicators for sustainable building energy efficiency retrofit in hotel buildings	–
Yeh and Huang [437]	Investigating of key factors in determining the location of wind farms	FDEMATEL

Table 17
The applied papers on the topic of *human resources management*.

Author(s)	Specific area	Other techniques combined or compared
Celik et al. [438]	Evaluating factors affecting the selection of the board of directors in maritime transport management companies	–
Certa et al. [439]	Providing an optimization model for skilled human resource allocation for R&D projects	FELECTERE III, LGP
Chang [440]	Selecting public relations personnel for the tourism industry	FDM, TOPSIS
Chen et al. [441]	Evaluating factors affecting staff stress reduction in indoor environments	Taguchi
Chen et al. [442]	Evaluating the performance of the R&D department staff in a precision machinery manufacturing company	–
Dağdeviren [443]	Selecting personnel for manufacturing systems	TOPSIS
Hor et al. [444]	Assessing leadership competencies in order to plan succession in a semiconductor component manufacturing company	–
Kabak et al. [445]	Selecting a sniper	FANP, FTOPSIS, FELECTERE
Lin [446]	Selecting personnel for an electric and machinery company	FDEA
Shyur and Shih [447]	Selecting the right vendor in a local company in Taiwan	TOPSIS

5.3. Journals

Table 20 shows the number and percentage of scientific articles published in the reviewed journals. According to Table 20, Expert Systems with Applications is the most popular journal for the publication of ANP applications, as more than 19.08% of all the reviewed articles were published in this journal. Two journals, i.e. Computers and Industrial Engineering as well as the International Journal of Production Research, which respectively included 5.92% and 5.26% of all the reviewed papers in the context of ANP, are among other popular journals for publishing ANP applications. It should be noted that in 16 journals out of the 63 reviewed journals, only one published an ANP paper.

5.4. Nationality and number of authors

Fig. 4 shows that 41 countries and nationalities participated in the publication of ANP articles. Taiwan, Turkey and China had the most published papers. Asia, Europe as well as North and South America accounted for 78.44, 12.98 and 8.25% of the surveyed papers, respectively.

6. Open areas for future work

Based on practical and theoretical dimensions, the future research direction of ANP can be discussed as follows:

Table 18
The applied papers on the topic of *other topics*.

Author(s)	Specific area	Other techniques combined or compared
Chen and Chen [448]	Ranking performance evaluation systems for the performance improvement of universities	DEMATEL, FANP
Chen and Chen [449]	Evaluating the performance of innovation support systems in higher education institutions	DEMATEL, FANP, TOPSIS
Chen and Chen [450]	Reviewing creativity criteria to improve students' creativity	DEMATEL
Chen and Chen [451]	Assessing the performance of universities in Taiwan	DEMATEL, FANP, GRA, TQM FAHP
Chen and Sun [452]	Identifying factors affecting the participation of elderly people in recreational sports and prioritizing strategies to improve this partnership	SAW, DEMATEL
Chen and Tzeng [453]	Ranking different publishers to print textbooks in elementary schools in China	DEMATEL, VIKOR
Cooper and Dong [454]	Prioritizing policies to improve China-US relations	BOCR
Crowe and Lucas-Vergona [455]	Ranking illegal immigration strategies	–
García-Melón et al. [18]	Evaluating Farmland appraisal in the municipality of Carlet	–
Gürbüz and Albayrak [456]	Evaluating the staff performance in the pharmaceutical industry	CI
Hsu [457]	Evaluating and selecting best media agencies to advertise new products	DM, GRA
Hu [458]	Investigating core competencies in innovative culinary development	Delphi
Hua Chen et al. [459]	Selecting an appropriate partner enterprise to implement vocational education systems	
Ismayilova et al. [460]	Planning classes, training courses and teaching time in Turkish schools	SM, ZOLP, Compared by AHP
Lin et al. [461]	Evaluating sustainable development programs in technological and vocational higher education	BSC, FDM, FST
Ölçer and Akyol [462]	Assessing the performance of countries in terms of international agreements	DEMATEL
Partovi and Corredoira [463]	Providing a model to change the rules of football to make it more attractive	QFD, AHP
Sagir and Ozturk [464]	Choosing caregivers to hold exams	–
Simunich [465]	Investigating the Iraq-United States war and selecting a better strategy to confront Iraq	BOCR
Tafreshi et al. [466]	Evaluating advertising media	DEMATEL, VIKOR
Tang et al. [467]	Identifying factors affecting the successful implementation of English language training programs for specialists in the MICE industry	DM, DEMATEL
Tavana et al. [468]	Evaluating the performance of publicly held companies in the pharmaceutical industry	BSC, DEEMATEL, FANP, FDEA, Shannon's entropy
Tavana et al. [469]	Evaluating e-government readiness	FANP, TOPSIS
Tseng et al. [470]	Evaluating the effectiveness of teaching or learning in an e-learning system in Taiwanese universities	FST
Villanueva et al. [471]	Determining factors influencing the production of olive	–
Wang et al Zeng [472]	Selecting and reconstructing a monument to reuse	FDM
Wu et al. [473]	Evaluating the performance of extension education centers	BSC, DEMATEL, VIKOR

6.1. Theoretical dimension

- There is a link between the number of pricewise comparisons and inconsistency rate. However, in ANP, the consistency threshold that should be provided for different amount of pricewise comparisons is 0.1. It appears that instead of 0.1, a matrix of thresholds for various comparisons should be used, which is suggested for future research.
- Although the inconsistency rate in the fuzzy environment is more than that in the crisp environment, no research has been carried out so far to improve the inconsistency rate of pricewise comparisons provided by FANP.
- In none of the reviewed studies conducted by ANP in fuzzy environments, the performance of membership functions compared to fuzzy numbers was investigated, which can be an interesting topic for future research.
- Particular versions of the ANP software such as Super Decisions and Expert Choice were not developed for calculating the weight of criteria in either hybrid mode or improved versions. Therefore, development of such types of software, in line with the proposed approaches, can have a great impact on evaluating the weight of criteria.
- ANP is sensitive to a number of criteria. As the number of criteria increases, the dimensions of the super matrices increase, which lead to the extension and/or impossibility of the process of resolution. Therefore, it is recommended to use methods to reduce the number of influencing factors in decision making as a complement to the ANP method in future research.

6.2. Practical dimension

- With regard to the studies conducted using ANP, it can be concluded that issues such as supply chain performance evaluation, assembly, human resources optimized allocation, risk assessment, energy system performance assessment, outsourcing, ranking effective factors on customer satisfaction and competitive advantage as well as issues relevant to the field of agriculture and medicine were ignored, which can be suggested for further research.

Table 19
Distribution of techniques combined or compared with ANP.

Techniques combined or compared	Business and Financial Management	Health, safety and environment management	Hydrology and Water Management	Logistics and Transportation	Design, Engineering and Manufacturing Systems	Energy Management	Human Resources Management	Tourism	Other topics	Total	%
FANP	19	13	2	22	31	4	1	1	3	96	18.15
DEMATEL	22	7	1	16	7	2		5	8	68	12.86
AHP	8	3	1	3	7	4			2	28	5.3
TOPSIS	4	1	2	7	6		3		1	24	4.54
VIKOR	11	2		2	1			4	2	22	4.16
QFD		2		1	11				1	15	2.84
FDEMATEL	3	4	1	3	2	1				14	2.65
FDM	3	2		1	3		1	2	2	14	2.65
BSC	6			2	2				1	11	2.08
BOCR	3	1		3	3			1	2	13	2.46
DM	2	1		2	2				1	8	1.52
FST	2	4			3	2			1	12	2.27
FTOPSIS		3	1	1	2		1			8	1.52
ISM	2			2	3			1		8	1.52
GP	3	1		1	3					8	1.52
DEA	2	3			1					6	1.14
ZOGP	3			2	1					6	1.14
PROMETHEE		1		1	3					5	0.95
FPP	1			3				1		5	0.95
FT	1					1				2	0.38
FQFD					4					4	0.76
SWOT	2	1				1				4	0.76
FL	1	2								3	0.57
PCA	1				2					3	0.57
GIS		2		1						3	0.57
ANN		1			2					3	0.57
GRA		1		1	1				1	4	0.76
FVIKOR	2		1	1						4	0.76
PROMETHEE II			1	1	1					3	0.57
NRM	2				1					3	0.57
CI				2	1				1	4	0.76
FAHP	1			1					1	3	0.57
FISM	1				1					2	0.38
FMMSM			2							2	0.38
MOMILP				2						2	0.38
SAW					1				1	2	0.38
DNP*	1									1	0.19
DNP				1						1	0.19
HFACS		2								2	0.38
COPRASG	1				1					2	0.38
COPRAS		1								1	0.19
FMEA		2								2	0.38
Other techniques combined or compared	33	15	2	23	12	5	4	0	4	98	18.53

Table 20
Distribution by publication journal.

Journal	Number	%
Expert Systems with Applications	87	19.08
Computers & Industrial Engineering	27	5.92
International Journal of Production Research	24	5.26
International Journal of Production Economics	23	5.04
The Int. J. Adv. Manuf. Technol.	17	3.73
Journal of Cleaner Production	16	3.51
Applied Soft Computing	14	3.07
Journal of Intelligent & Fuzzy Systems	11	2.41
Mathematical and Computer Modelling	11	2.41
Journal of Intelligent Manufacturing	10	2.19
Safety science	10	2.19
European Journal of Operational Research	8	1.75
Applied mathematical modelling	7	1.54
IEEE Transactions on Engineering Management	7	1.54
Information Sciences	7	1.54
International Journal of Computer Integrated Manufacturing	7	1.54
International Journal of Project Management	7	1.54
Knowledge-Based Systems	7	1.54
Quality & Quantity	7	1.54
Journal of Environmental Management	6	1.32
International Journal of Hospitality Management	5	1.10
Journal of Systems Science and Systems Engineering	5	1.10
Production Planning & Control	5	1.10
Supply Chain Management: An International Journal	5	1.10
Technological Forecasting and Social Change	5	1.10
Tourism Management	5	1.10
Waste management	5	1.10
Water resources management	5	1.10
Journal of Air Transport Management	5	1.10
Automation in construction	4	0.88
Computers in Industry	4	0.88
Annals of Operations Research	3	0.66
Computers & Mathematics with Applications	3	0.66
Energy Procedia	3	0.66
Evaluation and Program Planning	3	0.66
Group Decision and Negotiation	3	0.66
Industrial Management & Data Systems	3	0.66
International Journal of Intelligent Systems	3	0.66
International Journal of Strategic Property Management	3	0.66
Journal of Business Economics and Management	3	0.66
Land Use Policy,	3	0.66
conservation and recycling	2	0.44
Current Issues in Tourism	2	0.44
Energy Policy	2	0.44
Environmental Modelling & Software	2	0.44
Fuzzy Optimization and Decision Making	2	0.44
Human Factors and Ergonomics in Manufacturing & Service Industries	2	0.44
Informatica	2	0.44
Information & Management	2	0.44
International Journal of Operations & Production Management	2	0.44
International Transactions in Operational Research	2	0.44
Journal of Air Transport Management	2	0.44
Journal of Global Optimization	2	0.44
Omega	2	0.44
Renewable Energy	2	0.44
Soft Computing	2	0.44
The Journal of The Textile Institute	2	0.44
Tourism Management Perspectives	2	0.44
Others	26	5.70
Total	456	100.00

- Although this research attempted to cover a large part of the articles conducted by ANP, a comprehensive database of articles using ANP as a methodology can facilitate the easy access to such articles.
- So far, several studies have attempted to develop the ANP method and enhance the utility of this method. These studies were presented aiming at reducing the inconsistency rate [474–476], increasing the decision-making accuracy [477–479], improving outcomes in ambiguity conditions [480] and improving decision-making problems with large data [481]. Hence, it is suggested to use the developed ANP versions with these methods presented in the articles.

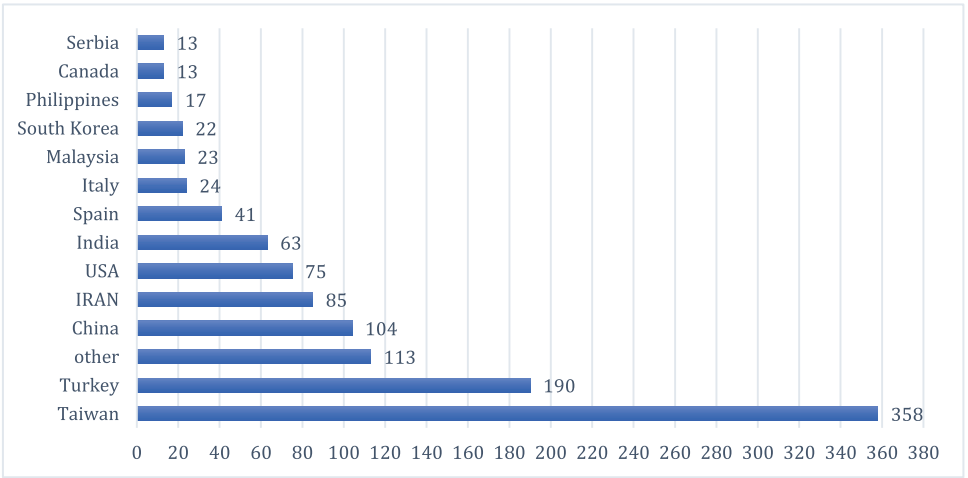

Fig. 4. Distribution by country.

7. Conclusion

This study aimed at comprehensively reviewing studies employing ANP as a methodology. To this end, 456 papers from 63 journals were reviewed from 2000 to 2017 and categorized into nine application topics. Furthermore, the reviewed papers were also classified by authors' nationality, publication year, publication journal, and other methods used either in combination or in comparison with ANP. Overall, it was found that the application of ANP as a methodology is far more in *business and financial management* compared to the other eight areas, and that more emphasis is required on studies classified into the *hydrology and water management* category.

Although this research did not include conference proceeding papers, master's theses, doctoral dissertations, book chapters and non-English articles, the papers reviewed provided an invaluable source of information for researchers and professionals in the field of MCDM, and in particular ANP.

Appendix

Table A1

Table A1
The abbreviation presented in this paper.

Abbreviation	Explanation
2TL-ANP	2-Tuple Linguistic Analytic Network Process
4P	Product, Price, Promotion, Place
ABC	Always Best Connected
AcciMapp	Accident Analyze Mapping
AGP	Archimedean Goal Programming
AHP	Analytical Hierarchy Process
ANN	Artificial Neural Network
ANP	Analysis Network Process
ARM	Association Rule Mining
ATHEANA	A Technique for Human Event Analysis
AUGMECON	AUGMEnted CONstraint
BCR	Benefits, Costs and Risks
BOCR	Benefits, Opportunities, Costs and Risks
BSC	Balanced Scorecard
CA	Conjoint Analysis
CFPR	Consistent Fuzzy Preference Relations
CI	Choquet Integral
COPRAS	COmplex PRoportional Assessment
COPRASG	COmplex PRoportional ASsessment with Grey relations
CP	Constraint Programming
CRM	Customer Relation Management
CREAM	Cognitive Reliability Error and Analysis Method

(*continued on next page*)

Table A1 (*continued*)

Abbreviation	Explanation
DEA	Data Envelopment Analysis
DEMATEL	Decision Making Trial and Evaluation Laboratory
DLC	Diagram Loop Causal
DMA	Digraph and Matrix Approach
DNP	De Novo Programming
DNP*	Dynamic Network Process
DRSA	Dominance based Rough Set Approach
DSS	Decision Support System
DST	Dempster Shafer Theory
EFA	Exploratory Factor Analysis
EIA	Environmental Impact Assessment
ELA	Evaluation Laboratory Approach
ELECTRE	Elimination et Choice in Translating to Reality
EQUIP	Extended Quadratic Interior Point
ER	Evidential Reasoning
ERP	Enterprise resource planning
EV	Engineering Value
FAD	Fuzzy Axiomatic Design
FAHP	Fuzzy Analytical Hierarchy Process
FANP	Fuzzy Analytical Network Process
FCANP	Fuzzy Cybernetic Analytic Network Process
FCOPRAS	Fuzzy COmplex PRoportional Assessment
FDEA	Fuzzy Data Envelopment Analysis
FDEMATEL	Fuzzy Decision-Making Trial and Evaluation Laboratory
FDM	Fuzzy Delphi Method
FDMS	Fuzzy Decision-Making System
FELECTRE II	Fuzzy Elimination et Choice in Translating to Reality II
FELECTRE III	Fuzzy Elimination et Choice in Translating to Reality III
FFMEA	Fuzzy Failure Mode and Effective Analysis
FGP	Fuzzy Goal Programming
FI	Fuzzy integral
FIS	Fuzzy Inference System
FISM	Fuzzy Interpretive Structural Modelling
FL	Fuzzy Logic
FLP	Fuzzy Linear Programming
FLQMEOWA	Fuzzy Linguistic Quantifiers-guided Maximum Entropy Order Weighted Averaging
FMEA	Failure Mode and Effective Analysis
FMMSM	Fuzzy Max-Min Set Method
FMOLP	Fuzzy Multi Objective Linear Programming
FPP	Fuzzy Preference Programming
FQFD	Fuzzy Quality Function Deployment
FSEU	Fuzzy Synthetic Evaluation Under
FST	Fuzzy Set Theory
FTOPSIS	Fuzzy Technique for Order of Preference by Similarity to Ideal Solution
FVIKOR	Fuzzy VIsekriterijumsko KOmpromisno Rangiranje
GCE	Game Cross Evaluation
GIS	Geographic Information System
GL	Goal Programing
GRA	Grey Relational Analysis
GST	Grey System Theory
HFACS	Human Factor Analysis and Classification System
HFACS-RAs	Human Factor Analysis and Classification System -Railway Accidents
HRA	Human Reliability Analysis
INRM	Influential Network Relations Map
IPA	Importance Performance Analysis
IRM	Impact Relations Map
ISM	Interpretive Structural Modelling
LCA	Life Cycle Assessment
LP	Linear Programming
LPPAM	Linguistic Possibility-Probability Aggregation Model
MABAC	Multi Attributive Border Approximation Area Comparison
MADM	Multi-Attribute Decision Making
MAH	Maximise Agreement Heuristic
MCDM	Multi Criteria Decition Making
MEC	means-end chain
MG	Model Gordon
MGP	Minmax Goal Programming
MGRT	Modified Grey Relation Theory

(*continued on next page*)

Table A1 (*continued*)

Abbreviation	Explanation
MICE	Meetings, Incentives, Conferences and Events
MILP	Mixed Integer Linear Programming
MIMOP	Mixed Integer Multi-Objective Programming
MINLP	Mixed-Integer Non-Linear Programming
MIP	Mix Integer Programming
MMT	Modigliani Miller Theorem
MODM	Multi Objective Decision Making
MOGA	Multi Objective Genetic Algorithm
MOMILP	Multi Objective Mixed Integer Linear Programming
MOMP	Multi Objective Mathematical Programming method
MOORA	Multi-Objective Optimization on the basis of Ratio Analysis
MOP	Multi Objective Programing
MP	Markov Process
NGT	Nominal Group Technique
NLP	Non-Linear Programming
NRM	Network Relation Map
NT	Niche Theory
OHSAS	Occupational Health and Safety Assessment Series
PAM	Process Analysis Method
PCA	Principal Component Analysis
PFIGP	Preemptive Fuzzy Integer Goal Programming
PM	Porter Model
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
PVC	Poly Vinyle Choloride
QFD	Quality Function Deployment
QFDE	Quality Function Deployment for Environment
R&D	Research and development
RBF-ANN	Radial Basis Function Artificial Neural Networks
RST	Rough Set Theory
SAT	Significance Acceptability Transformation
SAW	Simple Additive Weighting
SBSC	Sustainability Balanced Scorecard
SD	System Dynamics
SDEA	Super efficiency Data Envelopment Analysis
SEM	Structural Equation Modelling
SERVQUAL	SERvice QUALity
SICI	State of Industry Competition Index
SM	Scalarization Method
SMEs	Small and Medium Enterprises
SNA	Social Network Analysis
SSWOT	Sustainability Strengths, Weaknesses, Opportunities, Threats
SWOT	Strengths, Weaknesses, Opportunities, Threats
TDBU	Top Down and Bottom Up
TDM	Two-Dimensional Matrix
TFN-ANP	Triangular Fuzzy Number and Analytic Network Process model
TOM	Transshipment Optimization Model
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TQM	Total Quality Management
TRIZ	Teoriya Resheniya Izobrototelskikh Zadatch
UIT	Utility Interval Technique
VIKOR	VIsekriterijumsko KOmpromisno Rangiranje
VSM	Value Stream Mapping
WA	Warshall Algorithm
WLC	Weighted Linear Combination
WSN	Wireless Sensor Network
WVA	Weight Variance Analysis
ZOGP	Zero-One Goal Programing
ZOLP	Zero-One Liner Programming

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