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A Multi-Criteria Decision-Making Approach for Optimizing Sustainable Supplier Selection Using Analytical Network Process (ANP)

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Abstract:

Sustainable supplier selection is an essential part of the decision-making process in sustainable supply chains. This choice is focusing on social, economic, and environmental criteria in evaluation of suppliers. Sustainable supplier selection approaches have used both qualitative and quantitative data. Therefore, it is meaningful to use scientific methods that treatment both quantitative and qualitative data, as well as multiple criteria.

Analytical network process (ANP) is a one of the important multi-criteria decisions –making approaches. Also, the ANP technique is a general form that allows possible independency among criteria factors. This paper aims to select the best suppliers using an (ANP) approach which helps decision-makers to reach the best strategy with correct decisions. Using ANP each criterion has its assign weight, which reflects its importance for the process of comparison between alternatives to suppliers. The presented approach consists of the three main steps: the first step is to identify the criteria used in the comparison process between suppliers, the second step is to identify the decision matrix using AHP and the third step is to construct the super matrix and limiting super matrix and compare between the alternatives, and rank them from the best to the worst through using ANP. This work has used the data as in [30] which represents data for a company that has four suppliers and five criteria. The results show that the best supplier is supplier 2, which has weight equal to 39%. Also, our results are matching the AHP result that is presented in [30]. Moreover, this work can be extended for future work using fuzzy environment and real application such as Iraqi oil companies.

Keyword: Decision making, Sustainable Supplier Selection, AHP, ANP.

1. Introduction

Many qualitative and quantitative factors should be considered in sustainable supplier selection (SSS). These multiple factors are generally conflicting, and many alternatives exist in selecting the appropriate supplier. Therefore, multi-criteria decision-making (MCDM) techniques involve methods and approaches to achieve the best solution in view of the multiple conflicting criteria in SSS [1].

The researchers have employed multi-criteria decision making in the supplier selection in the past few years [2].

The most important goal of the supplier selection process is to find the supplier who has the highest probability of consistently meeting a company's needs at a suitable price. This selection is made through extensive comparisons between suppliers based on a set of criteria [2].

However, the choice of best suppliers requires consideration of other variables such as quality, durability, delivery, and pricing, in addition to the lowest price offered by suppliers, to assist solve complicated issues and contradictory criteria in decision making, Thomas Saaty created a well-known approach called Analytic Hierarchy Process (AHP).

AHP allows to create a hierarchy tree with goals, criteria, sub-criteria, and alternatives at various levels. Many businesses have used AHP to choose the best supplier in the past. AHP is a powerful support tool that is used in a variety of sectors, including manufacturing, layout design, and supplier selection.

AHP, on the other hand, has a maximum of nine things at each level. As a result, AHP is unable to deal with difficult situations. In order to overcome this deficiency, TOPSIS treatment this shortcoming [3].

TOPSIS is others Multi Criteria Decision Making (MCDM) used in a variety of sectors and decision-making processes. TOPSIS chooses the best solution among ideal and counter-ideal alternatives based on two distance functions. "The best solution should be closest to the Positive Ideal Solution (PIS) and farthest from the Negative Ideal Solution (NIS)", after determining the distance between each option using PIS and NIS, a closeness coefficient is calculated for each, and the alternatives are ranking using the closeness values. In many issues, the use of MCDM approaches in conjunction has yielded promising results with robust solutions [4].

The accurate results cannot be used in the computation by AHP. Furthermore, pairwise comparisons to decision makers are computationally difficult. Therefore, the researchers have developed an efficient and robust approach which is known as analytical network process (ANP) to handle complex decision making models and allows interdependencies among decision criteria.

The paper [5] presents some possible method upgrades that might decrease the complexity of the original ANP. SWOT with AHP and ANP decision making techniques have been presented in [6].

The paper [7] determined the most suitable strategy for energy recycle using ANP technique.

Application of ANP model to assist policymakers in identifying and prioritizing allocation indicators has been presented in [8]. The paper [9] (ANP) technique to find the best form of public-private partnership contracts to fund abandoned projects in Iraq. The papers presented a comprehensive review of applications of ANP in different fields such as economics and finance. AHP and ANP can be integrated with other multi criteria techniques such as DEA which is a linear programming technique, see [12],[13],[14],[15] for more details.

Many researchers have strived to develop the optimal decision-making procedures."The proposal methodology is built in such a way as to maximize the efficiency of MCDM techniques. In order to rank the alternatives according to the criteria, two different technologies, AHP and ANP, were combined. AHP approach used to structure the hierarchy and find the relative weight of the criteria, while ANP technique used to arrange supplier alternatives".

2. Methodology

The methodology of the paper which includes the research problem, aims and the search importance is described as follows.

2.1. Research Problem

Sustainable Supplier selection is an important process for companies in order to optimize the performance of its supply chain. Also, the decision of obtaining the best supplier by evaluating multiple criteria with interdependency, making the decision-making process complex. In addition, some multi criteria approach like the Analytic Hierarchy Process (AHP) have limitations in handling such interdependencies. ANP is used in this study to get the general form of AHP which is a more robust framework and also, allowing for interdependencies among criteria.

2.2. Research Aims

This paper aims to obtaining the best supplier by evaluating multiple criteria using more general form of AHP which known as ANP.

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Also, validate the robustness and effectiveness of the ANP method by comparing the results of AHP and ANP using some available data. Additionally, to provide future direction can be extended to real word application such as the Iraqi oil industry in both deterministic and fuzzy environments.

2.3 Research Importance

This paper provides a computational approach to supplier selection using a more flexible decision-making tool using ANP. This approach is crucial for real-world applications where criteria are rarely independent. Also, this paper shows demonstrating how ANP can account for interdependencies among criteria. Moreover, this paper lays the groundwork for future research in enhancing supplier selection techniques, particularly in industries with complex supply chains like oil companies, and in uncertain environments through fuzzy logic extensions.

2.4. Analytic Hierarchy Process (AHP)

Saaty invented AHP in (1977 and 1994), which is MCDM technique. The AHP has attracted the interest of more academics due to the method's appealing mathematical features and the ease with which the essential input data may be obtained [16].

AHP is the most well mathematical calculation approach for structuring multi-criteria choice, comparing criteria in a natural pairwise manner, and generating real or approximate total weights to help with decision making and ranking suitable supplier alternatives [17].

The hierarchical analysis process consists of three levels: the goal, the criteria, and the alternatives. The goal of the supplier selection problem is to choose the overall best supplier. Quality, pricing, service, and delivery are examples of criterion that might be employed. The alternatives are the many proposals provided by the suppliers [8].

There are steps as following:

Step 1 build a hierarchy for the decision, as described in figure 1 [19,20].

Step 2. Create pairwise comparison matrix. [22].

The pairwise comparison matrix is defined as part of the problem structuring this matrix as follows [23].

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2j} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix}$$

where

$$a_{ij} = \frac{w_i}{w_j} \; ; i, j = 1,2, \dots, n$$

$0 \neq a_{ij} = 1/a_{ji}$

$a_{ij} = 1, \;\; when \;\; i = j$

n = number of criteria to be evaluated

a_{ij} = importance of i^{th} criteria according to j^{th} criteria

The basic Saaty scale is mentioned in Table 1 as the most common form of grading (Saaty, 1980).

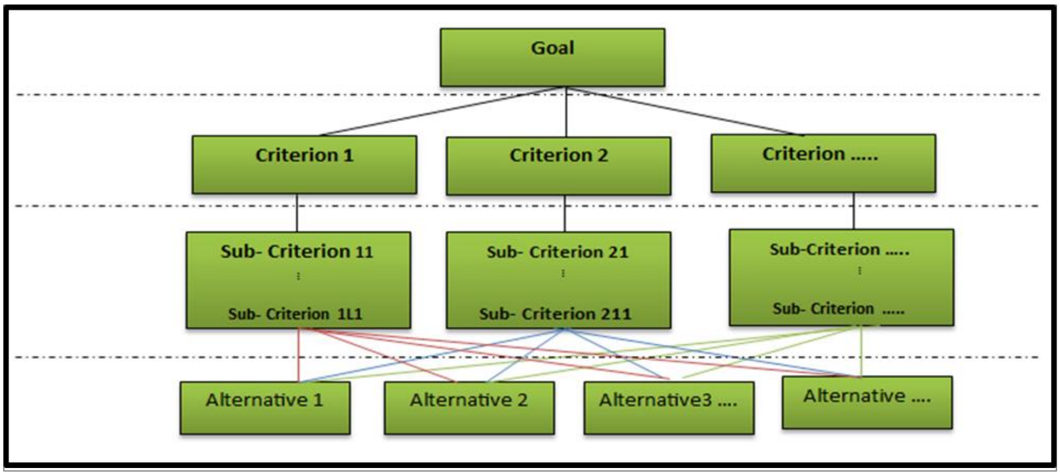

Figure 1: Generic Hierarchic Structure [21].

Table 1: The most common form of grading

Importance	Definition	Description
1	Equality important	Two parameters has equal important
3	Moderately important	One parameter is slightly preferred over another
5	Strongly important	One parameter is strongly preferred over another
7	Very strongly important	One parameter is very strongly preferred over another
9	Extremely important	Evidence parameter one attribute is of higher preferred halfway
2,4,6,8	Intermediate values	Intermediate weights between above provision

Step3. "Focus on consistency leads to the eigenvalue formulation, assume that the priorities w= (w_1 ,..., w_n) ,then create the matrix of ratio comparisons and multiply it on the right by w to obtain nw as follows:

$$\begin{pmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ \vdots \\ w_n \end{pmatrix} = n \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ \vdots \\ w_n \end{pmatrix}$$

Step 4. Estimate the relative weights

The relative weights (W) of matrix A is obtained from following equation [25].

$$A \times W = \lambda_{max} \times W$$

$\boldsymbol{\lambda_{max}}$: The biggest eigenvalue of matrix A.

W_i: vector weight of individual elements of a hierarchical structure.

Step 5. Compute the Consistency Ratio (CR)

The Consistency Ratio (CR) must be less than 0.1 to be the judgments of the decision makers can be accepted as consistent, otherwise the decision makers are repeat the pairwise comparison until the judgments become consistent [15,26]. The consistency rate (CR) is calculated by:

$$CR = \frac{CI}{RI}$$

Where RI (Random Index) is the random consistency index, (RI) value changes with the differences in the dimensions shown in Table (2), while the consistency index (CI) is calculated by the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Step 6: The final step finds relative weights for all alternatives and repeat arranging the alternatives from best to worst [28].

2.5. Analytical Network Process (ANP)

ANP technique is a general form that allows possible independency among criteria factors. Also, it is well-known that in the AHP the influence is from lower level elements into higher level elements which means that it is linear hierarchy while in the ANP we have a network of clusters and some possible dependencies between them as we have shown in Fig. 1.

2.6. ANP Computational Procedure

We illustrate the fundamentals steps for ANP as in [6] as following:

Step 1: Construct the model that represents the structure of the problem: The problem should be stated clearly and be decomposed into a rational system, like a network. This network structure can be obtained by decision-makers through brainstorming or other appropriate methods.

Step 2: Pairwise comparison matrices and priority vectors: Similar to the comparisons performed in AHP, pairs of decision elements at each cluster are compared with respect to their importance towards their control criteria. The clusters themselves are also compared pairwise with respect to their contribution to the objective. Decision-makers are asked to respond to a series of pairwise comparisons of two elements or two clusters which are evaluated in terms of their contribution to their particular upper-level criteria. In addition, interdependencies among elements of a cluster

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must also be examined pairwise. The influence of each element on other elements can be represented by an eigenvector. The relative importance values are determined with Saaty's 1–9 scale, where a score of 1 represents equal importance between the two elements and a score of nine indicates the extreme importance of one element (row cluster in the matrix) compared to the other one (column cluster in the matrix).

Step 3: Super matrix formation: The super matrix concept is similar to the Markov chain process. To obtain global priorities in a system with interdependent influences, the local priority vectors are entered in the appropriate columns of a matrix. As a result, the super matrix is actually a partitioned matrix, where each matrix segment represents a relationship between two clusters in a system.

Step 4: Selection of the best alternatives: If the super matrix formed in Step 3 covers the whole network, the priority weightings of the alternatives can be found in the column of alternatives in the normalized super matrix. On the other hand, if a super matrix only comprises clusters that are interrelated, additional calculations must be made to obtain the overall priorities of the alternatives. The alternative with the largest overall priority should be selected, as it is the best alternative as determined by the calculations made using matrix operations.

Table 2: The values of the random index (R1) [27]

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

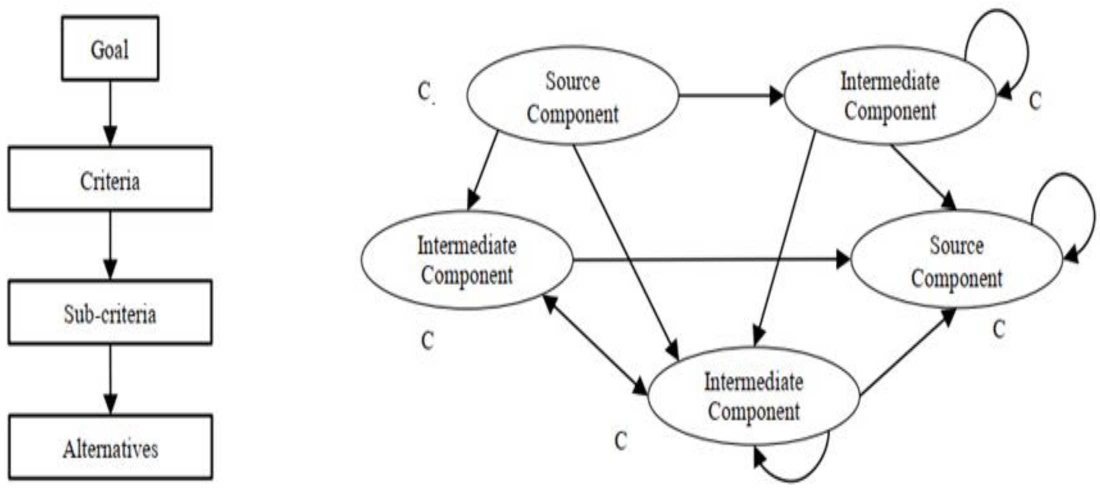

Figure 2: The difference between AHP and ANP, [5]

3. Results and discussion

This work has used the data as in [30] which represents data for company that has four suppliers and five criteria.

The presented approach consists of the three main steps:

1.The first step is to identify the criteria used in the comparison process between suppliers, where four suppliers denoted as (A1, A2, A3, A4) and five criteria represent (price, pollution control, due time, energy consumption, and warranty), where two criteria considered sustainable criteria (pollution control, energy consumption) and the rest economic criteria. These five criteria denoted as (C1, C2, C3, C4, C5).

2. The second step is to identify the decision matrix using AHP as shown in Table 3.

Table 3: Decision matrix and weight of criteria using AHP

Weight	0.342	0.329	0.125	0.082	0.052
	C_1	C_2	C_3	C_4	C_5

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A_1	0.232	0.154	0.448	0.547	0.161
A_2	0.489	0.454	0.166	0.119	0.332
A_3	0.182	0.309	0.200	0.164	0.416
A_4	0.042	0.084	0.186	0.170	0.091

Note that Table 3, represents the weights of the criteria C1, C2, C3, C4, C5 that already obtained by AHP using pairwise comparison between the criteria and then dividing each element in the comparison matrix by the total number of each column after that we find the average of each row in the comparison matrix which represent the weight of the criteria.

Also, the decision matrix is obtained using AHP and each column represents the priority value of each alternative based on each criteria, for example the column under the criteria C1 gives the priority values of each alternatives based on this criterion.

3.The third step is to construct the super matrix and limiting super matrix and compare between the alternatives and rank them from the best to the worst through using ANP.

Table 4 represents the super matrix and this matrix is constricted using ANP algorithm and based on the information in Table 3 as follows

Table 4: Super Matrix

	Goal	C_1	C_2	C_3	C_4	C_5	A_1	A_2	A_3	A_4
Goal	0	0	0	0	0	0	0	0	0	0
C_1	0.342	0	0	0	0	0	0	0	0	0
C_2	0.399	0	0	0	0	0	0	0	0	0
C_3	0.125	0	0	0	0	0	0	0	0	0
C_4	0.082	0	0	0	0	0	0	0	0	0
C_5	0.052	0	0	0	0	0	0	0	0	0
A_1	0	0.232	0.154	0.448	0.547	0.161	1	0	0	0
A_2	0	0.489	0.454	0.166	0.119	0.332	0	1	0	0
A_3	0	0.182	0.309	0.200	0.164	0.416	0	0	1	0
A_4	0	0.092	0.084	0.186	0.170	0.091	0	0	0	1

The first column from Table 4 represents the goal with all criteria and alternatives, the second column represents the weight of the criteria, third columns give the priority values of each alternative based on criteria C1, similarly for fourth column, fifth column, sixth column and seventh column. Also, the last four columns represent the identity matrix which gives the relation between the alternatives.

Table 5; gives the Limiting Super Matrix which is obtained using ANP algorithm by multiplying the super matrix n times until we reach values between last two matrices does not change as follows.

Table 5: Limiting Super Matrix

	Goal	C_1	C_2	C_3	C_4	C_5	A_1	A_2	A_3	A_4
Goal	0	0	0	0	0	0	0	0	0	0
C_1	0	0	0	0	0	0	0	0	0	0
C_2	0	0	0	0	0	0	0	0	0	0
C_3	0	0	0	0	0	0	0	0	0	0
C_4	0	0	0	0	0	0	0	0	0	0
C_5	0	0	0	0	0	0	0	0	0	0
A_1	0.2550	0.2320	0.1540	0.4880	0.5470	0.1610	1	0	0	0
A_2	0.3962	0.4890	0.4540	0.1660	0.1190	0.3320	0	1	0	0
A_3	0.2456	0.1820	0.3090	0.2000	0.1640	0.4160	0	0	1	0
A_4	0.1069	0.0920	0.0840	0.1860	0.1700	0.0910	0	0	0	1

Note Table 6, represents the final priority values of each alternative which is taken from Table 5 second column.

Table 6: Ranking of alternatives using ANP

Alternatives	Priorities	Ranking
A1	0.2550	2
A2	0.3962	1
A3	0.2456	3
A4	0.1069	4

From the final results shown in Table 6, that the best supplier is the supplier 2 which has biggest weight equal to 39% , then suppliers rank (supplier 1, supplier 3, supplier 4) respectively, where the worst supplier is supplier 4 which has lowest weight equal to 10% .
The optimal decision is select the supplier 2 depend on Multi-Criteria (five criteria) from four suppliers Using Analytical Network Process (ANP).

4. Conclusions

In this paper, we present an effective multi-criteria decision-making approach for selecting the best suppliers which known as Analytical Network Process (ANP). This approach is allowing interdependencies among criteria, enhances its ability to model complex decision-making scenarios compared to simpler approaches like AHP (Analytical Hierarchy Process). Additionally, ANP leads decision-makers with a more precise comparison between alternatives and a structured method for assigning weights to criteria. Moreover, the obtained decisions are robust and well informed which meet with the company's strategic objectives. Furthermore, our study shows that Supplier 2 as the best option with a weight of 0.39, indicating its superior performance relative to the other suppliers. Also, the reliability of the method used have supported by the consistency between the ANP and AHP.

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