



REVIEW

Analytic Network Process (ANP) Method: A Comprehensive Review of Applications, Advantages, and Limitations

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Abstract: Nowadays, multi-criteria decision-making (MCDM) methods possess manifold applications in many areas from engineering to supply chain and management. The analytic network process (ANP) method is one of the most widely used MCDM methods. ANP is an extended version of the analytic hierarchy process that enables feedback and interactions between and within clusters, making it a more comprehensive decision-making tool. This paper provides a detailed review of the ANP method, including its concept, process steps, application areas, advantages, and limitations. ANP has been applied to a wide range of decision-making problems, including project management, risk assessment, supplier selection, and product design. ANP's main advantages include its ability to handle complex decision-making problems with multiple criteria, subjective inputs, and interdependent relationships among criteria. This paper aims to provide a comprehensive understanding of the ANP method to help researchers and practitioners make more informed decisions when using this technique.

Keywords: decision-making, multi-criteria decision-making, analytic network process, ANP method, multi-attribute decision-making

1. Introduction

The decision-making processes of organizations have been greatly influenced as a result of the huge growth in the complexity of the choices that firms need to make to survive and accomplish their competitive goals (Dias & Mousseau, 2018). The typical setting in which decision-makers find themselves in the position of having to make selections is one in which several different companies have articulated several different goals, each of which then explodes into several different criteria and options (Toloie-Eshlaghy & Homayonfar, 2011). As a result, the procedure for selecting decision-makers has developed into a more explicit form. In this setting, the decision-maker is no longer able to depend just on an approximation or intuition of an analysis of the options; rather, they are required to search for new techniques and methodologies that assist and support them in the process of decision-making (Greco et al., 2016).

During the 1980s, there has been growing concern for the environment, which resulted in a shift in the structure of decision-making regarding individual criteria (Taherdoost & Brard, 2019;

Wang et al., 2009). As a result, environmental preservation takes into account a wider range of considerations than just economic ones, compelling decision-makers to use techniques of multi-criteria decision making (MCDM) to find workable solutions to energy issues (Büyükoğuzkan et al., 2018).

MCDM methods are being used recently by researchers in different fields of study such as finance, business, science, and engineering. These methods are utilized to evaluate, sort, rank, and select between different alternatives (Kheybari et al., 2020). Numerous MCDM methods have been developed, and even small variations compared to existing methods have made the application of MCDM in different areas possible (Velasquez & Hester, 2013).

One of the main MCDM techniques is the analytic network process (ANP) method. ANP is a new, broader, and deeper form of the analytic hierarchy process (AHP) method developed by Saaty (1980). AHP is a comprehensive method that can cope with a vast range of multi-objective, multi-actor, and multi-criteria problems, even for uncertain decisions with different numbers of alternatives (Bayazit, 2002; Velasquez & Hester, 2013). Although AHP addresses many deficiencies of some other MCDM techniques, it does not consider possible dependencies among different elements and assumes the factors independently. This assumption is not appropriate in some internal and external environmental effects. These problems must be based on network

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systems with functional dependencies allowing for feedback among the clusters and high-level factors dependent on low-level ones (Yüksel & Dagdeviren, 2007).

To solve this, Saaty (1996) extended AHP as the ANP method in a book in 1996, which was revised in 2001. ANP can be used in very sophisticated MCDM problems by allowing feedback and interactions both between and within the clusters. Therefore, ANP makes dealing systematically with feedback and dependence in decision-making systems possible. It is a more general form of AHP that considers interactions, making the complex interrelationships among attributes and different levels of decision-making possible.

In ANP, linear top-to-bottom hierarchy structures are replaced with a feedback approach. Unlike the hierarchy where only criteria influence the alternatives' importance, in ANP, the importance of alternatives can also impact the criteria's importance. Therefore, representing relationships between levels easily with concepts such as higher/lower, direct/indirect, and dominant/subordinate is not possible (Yüksel & Dagdeviren, 2007). The ANP includes two parts:

- The first part is control hierarchy or network of criteria, and also sub-criteria aiming to control the understudy system's interactions;
- The second part is a network of influences among the clusters and elements.

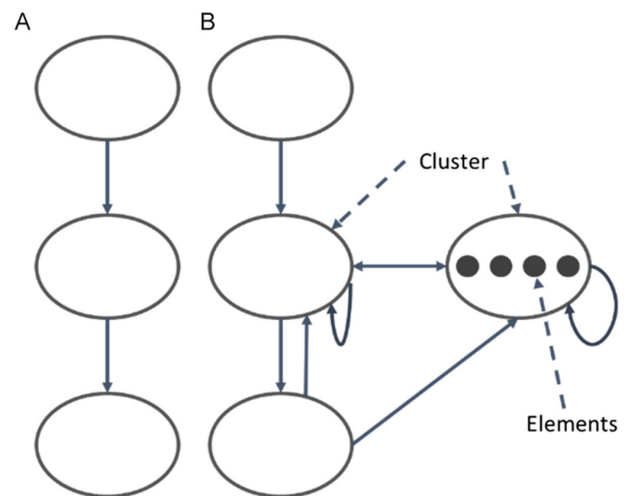
In the revised ANP method in 2001, decision problems are studied through a control hierarchy/network for benefits, as well as a second one for opportunities, a third one for costs, and another for risks (BOCR). In this method, a decision possesses links, clusters, and elements. The clusters are a series of relevant elements (within a network/sub-network). The system's clusters and their elements are calculated for each control criterion, including opportunities, benefits, risks, and costs.

Another important concept in these systems is inner and outer dependencies that are related to all of the feedback and interactions within and between clusters, respectively. These concepts help to represent and capture the concepts of influencing and being influenced between both clusters and elements related to a criterion in the decision-making process (Bayazit, 2002; Saaty & Vargas, 2013). To sum up, in ANP, a network is used to represent a system with feedback. The differences between the network system in ANP and the hierarchy structure in the AHP method are shown simply in Figure 1. It can be seen that in a network, the elements of a cluster can impact all or just some of the elements in any other cluster. A network includes sources, intermediates, and clusters, and arcs are used to show the relationships in the network. The arcs' directions impact the directional dependence here. Two-way arrows and looped arcs are also used to show the outer (between two clusters) and inner (among elements of a cluster) dependencies, respectively (Yüksel & Dagdeviren, 2007).

Nowadays, the ANP method is widely utilized to address manifold issues in the real world as it considers interrelated and complex relationships between the elements of decision-making problems. This method also can apply simultaneously both qualitative and quantitative attributes (Kheybari et al., 2020).

The purpose of this paper is to present an extensive examination of the ANP technique, which encompasses its fundamental concept, process steps, application domains, benefits, and drawbacks. The ANP methodology has found broad application in decision-making predicaments such as project management, risk assessment, supplier selection, and product design. One of ANP's

Figure 1
Structures of (A) a hierarchy and (B) a network



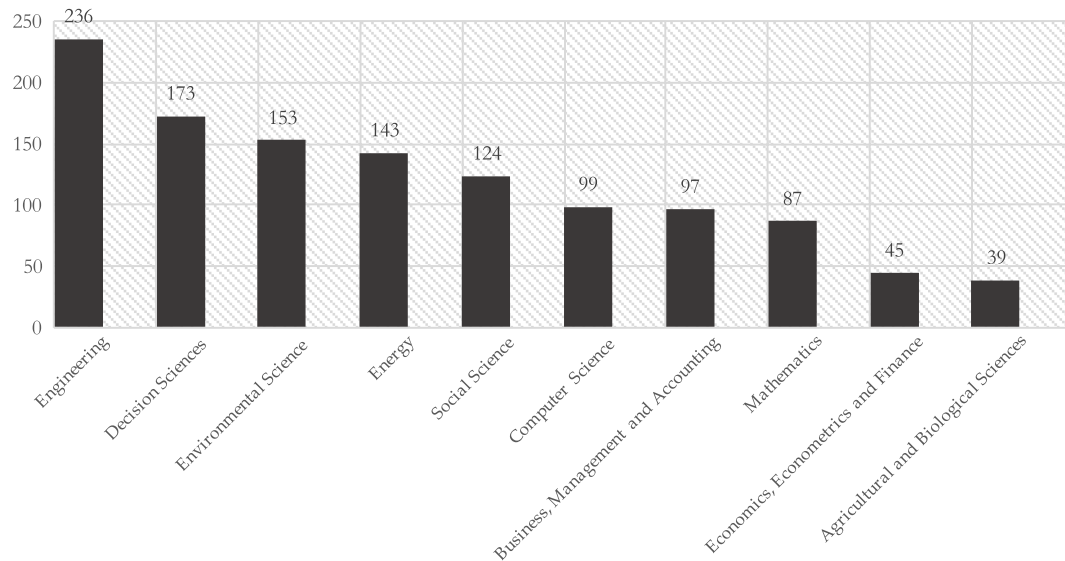
key strengths is its ability to manage complicated decision-making situations involving multiple criteria, subjective input, and interdependent relationships among criteria. The objective of this paper is to offer a comprehensive comprehension of the ANP approach that can help researchers and practitioners make better-informed decisions when utilizing this technique.

2. Applications for ANP

Making choices is necessary for most human activities. Every one of these decisions is grounded in an analysis of the various individual decision options, which is typically determined by the preferences, experience, and other information held by the decision-maker (Salabun et al., 2020). Some decisions are straightforward, while others are more involved (Behzadian et al., 2012). According to Govindan and Jepsen (2016) and Kahraman et al. (2015), some choices are relatively simple, particularly if the repercussions of making the wrong decision are relatively minor, whereas other decisions are extremely complex and have significant effects. Real-life problem-solving typically involves several competing viewpoints that, to arrive at a reasonable decision, need to be taken into consideration (Wang et al., 2008). Formally speaking, a decision may be described as either a choice that is made based on the information that is available or a course of action that is targeted at addressing a particular decision issue (Greco et al., 2016).

From finance and economics to engineering design and medicine, MCDM has many applications across several fields. Owing to the complexity of the health and socioeconomic systems and the multidimensionality of this crisis, MCDM techniques have been more often used to simulate COVID-19 issues. It should be highlighted that MCDM strategies have a direct impact on finding sustainable solutions. This highlights the value and explosive expansion of MCDM approaches. MCDM techniques are used in several industries, ranging from the energy sector to the business. Several study areas, including those in computer science, energy, mathematics, etc., utilize MCDM techniques (Taherdoost & Madanchian, 2023). Similarly, the ANP method possesses various application areas. This method can be used in manifold fields such as engineering, manufacturing, civil works, economics,

Figure 2
Subjects areas of ANP research articles



construction, agriculture, finance, healthcare, waste management, and supply chain management (Chen et al., 2019; Khan & Ali, 2020).

To gain a better and more general understanding of the ANP application areas, Figure 2 shows the number of articles that used the ANP method in different subject areas in the “ScienceDirect” database as of May 21, 2022. The research articles were found based on the search term “ANALYTIC NETWORK PROCESS” in the title, abstract, or author-specified keywords. The subject areas for the achieved results are shown in the figure. The results indicate the broad applicability of the ANP in various subject areas, such as engineering, decision-making, and environmental science.

Kheybari et al. (2020) reviewed the areas of application of the ANP method more specifically using nine different categories. Some of the results are listed here in Table 1 to gain an overview of the application of this method in different fields. It must be noted that in some of the studies the ANP is applied as a single method, and in some others, integrated/hybrid approaches are used based on ANP with other MCDM techniques such as the technique for order of preference by similarity to ideal solution (TOPSIS), decision-making trial and evaluation laboratory (DEMATEL), etc.

3. Advantages and Disadvantages

The ANP is a general form of the AHP method that is concerned with a networked-structure format. As can be seen in other MCDM methods, the ANP also possesses different advantages and disadvantages. The main ones are summarized in Table 2.

4. ANP Method Procedure

The ANP method procedure includes four main steps. These steps are shown in Figure 3 and are also discussed in this section in detail.

Step 1: Constructing the Model and Structuring the Problem

In this step, the model is constructed, and the problem is structured. For this, the decision-maker should state the problem clearly and decompose it into a rational system as a network.

The decision-makers can gain the structure of the problem network by using different ways such as brainstorming.

Step 2: Preparing the Pairwise Comparison Matrices and Priority Vectors

In the second step, priority vectors and pairwise comparison matrices should be prepared. To accomplish this, a comparison must be performed between pairs of elements in each cluster by considering the importance of elements toward their control criteria. This step is similar to the AHP comparison step. Furthermore, the clusters also need to be compared pairwise by considering their contributions to the objective. Therefore, this step includes responding to pairwise comparison series (between two clusters or two elements) that should be assessed by considering their contribution to the specific criteria of their upper level. Additionally, other pairwise examinations are also necessary in terms of interdependencies among a cluster’s elements. An eigenvector is used to represent the impact of each element on the other.

The fundamental AHP comparison scale (1–9) can also be used in the ANP method to help decision-makers identify how many times an element dominates another one and determine the relative importance values by considering the related criterion. It can also be used to incorporate the knowledge and experience of decision-makers in an intuitive way. This scale uses absolute numbers instead of ratio, interval, or ordinal ones (Bayazit, 2002). In this method, the descriptive preferences of decision-makers can be translated into numerical values. For example, in this table, 1 is used for equal importance of the elements, and 9 represents the extreme importance of one element in the matrix, where the element is the row cluster in comparison with another one that is the column cluster in the matrix. Table 3 shows the 1–9 scale used in this method.

Another point is that, for inverse comparison, a reciprocal value is determined. For this, $a_{ij} = \frac{1}{a_{ji}}$ is used. In this equation, the a_{ij} factor represents the importance of the i th element, and a_{ji} represents the importance of the j th element. In the ANP method (similar to the AHP), a matrix is used to show the pairwise comparisons. A local

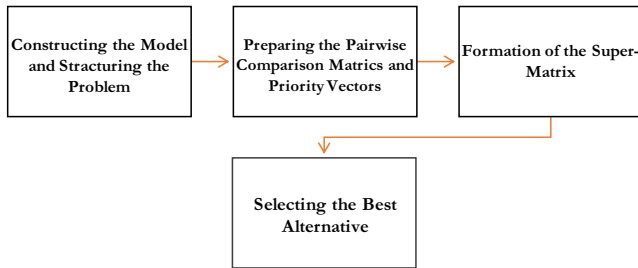
Table 1
ANP method application areas (Kheybari et al., 2020)

No.	Category	Examples of specific areas	Description
1	Health, safety, and environmental management	<ul style="list-style-type: none"> Assessing safety management in airlines, maritime industry, and construction industry; Selecting the best place for waste disposal; Selecting the best method for recycling wastes Etc. 	Articles in the fields of waste management life cycle management, environmental impact assessment, and land-use planning
2	Hydrology and water management	<ul style="list-style-type: none"> Evaluating and prioritizing watershed plans; Vulnerability assessment of water supply systems; Etc. 	Articles based on water management strategy assessment, irrigation planning, and sustainable water resource planning fields
3	Business and financial management	<ul style="list-style-type: none"> Assessing performance of airlines, research, and development (R&D) projects, hospital services, banking industry; Selecting information system, R&D, and power projects; Ranking mining strategies; Evaluating information security risks; Assessing industrial lands in urban areas; Studying the factors impacting the economic performance of businesses; Etc. 	Articles in the main aspects of management, for example, measurement of performance, analysis of investments, portfolio management, etc.
4	Tourism	<ul style="list-style-type: none"> Investigating the factors impacting the medical tourism development; Assessing ecotourism sites Assessing and ranking the national park websites; Etc. 	Articles related to tourism and hotel related to tourism, pilgrimage, and medicine, policies related to tourism and hotel industries, etc.
5	Logistics and supply chain management	<ul style="list-style-type: none"> Select suppliers in different industries such as the automotive industry, electronic companies, and manufacturing companies 	Related to the location problems, outsourcing and supplier selection in various fields
6	Design, engineering, and manufacturing systems	<ul style="list-style-type: none"> Prioritizing and ranking the requirements for design in companies; Investigating the most vital product components at the design stage by considering the resource constraints in manufacturing companies; Etc. 	Related to automation, material engineering, product design, modern manufacturing systems, etc.
7	Energy management	<ul style="list-style-type: none"> Selecting a strategy for risk reduction in the energy industry; Studying the important factors to determine the location of power plants; Etc. 	Related to assessment and selection of the methods of energy generation, the energy systems' performance assessment, etc.
8	Human resources management	<ul style="list-style-type: none"> Selecting snipers and personnel for different companies 	Related to the employment of candidates
9	Other topics	<ul style="list-style-type: none"> Assessing the innovation support systems performance in different sectors such as higher education institutions; Ranking the systems used for performance improvement in universities; Etc. 	Related to areas such as medicine, sports, education, agriculture, and government

Table 2
Merits and demerits of the ANP method (Aruldoss et al., 2013; Velasquez & Hester, 2013)

Advantages	Disadvantages
<ul style="list-style-type: none"> Handling multiple inputs and outputs; No need for relations between outputs and inputs; Possibility of different units for inputs and outputs; Directly comparisons against peers; Both allowing for dependence and including independence; The ability to prioritize clusters/groups of elements; Supporting complex problems with intangible criteria better than AHP. 	<ul style="list-style-type: none"> Ignoring different effects among clusters; Possibility of significant problems due to the measurement error; Being demanding in the case of large problems; Disability to measure absolute efficiency; Inapplicability of statistical tests

Figure 3
The main steps of the ANP method



priority vector is extracted to determine the relative importance of clusters/elements using equation 1:

$$A = \lambda_{max} \times \omega \tag{1}$$

A , ω , and λ_{max} are the pairwise comparison matrix, eigenvector, and largest eigenvalue of the pairwise comparison matrix, respectively. Manifold algorithms are suggested to determine ω by Saaty (1980).

Step 3: Formation of the Super-matrix

In this step, the super-matrix must be formed which possesses a similar concept to the Markov chain process. For this, the local priority vectors should be entered in a suitable column to gain the global priorities by considering that the system includes interdependent influences. Therefore, this matrix acts like a partitioned matrix. That is to say, the relationship between two clusters is represented by each segment of the matrix.

To shape a super-matrix, the local priority vectors from Step 2 are used. They must be grouped and then placed in a suitable place in the super-matrix. This position is based on the influence flows that can be obtained from two different situations including a cluster to another one, and also a loop that is from a cluster to itself. A super-matrix is shown in equation (2) (Yüksel & Dagdeviren, 2007).

$$W = \begin{matrix} & \begin{matrix} c_1 & & c_k & & c_n \end{matrix} \\ \begin{matrix} e_{11} & e_{12} & \dots & e_{1\ m1} \\ \vdots & \vdots & & \vdots \\ e_{k1} & e_{k2} & \dots & e_{k\ mk} \\ \vdots & \vdots & & \vdots \\ e_{n1} & e_{n2} & \dots & e_{n\ mn} \end{matrix} & \begin{bmatrix} w_{11} & \dots & w_{1k} & \dots & w_{1n} \\ \vdots & \dots & \vdots & \dots & \vdots \\ w_{k1} & & w_{kk} & & w_{kn} \\ \vdots & & \vdots & & \vdots \\ w_{n1} & & w_{nk} & & w_{nn} \end{bmatrix} \end{matrix} \tag{2}$$

As is shown in equation (2), in the super-matrix, C_k represents the clusters ($k = 1, 2, \dots, n$), and each cluster (k) possesses m_k elements. These elements are shown as $e_{k1}, e_{k2}, e_{k3}, \dots, e_{k\ mk}$. When the elements have no influence, zero entries are used in the related positions in the matrix. Consider a three-level network structure shown in Figure 4 as an example with goal, criterion, and alternatives. The super-matrix for this problem can be shown as equation (3).

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

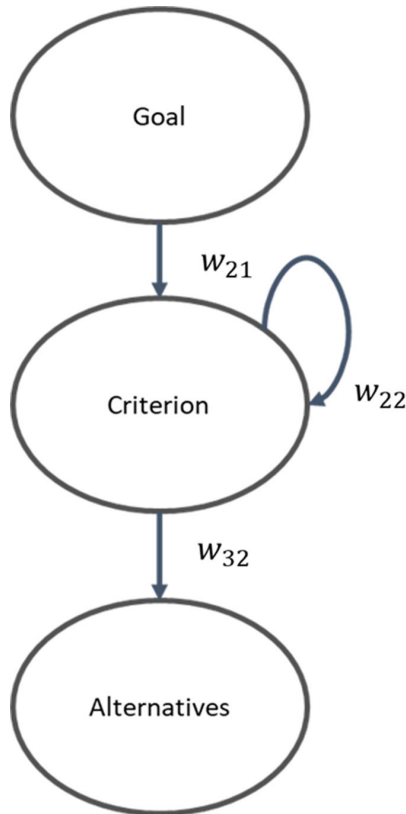
I is the unit matrix, and if instead a network, the structure was a hierarchy, then w_{22} must be considered zero. It must be also noted that it is possible to replace a zero value by a matrix in the situation that an interrelationship of the elements between two clusters/within a cluster is identified. This matrix is called primary super-matrix that is unweighted, and just the vectors of internal priorities, matrices, and elements are replaced in it.

Then the primary super-matrix should be weighted. For this, the un-weighted super-matrix values are multiplied in the cluster matrix to compute a weighted matrix that is stochastic. Finally, in this step, a new limit super-matrix should be examined to obtain the elements'

Table 3
The fundamental 1–9 Scale (Saaty, 1996)

Intensity of importance	Explanation	Definition
1	Two activities contribute equally to the objective	Equal importance
3	Experience and judgment slightly favor one over another	Moderate importance
5	Experience and judgment strongly favor one over another	Strong importance
7	Activity is strongly favored, and its dominance is demonstrated in practice	Very strong importance
9	The highest possible order for the importance of one factor over another one is considered	Absolute importance
2, 4, 6, 8	Compromising between the above priorities	Intermediate values

Figure 4
A three level network structure (Yüksel & Dagdeviren, 2007)



relative influences on each other in a long-term way. For this, it is recommended to raise the former matrix to exponential powers. Different values are suggested for this purpose (k, 2k + 1, etc.). For example, the following equation (4) can be used to bring all the elements of the weighted super-matrix noting that the operations continue until all elements of the super-matrix are identical.

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

Then, all elements' final priorities are gained by normalizing each cluster of the final matrix obtained. Furthermore, where the number of elements is relatively few, they can be estimated by using matrix operations.

Step 4: Selecting the Best Alternative

Finally, the best alternative is selected. For this, in the situation that the final matrix (from Step 3) covers the whole network, the alternatives' column in the normalized super-matrix is used to find priority weights, and the alternative with the highest weight is the best choice. But, if a super-matrix only comprises interrelated clusters, then overall priorities should be calculated requiring some additional calculations, and then the best option can be selected (Görener, 2012; Kheybari et al., 2020; Piantanakulchai, 2005; Yüksel & Dagdeviren, 2007).

5. Conclusion

In conclusion, the ANP method is a versatile and widely applicable MCDM method that offers a range of advantages over other similar methods, such as AHP. This paper aimed to provide a comprehensive survey of the ANP method, outlining its key features and benefits. By reviewing the application areas and providing some research examples, we demonstrated the potential of the ANP method in a variety of fields. Moreover, we discussed the advantages and disadvantages of the method, highlighting its strengths, such as its ability to make direct comparisons against peers, and its limitations, such as the inability to measure absolute efficiency.

The ANP method comprises four main steps, which were clearly defined in this paper. These steps include the structuring of the problem, the construction of the network, the synthesis of priorities, and the sensitivity analysis. Each of these steps plays a critical role in the ANP method and must be carefully considered to ensure accurate and reliable results.

Overall, the ANP method offers a powerful and flexible approach to MCDM that has the potential to significantly improve decision-making processes in a wide range of fields. As such, it represents an important tool for researchers and practitioners seeking to enhance their ability to make informed and effective decisions in complex and uncertain environments.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

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