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A HYBRID APPROACH BASED ON A NEW OUTRANKING HYPOTHESIS COMBINING THE AHP AND ELECTRE II METHODS FOR MULTI-CRITERIA DECISION-MAKING

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Abstract

Multi-criteria decision-making is crucial in many fields, as decision-

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makers must evaluate a variety of criteria that are sometimes contradictory. Among the methods widely used to structure and solve complex problems are the analytic hierarchy process (AHP) and the ELECTRE II method (elimination and choices translating reality). However, each of these methods has its limitations. AHP is effective for weighting criteria, but it is compensatory in nature, allowing one alternative to compensate for the weakness of one criterion with the strength of another. Conversely, ELECTRE II, a non-compensatory method, is excellent for managing preferences using concordance and discordance indices. However, it can lack flexibility in adjusting weightings and concordance and discordance thresholds. To overcome these limitations, this work proposes a hybrid method, the hybrid AHP-ELECTRE II approach (APHY-AHP-ELECTRE II), which combines the advantages of AHP and ELECTRE II by relying on the principles of concordance-dominance and discordance-dominance as ranking assumptions. This hybridization improves the accuracy and robustness of multi-criteria decisions by integrating the weighting of criteria using AHP. The resulting model is balanced and flexible, and particularly suited to problems where many criteria are in conflict. This document presents a clear methodology for the different stages of this hybrid method, explores the properties of the outranking assumption and demonstrates its effectiveness using a numerical application. The integration of the advantages of analytic hierarchy process (AHP) and ELECTRE II makes the APHY-AHP-ELECTRE II hybrid method flexible and robust decision-making tool, capable of effectively responding to the challenges of complex decision-making environments.

1. Introduction

Since its very beginnings, mankind has maintained close relations with the components of its environment, both near and far. Some of these relationships are complex, leading us to make choices based on our priorities. However, this is not always easy, particularly when several criteria need to be taken into account in order to achieve an objective. The issue of decision making remains a topical one and a major challenge for many decision-makers in various sectors of social and economic life [1]. Very early on, it aroused the interest of researchers, which led to the development of several decision support tools. These tools include well-known methods such as AHP, EVAMIX, TOPSIS and ELECTRE II, which offer aggregation procedures that often produce satisfactory results for multi-criteria decision-making [2, 3]. In practice, however, they have certain limitations. Indeed, the preferences of decision-makers are not always well translated to faithfully reflect reality, particularly when many conflicting criteria come into play in the decision-making process [4]. Outranking methods, such as ELECTRE, use weighted criteria and thresholds for agreement and disagreement. However, these methods do not always have rigorous tools for weighting or setting thresholds, which often leads to arbitrary choices and controversial results.

The objective of this study is to propose a hybrid methodology combining the advantages of the AHP and ELECTRE II methods, while incorporating a new outranking assumption based on concordance-dominance and discordance-dominance scores to establish a ranking procedure between alternatives. This approach will improve the robustness of multi-criteria decisions and encourage greater involvement of decision-makers in determining decision parameters using mathematical tools. To do this, we begin with a simplified review of the literature on the two methods mentioned, present the new approach, study the properties of the outranking assumption, and then perform a numerical application. Finally, we discuss the strengths and weaknesses of this new approach.

2. Review of the Literature

This section gives an overview of the AHP method, ELECTRE II and some of the foundations of outranking relationships.

2.1. Method AHP

Created by Thomas SAATY, the AHP method is a multi-criteria method using a single synthesis criterion to select the best alternative. In principle, it breaks down a complex problem into a hierarchical structure, making it easier to understand and solve. The principle is to carry out pair-wise comparisons of the elements at the same level of the hierarchy of the structure, thereby establishing the priorities of the criteria on the basis of the judgements obtained from the comparisons made. These priorities are validated on the basis of a consistency test. Finally, the overall priorities of the actions are defined, enabling the actions to be ranked in order of importance. The AHP method thus makes it possible to obtain normalized weights for the criteria through a calculation process that uses the concept of iteration to find the eigenvalue of the optimal eigenvector [2, 3].

2.2. Method ELECTRE II

The method of ELECTRE (elimination and choice translating reality): ELECTRE II, is a multi-criteria aggregation function relating to the γ problem which results in a ranking of alternatives from the best to the least good. It uses concordance and discordance indices to express the decision-maker's preference in terms of the performance of each alternative according to the decision criteria. This method has undergone a great deal of development since it was created in 1965-1970 by a team of researchers led by Bernard Roy, within the LAMSADE (laboratory of analysis and modelling of systems for decision support). It has several versions which are still active in the field of multi-criteria decision making: [5, 6]. Hybrid integration models with other methods exist in the literature. The ELECTRE II method uses the outranking relationship S constructed on the basis of concordance and discordance indices. Each outranking relationship is represented by a graph called an *outranking graph*. The various outranking graphs are used to rank potential actions on the basis of an algorithm called the *outranking algorithm*. This algorithm produces two types of ranking: a direct ranking and an indirect or inverse ranking. The two rankings are used to produce a final ranking of the stocks [7].

3. Hypotheses/Objectives

The aim of this study is to set up a multi-criteria decision support model based on the AHP and ELECTRE II methods, using mathematical calculations to determine decision parameters such as criteria weights and outranking parameters.

In the literature, there are several cases of combining several methods to solve decision problems, such as AHP, TOPSIS, EVAMIX, VIKOR ELECTRE, [8-11]. These combinations allow us to benefit from the advantages of each method. We did not find any formal techniques for determining parameters such as concordance or discordance thresholds and criterion weights in the ELECTRE II method in the literature. Our hybrid approach therefore makes a considerable contribution to the process of modelling decision-maker preferences.

4. Research Design/Methodology

In the literature, we are increasingly seeing decision support models developed by combining several existing methods. The ELECTRE II method does not include in its application procedure a technique for setting the parameters of the decision, such as the weights of the criteria and the concordance and discordance thresholds. In this study, we have therefore developed a rigorous approach that allows the determination of the decision parameters in an environment where the decision problem is based on real criteria that conflict.

5. Mathematical Formulation of the Problem

We solve a multi-criteria decision problem where we have several possible alternatives (n alternatives), with several criteria (m criteria) and each alternative is evaluated according to each criterion. In addition, each criterion has a relative weight that expresses its degree of importance for achieving the objective of the decision. We formulate this problem as follows:

$A = \{a_1;\ a_2;\ ...;\ a_n\}$, where A denotes the set of n possible alternatives.

$C = \{g_1;\ g_2;\ ...;\ g_m\}$, where C designates all the m evaluation criteria.

$G = \{g_1(a_1);\ g_2(a_2);\ ...;\ g_m(a_n)\}$ is the total performance of the alternatives by criterion.

$W = \{w_1;\ w_2;\ ...;\ w_m\}$ represents all the weights of the decision criteria.

The solution to this problem consists of carrying out an evaluation of all the n alternatives of A while taking into account the m criteria of C and the elementary evaluations $g_i(a_i) \in G$ of the alternatives as a function of the criteria $g_i \in C$ and the weights of each criterion $w_i \in W$ in order to rank them in order of importance from the best alternative to the least good, to facilitate the decision-maker's choice.

6. Presentation of the New APHY-AHP-ELECTRE II Hybrid Approach

This new approach uses the strengths of the AHP and ELECTRE II methods. It consists of determining the weights of the criteria using the AHP method and then using the principle of the ELECTRE II method to calculate and establish the matrices of the concordance and discordance indices. The out-classification relationships are constructed on the basis of concordance-dominance and discordance-dominance.

6.1. The stages in the method

Step 1: Weighting of criteria

➢ Carry out a binary comparison between the criteria identified

At this stage, the analyst provides the decision-maker with the list of criteria and asks them to compare them in pairs using SAATY's verbal scale [12]. The comparison is made between criteria belonging to the same level of hierarchy. The decision-maker's assessments are then converted into numerical values using the SAATY numerical scale.

➢ Establish the judgement matrix

After converting the decision-maker's verbal evaluation expressions into numerical values, we arrange the data in a matrix according to the following principle:

$$A = [a_{(i,j)}] \begin{cases} a_{(i,i)} = 1; & \text{for } i = 1 \cdots k \text{ and} \\ a_{(i,j)} = 1; & \text{if } a_i = a_j \text{ and} \\ a_{(i,j)} \succ 1; & \text{if } a_i \text{ is prefered to } a_j \\ a_{(j,i)} = \dfrac{1}{a_{(i,j)}} & \text{(reciprocal value),} \end{cases} \tag{1}$$

see [13].

➢ Determining the weights of the criteria

The weights of the criteria are calculated on the basis of the judgement matrix established by the relationship (1). It consists of calculating the eigenvalues of the matrix.

➢ Priority calculation

The aim is to find a set of weights $w_1, w_2, ..., w_m$ of the criteria. The calculation is done according to the three steps below.

➢ Perform the sum of the elements in each column *j*,

$$\sum_{i=1}^{n} a_{i,j}. \tag{2}$$

➢ Divide each element of the matrix by the sum of the elements in its column: normalization

$$a'_{i,j} = \frac{a_{i,j}}{\sum_{i=1}^{n} a_{i,j}}. \tag{3}$$

❖ Calculate the arithmetic mean of each line *i*; $i = 1, ..., n$,

$$w_i = \sum_{i=1}^{n} \frac{a'_{ij}}{n}; \quad \forall j. \tag{4}$$

The w_i are the weights of the *i* criteria or *i* factors.

✓ Testing the consistency of judgements

The consistency of judgements is tested by calculating the consistency ratio. If this ratio is less than or equal to 0.10, then the decision-maker's judgements are considered to be consistent and, consequently, the weights of the criteria are well determined. Otherwise, the judgements are repeated. To calculate the consistency ratio, we apply the relationships [13],

$$CI = \frac{\lambda_{\max - n}}{n - 1}, \tag{5}$$

where n is the dimension of the comparison matrix and $\lambda_{\max}$ is the maximum eigenvalue of the comparison matrix

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{Vp}{w_i}; \quad \forall j, \tag{6}$$

Vp is the sum of the coefficients of the i lines of the products of the $a_{i,j}$ judgements by the w_i weights,

$$Vp = \sum_{i=1}^{n} a_{ij} w_i, \ \forall j. \tag{7}$$

The Consistency Ratio (CR) is calculated by the formula:

$$CR = \frac{IC}{RI} \tag{8}$$

such that

CR is the coherence or consistency ratio.

RI is random consistency index (RI) determined by Saaty as a function of the number n of factors to be compared.

Table 1. Random consistency index (RI) table taken from Wind and Saaty (1980) [12]

n	1	2	3	4	5	6	7	8	9	10
IA	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

CI is consistency index.

If *RC* is less than or equal to 0.1, then the matrix is considered to be consistent and acceptable, otherwise the comparisons should be reviewed. Draw up the action evaluation matrix with the weights of the criteria determined:

$$G = \begin{pmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ g_{n1} & g_{n2} & \cdots & g_{nn} \\ w_1 & w_2 & \cdots & w_n \end{pmatrix}.$$

Step 2: Determination of concordance and discordance matrices

In this step we use the principle of the ELECTRE II method to determine preference sets.

➢ Determination of preference sets

The following sets are called *preference sets* [1]:

$$\checkmark \begin{cases} J^{+}(a_i; a_k) = \{j \in F;\ g_j(a_i) > g_j(a_k)\} \\ J^{=}(a_i; a_k) = \{j \in F;\ g_j(a_i) = g_j(a_k)\} \\ J^{-}(a_i; a_k) = \{j \in F;\ g_j(a_i) < g_j(a_k)\}, \end{cases} \tag{9}$$

$$\checkmark \begin{cases} P^{+}(a_i; a_k) = \sum P_j;\ j \in J^{+}(a_i; a_k) \\ P^{=}(a_i; a_k) = \sum P_j;\ j \in J^{=}(a_i; a_k) \\ P^{-}(a_i; a_k) = \sum P_j;\ j \in J^{-}(a_i; a_k) \\ P^{+}(a_i; a_k) + P^{=}(a_i; a_k) + P^{-}(a_i; a_k) = P(a_i; a_k). \end{cases} \tag{10}$$

The sets of preferences and the weights are defined as follows:

Annotations	Significations
$J^{+}(a_i; a_k)$	The set of criteria for which action a_i is preferred to action a_k
$J^{=}(a_i; a_k)$	Equivalence of shares
$J^{-}(a_i; a_k)$	The set of criteria for which action a_k is preferred to action a_i
$P^{+}(a_i; a_k)$	Sum of the weights of the criteria belonging to the set J^{+}
$P^{=}(a_i; a_k)$	Sum of the weights of the criteria belonging to the set $J^{=}$
$P^{-}(a_i; a_k)$	Sum of the weights of the criteria belonging to the set J^{-}

➢ Determination of the concordance and discordance indices

The concordance and discordance indices respectively implement the principles of majority and respect for minorities in order to affirm the outclassing (or not) of an action *b* by an action *a*.

The concordance indices are calculated using the following formulae:

$$C(a_i;\, a_k) = \begin{cases} \dfrac{P^{+}(a_i;\, a_k) + P^{=}(a_i;\, a_k)}{P(a_i;\, a_k)} \\ 0 \leq C(a_i;\, a_k) \leq 1, \end{cases} \tag{11}$$

see [1].

The mismatch indices are determined by the relationship below:

$$D(a_i,\, a_k) = \begin{cases} 0 \text{ } if \quad j^{-}(a_i,\, a_k) = \varnothing \\ \dfrac{\max{}_j - [gj(a_k) - gj(a_i)]}{\max{}_j [g\max{}_j - g\min{}_j]}, \end{cases} \tag{12}$$

see [14].

Step 3: Upgrade hypotheses

❖ The concordance indices are calculated using the following relationships.

❖ Concordance-dominance relationship.

❖ **Definition 1.** The concordance-dominance score of an alternative or action measures the degree of concordance of the coalition of concordant criteria of alternative a_i relative to the other alternatives,

$$Cd(a_i) = \sum\nolimits_{k=1}^{n} C(a_i,\, a_k) - \sum\nolimits_{k=1}^{n} C(a_k,\, a_i). \tag{13}$$

❖ Discordance-dominance relationship.

❖ **Definition 2.** The discordance-dominance score of an alternative or action measures the degree of opposition of the coalition of discordant criteria of alternative a_i relative to the other alternatives,

$$Dd(a_i) = \sum_{k=1}^{n} D(a_i, a_k) - \sum_{k=1}^{n} D(a_k, a_i). \tag{14}$$

❖ Exploiting outranking relationships.

There are two types of upgrade relationships. They are full upgrade and partial upgrade.

Definition 3. We say that alternative a_i totally outranks alternative a_k if and only if

$$\begin{cases} Cd(a_i) \geq Cd(a_k) \\ \text{and} \\ Dd(a_i) \leq Dd(a_k). \end{cases} \tag{15}$$

Definition 4. The alternative a_i is said to partially outrank a_k if and only if

$$\begin{cases} Cd(a_i) \geq Cd(a_k) \\ \text{and} \\ D(a_i, a_k) \leq Dd(a_k, a_i), \end{cases} \tag{16}$$

or

$$\begin{cases} Dd(a_i) \leq Dd(a_k) \\ \text{and} \\ C(a_i, a_k) \leq D(a_k, a_i). \end{cases} \tag{17}$$

Based on this procedure, a matrix of upgrades between actions is established. This determines a direct ranking, an indirect ranking and, finally, the final ranking according to the ELECTRE II ranking algorithm. For details on the algorithm, see (4).

6.2. Properties of the outclassing hypothesis

6.2.1. Transitivity

Total outranking is transitive, i.e., if alternative a_i totally outranks alternative a_k and alternative a_k totally outranks alternative a_j, then a_i totally outranks a_j.

Theorem 6.2.1. *Total outranking is transitive for all pairs of actions that admit total outranking relations.*

Proof. By hypothesis; if $a_i S^T a_k \Rightarrow Cd_{(a_i)} \geq Cd_{(a_k)}$ and $Dd_{(a_i)} \leq Dd_{(a_k)}$ also, if $a_k S^T a_j \Rightarrow Cd_{(a_k)} \geq Cd_{(a_j)}$ and $Dd_{(a_k)} \leq Dd_{(a_j)}$ and this necessarily implies that $Cd_{(a_i)} \geq Cd_{(a_j)}$ and $Dd_{(a_i)} \leq Dd_{(a_j)}$. The concordance-dominance and discordance-dominance scores establish total preorders that are therefore reflexive and transitive. Furthermore, the outranking relationship establishes a partial preorder, meaning that incomparability is permitted, so all pairs of actions a_k that have strong outranking relationships are transitive.

6.2.2. Asymmetry

Theorem 6.2.2. *If alternative a_i totally outranks alternative a_k, then a_k cannot totally outrank a_i.*

Proof. According to the definition of total outranking $a_i S^T a_k \Leftrightarrow Cd_{(a_i)} \geq Cd_{(a_k)}$ and $Dd_{(a_i)} \leq Dd_{(a_k)}$. For a_k to completely outrank a_i, it must be that $Cd_{(a_k)} \geq Cd_{(a_j)}$ and $Dd_{(a_k)} \leq Dd_{(a_j)}$ which would naturally imply that $Cd_{(a_i)} = Cd_{(a_k)}$ and $Dd_{(a_i)} = Dd_{(a_k)}$, i.e., a strict equality that can only occur when the two alternatives are indifferent. Therefore, a_k cannot completely outrank a_i.

6.2.3. Strict non-compensatory criteria

Theorem 6.2.3. *There is no compensation between concordance-dominance scores and discordance-dominance scores. A very strong advantage in concordance dominance cannot compensate for a very high discordance dominance.*

Proof. Given that concordance-dominance and discordance-dominance scores are evaluated separately and are not linearly combined into an evaluation function, no coefficient can be found to transform a disadvantage into an advantage. This proves the non-compensatory nature of outranking.

7. Implementation of the New Hybrid AHP-ELECTRE II Approach with the New Outclassing Assumption

The problem consists of ranking market gardening crops according to their profitability, from best to worst. To do this, we consider the following criteria: Average yield per hectare (AY), production cycle (PC), post-harvest loss rate (PH), resistance to pests and diseases (RPD), and production potential under local condition (PLC). The crops concerned are: chilli peppers, aubergines, tomatoes, onions and cabbages.

❖ Problem resolution.

(1) Step 1: Determining the weights of the criteria.

Performing binary comparisons according to Thomas Saaty's numerical scale, we obtain the following matrix according to relation (1).

Table 2. Criteria judgment matrix according to Saaty Thomas' numerical scale

Criteria	AY	PH	PLC	RPD	PC
AY	1	5	6	7	5
PH	1/5	1	5	6	4
PLC	1/6	1/5	1	4	4
RPD	1/7	1/6	1/4	1	3
PC	1/5	1/4	1/4	1/3	1

Applying relations (2); (3); (4); (5); (6); (7) and (8), we get the following results:

Criteria	AY	PH	PLC	RPD	PC	Total
Weight	0.53	0.25	0.12	0.06	0.04	1

$\lambda_{max} = 5.21$; $IC = 0.053$; $CR = 0.04$, CR being less than 0.1, then the judgements are consistent.

Table 3. Speculation performance matrix with criterion weights

Criteria	AY(t/ha)	PH(%)	PLC(t/ha)	RPD(/5)	PC(day)
Weight	0.53	0.25	0.12	0.06	0.04
Tomato	15	25	40	2	70
Chilli pepper	8	15	20	3.5	90
Onion	18	10	35	4	120
Cabbage	25	20	50	2	70
Aubergine	12	20	30	2.5	90
Meaning d'opt	Max	Min	Max	Max	Min

(2) Step 2: Determination of concordance and discordance matrices.

By applying relations (9) and (10), we determine the sets of preferences on which relations (11) and (12) allow us to determine the matrices of concordance and discordance indices, respectively.

Table 4. Matrix of concordance indices

Speculation	Tomato	Chilli pepper	Onion	Cabbage	Aubergine
Tomato	---	0.69	0.34	0.1	0.69
Chilli pepper	0.31	---	0.23	0.25	0.53
Onion	0.82	0.95	---	0.65	0.5
Cabbage	1	0.69	1	---	0.92
Aubergine	0.31	0.67	0.04	0.30	---

Table 5. Matrix of discordance indices

Speculation	Tomato	Chilli pepper	Onion	Cabbage	Aubergine
Tomato	---	0.5	0.30	1	0.25
Chilli pepper	1	---	0.5	1	0.50
Onion	1	1	---	1	1
Cabbage	0	0.16	0	---	0.025
Aubergine	1	0.5	0.33	0.1	---

(3) Step 3: upgrade assumptions.

By applying relations (13) and (14), we obtain the concordance-dominance and discordance-dominance scores for each speculation, respectively.

Table 6. Concordance-dominance and discordance-dominance scores

Speculation	Tomato	Chilli pepper	Onion	Cabbage	Aubergine
$Cd(a_i)$	-0.52	-1.68	1.31	2.31	-1.32
$Dd(a_i)$	-0.95	0.84	2.87	-2.92	-0.16

Applying relations (15), (16) and (17) allows us to establish the outranking relationships between the speculations. Applying the ELECTRE II outranking algorithm gives the following ranking:

Table 7. Results obtained using the method APHY-AHP-ELECTRE II

Speculation	Direct ranking	Indirect ranking	Final ranking
Tomato	3	3	3
Chilli pepper	4	4	4
Onion	2	2	2
Cabbage	1	1	1
Aubergine	3	3	3

8. Discussions

This article introduces a hybrid approach based on the AHP and ELECTRE II methods: APHY-AHP-ELECTRE II. It is an innovative approach that exploits the strengths of both methods. However, like any decision-making method, this approach is not without its limitations.

8.1. Strengths of the APHY-AHP-ELECTRE II approach

APHY-AHP-ELECTRE II is an approach that exploits the strengths of the AHP and ELECTRE II methods. Its strengths are as follows:

• Objective evaluation of decision criteria weights.

• The expert or decision-maker has a tool for evaluating the relative importance of decision criteria.

• Evaluates criteria, whether quantitative or qualitative.

• Provides a consistency test for the judgements made by the expert or decision-maker on the importance of each criterion in the decision-making process.

• It circumvents the often-arbitrary setting of decision parameters such as concordance and discordance thresholds by introducing an outranking hypothesis based on concordance-dominance and discordance-dominance scores.

• It significantly reduces cases of incomparability between alternatives.

8.2. Weaknesses of the APHY-AHP-ELECTRE II approach

• Although innovative, this approach also has limitations in its implementation. These limitations include:

• Increased number of pairwise comparisons due to the introduction of the outranking assumption.

• Very costly in terms of computing time if the number of criteria and alternatives is high.

• May lead to controversial results if the criteria are not true criteria.

8.3. Innovation and originality of the APHY-AHP-ELECTRE II method

This method, which aims to overcome the limitations of setting decision parameters (weights and thresholds) in the ELECTRE II method, is an innovative and original approach. It stands out for its ability to set the weights of decision criteria through pairwise comparison, through testing the consistency of the various judgements made by the expert or decision-maker, and through its outranking hypothesis based on the concordance-dominance and discordance-dominance scores between alternatives.

9. Conclusion

In this article, we have developed a multi-criteria approach combining the qualities of two well-known methods in the literature: the analytic hierarchy process (AHP) and ELECTRE II. This approach consisted in particular of determining the weights of the criteria using the AHP method, then using the concordance and discordance indices calculated according to the principle of the ELECTRE II method and the calculation of concordance-dominance and discordance-dominance scores to rank the alternatives. The aggregation method we developed is based on an over classification hypothesis, which relies on concordance-dominance and discordance-dominance.

Analysis of the properties of this hypothesis enabled us to evaluate the effectiveness of the method. Indeed, it has interesting characteristics, such as asymmetry, transitivity, non-compensation and a reduction in often arbitrary cases of incomparability, often due to an incorrectly set threshold. This approach has enabled us to circumvent the uncertainties often associated with determining parameters in the traditional ELECTRE method. This new method has proven to be suitable for solving multi-criteria decision problems. In our future work, we will adopt this approach for group decisions and implement the method in software for faster decision-making.

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