Use of multicriteria AHP (Analytical Hierarchy Process) method to rank feeding solutions, tested on layers, while observing environmental protection

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SUMMARY

The Analytical Hierarchy Process (AHP) is a structured method which allows organising and ranking complex decisions on the basis of mathematics and psychology. Rather than prescribing a ”correct” decision, AHP helps the decision-makers to find a solution that fits best their purpose and the manner of understanding the problem. This method provides a comprehensive and rational framework for the decision-making process, to represent and quantify its elements, to link these elements to the general objectives and to evaluate the alternative solutions. AHP users start by decomposing their decision-making problem into a hierarchy of sub-problems that are easier to understand, and which can be analysed independently. The elements of the hierarchy can refer to any aspect of the decision-making problem – tangible or intangible – carefully measured or approximated, properly or poorly understood. The paper gives an example of using the multicriteria AHP method to rank feeding solutions tested on layers, with the purpose of decreasing the egg cholesterol level, while observing environmental protection.

Keywords: AHP method, ranking, feeding solutions, layers, pollution

INTRODUCTION

The Analytical Hierarchy Process (AHP) is a method developed by Thomas L. Saaty in the 70s, which has been intensely studied and refined since then (Saaty, 1990; Saaty, 2008). It is mainly used to take group decisions and it is used worldwide in a variety of decision-making situations, in areas such as governing, business, industry, health and education (Ho, 2008). AHP is a flexible method, which assigns proportions to the different elements of a hierarchical structure by comparing pairs. The method allows alternative comparisons in relation to several attributes. It is highly useful for complex problems, and when values are involved. The AHP user identifies an objective that has to be accomplished, as well as the alternatives that can be used to achieve this objective, makes a hierarchy of the factors that influence the objective, and populates a sequence of matrixes that compare the pairs using AHP notation rules (Eagan and Weinberg 1999).

The AHP users first decompose their decision-making problem into a hierarchy of easier to understand sub-problems, each of which can be analysed independently. The elements of the hierarchy can refer to any aspect of the decision-making problem – tangible or intangible, carefully measured or approximated, properly or poorly understood (Saaty, 2008). Once the hierarchy is constructed, the decision factors evaluate systematically its elements comparing them two by two, regarding their impact on an element above them in this hierarchy. In making comparisons, the decision factors, using concrete data about the elements, use their own judgement regarding the significance and relative importance of the elements. The essence of AHP is that human judgements, not just the basic information, can be used to make evaluations. AHP converts these evaluations in numeric values that can be processed and compared considering the whole range of problems. A numeric value or a priority results for each element of the hierarchy, enabling thus to compare, rationally and uniformly, different and often unmeasurable elements. This capacity distinguishes AHP from other decision-making techniques. Numeric priorities for each decision alternatives are calculated in the final stage of the process. These figures represent the relative capacity of the alternatives to accomplish the object of decision, so that they can be used to consider various courses of action (Bhushan Navneet, Kanwal Rai, 2004).

The Analytical Hierarchy Process (AHP) is most useful in the case in which teams of people are working on complex problems, particularly those with high stakes, which involve human perceptions and prejudices, whose solutions can have long-term effects (Forman and Gass, 2001).

This decision-making method is rather little used in agriculture. Maino et al., (2012), used AHP to make decisions regarding the animal health programs, by assigning priorities to the problems of interest for the goat breeders. Huang et al., (2003) used a model based on AHP to evaluate the efficiency of a set of four strategies for smell management in a pig farm.

Considering the above, we applied AHP to rank several feeding solutions tested on layers, which aim to lower the cholesterol concentration of the eggs, while protecting the environment. The paper gives an example of how the method can be used.

MATERIAL AND METHODS

The feeding solutions enriched in polyunsaturated fatty acids ranked by AHP have been studied within a 5-week small-scale experiment conducted on 190 Lohmann Brown layers aged 59 weeks (including a 3-day accommodation period of the layers to the new feeds). The layers have been assigned to 5 groups, one control group (C) and four experimental groups (E1, R2, E3 and E4), which differed by the raw ingredients rich in polyunsaturated fatty acids. The purpose of the experiment was to produce low-cholesterol eggs.

With the view of making a coherent analysis based on evidences provided by research/analytical measurements, we established a panel of three expert evaluators in this field or in related fields, who expressed their opinions based on the experimental evidences, own experience and knowledge, with the purpose to evaluate the advantages and disadvantages of each of the four feeding formulations.

The multi-criteria AHP method allows the decision-makers to:

a) Model a complex problem such a hierarchical structure, which shows the relation between the objective, the main criteria/sub-criteria and the alternatives.

The example below demands the decision-makers/evaluators to choose the best feeding formulation out of the four ones that have been tested, analyzing data and information that show the values and trends of the relevant indicators for the proposed objective as shown in Tables 1 and 2.

The hierarchical structure of decision has three levels:

(i) Level of the objective

Objective: production of low-cholesterol hen eggs enriched in omega-3 polyunsaturated fatty acids, at a price that allows penetrating the market with this new type of egg, while protecting the environment.

(ii) Level of the criteria/sub-criteria

Criterion C1 = Technical evidences - in agreement with the experimental results obtained for alternatives/formulations AltRT1÷AltRT4 compared to the simple, unamended (conventional) formulation, indicators shown synthetically in Table 1.

Criterion C2 = Economic evidences - in agreement with the experimental results obtained for alternatives/formulations AltRT1÷AltRT4 compared to the simple, unamended formulation, described in Table 1.

Criterion C3 = Ecologic evidences - in agreement with the experimental results of testing the poultry droppings, physical and chemical indicators that show the positive trend for ecological protection due to the lower polluting emissions for the alternatives/formulations AltRT1÷AltRT4 compared to the simple, unamended (conventional) formulation, described in Table 1.

(iii) Level of the alternatives – feeding solutions for layers, Tables 1 and 2:

- Alt RT1 – SN1 (feeding solution 1) – compared to a conventional, control (SNM) formulation with 16.35% crude protein and 2544kcal/kg ME, it also contains: 5% flax seeds + 2% camelina seeds;
- Alt RT2 – SN2 (feeding solution 2) - compared to SNM it also contains: 5% flax meal + 2% camelina meal;
- Alt RT3 – SN3 (feeding solution 3) - compared to SNM it also contains: 3% flax seeds + 3% camelina seeds + 1% fenugreek seeds
- Alt RT4 – SN4 (feeding solution 4) - compared to SNM it also contains: 3% flax meal + 3% camelina meal + 1% fenugreek seeds

Table 1- Experimental results of testing the four feeding formulations intended to produce low-cholesterol eggs

Tested indicators		Control group	Exp. group 1 - AltRT1	Exp. group 2 - AltRT2	Exp. group 3 - AltRT3	Exp. group 4 - AltRT4
Egg weight, g		62.68	63. 95	63.22	64.18	65.53
Yolk weight, g		17.230	16.480	17.080	16.900	17.790
Total cholesterol concentration in the egg (mg cholesterol /egg)		231.91	211.99	187.68	197.77	189.13
Concentration of omega 3 fatty acids in the egg yolk (g fatty acid/ 100 g fat)	Linolenic	0.562	0.988	2.134	1.128	1,567
	Eicosatrienoic	0.200	0.213	0.192	0.201	0,234
	Docosapentaenoic	0.117	0.139	0.143	0.110	0.205
	Docosahexaenoic	1.028	1.753	2.370	1.367	2,158
Concentration of cholesterol in the liver (g cholesterol /100 g sample)	g cholesterol /100g dry sample	0.637	0.620	0.542	0.594	0.512
Concentration of cholesterol in serum (mg/dL)		148.200	134.800	113.800	127.200	97.200
Cost/kg compound feed, Ron		1.44	1.64	1.71	1.61	1.69

b) <u>To integrate the knowledge and personal experience, as well as the available information, with the decision to be made</u>.

In order to submit the indicators used as criteria to coherent analysis based on the evidences provided by the research/analytical measurements, a panel of evaluators/experts in the field of evaluation or in related areas was established. In the case of our example, the panel consisted of a poultry breeding expert, an economic expert and an ecological expert. They are to express their opinions using available evidences (trial results), their own experience and knowledge, in order to evaluate the advantages and disadvantages of each of the four feeding formulations whose synthetic description is shown in Tables 1 and 2.

Table 2 – Synthetic description of the advantages and disadvantages which resulted from the feeding trial

Alternative	Main advantages	Main disadvantages
SN1	- The egg yolk is rich in omega 3 polyunsaturated fatty acids; - 43 % of the microbiological indicators ecologically relevant to the environmental impact improve the environmental protection by their decrease; - 75 % of the physical-chemical indicators ecologically relevant to the environmental impact improve the environmental protection by their decrease, compared to the control; - It has the best performance of the microbiological indicators of the four feeding formulations	- The flax and camelina seeds are included as such in the feed; - The formulation is the third most expensive, compared to the control.
SN2	- It uses by-products from oil production industry; - It lowers most of all four formulation the total cholesterol in the egg yolk and in the liver; - The egg yolk is rich in omega 3 polyunsaturated fatty acids (highest amounts of the four formulations); - Over 70 % of the microbiological indicators ecologically relevant to the environmental impact improve the environmental protection by their decrease, compared to the control; - 50 % of the microbiological indicators ecologically relevant to the environmental impact improve the environmental protection by their decrease, compared to the control;	- The content of bacteria (10^7-10^9 CFU/g DM), although close to the normal range for the fresh poultry droppings; has a slightly higher infectious potential compared to the control; - The formulation is more expensive compared to the control, and the third most expensive of the four formulations.
SN3	- The egg yolk is rich in omega 3 polyunsaturated fatty acids; (second highest of all four formulations) - Low cholesterol content of the yolk (third lowest cholesterol concentration of the four formulations) ; - High concentration of linolenic acid in the yolk (two times higher than the control and third highest of the four formulations); - Over 70 % of the microbiological indicators ecologically relevant to the environmental impact improve the environmental protection by their	- The used form of flax and camelina is more difficult to compound. - It has a specific taint due to the fenugreek - Just 25 % of the microbiological indicators ecologically relevant to the environmental impact improve the environmental protection by their decrease. - The content of bacteria (10^7-10^9 CFU/g DM), although close to the normal range for the fresh poultry droppings; has a slightly higher infectious potential compared to the control.

	decrease, compared to the control - It has the best price compared to the control and the lowest price increase of the four formulations.	
SN4	- It decreases significantly the total cholesterol concentration in the egg yolk (second highest decrease of the four formulations, second only to formulation AltRT2); - The egg yolk is rich in omega 3 polyunsaturated fatty acids (second highest concentration of fatty acids of the four formulations); - The formulation uses by-products ; - It increases significantly the linolenic acid and the docosahexanoic acid (second highest concentration of the four formulations); - Over 70 % of the microbiological indicators ecologically relevant to the environmental impact improve the environmental protection by their decrease.	- Just 25 % of the microbiological indicators ecologically relevant to the environmental impact improve the environmental protection by their decrease. - The content of bacteria (10^7-10^9 CFU/g DM), although close to the normal range for the fresh poultry droppings; has a slightly higher infectious potential compared to the control. - The formulation has the second most expensive price of the four formulations, and compared to the control;

c) <u>To measure the magnitude of the relative importance of the objects to be compared (criteria/alternatives) by comparing them two-by-two, according to the following methodological procedure proposed by AHP.</u>

We have to rank "m" alternatives using "n" previously agreed decision-making criteria. In the case of our example, there are four alternatives, therefore "m" = 4, the alternatives being noted $AltRT_1 \div AltRT_4$. We also have three criteria, therefore "n" = 3, the criteria being noted C1÷C3; these criteria include sub-criteria, in the form of indicators, $I_1...I_z$ linked to the characteristics shown in Tables 1 and 2. The criteria have been previously agreed by the panel of evaluators and are formulated at point a).

Each evaluator/decision-maker will have to rank, according tom his/her own opinion, in the order of their importance, the three types of agreed criteria, C1÷C3. This ordering is to be done according to AHP methodology, i.e., by writing a 3x3 matrix, A (Table 3), because we have n=3 types of criteria to be entered on the rows and columns of this matrix. Any entry on row "j" and column "k" of such matrix is termed in this case p_{jk}, where, in this case, j= 1÷n; and n=3; k=1÷n and n=3;

Each evaluator/decision-maker ranks the four alternatives $AltRT_1 \div AltRT_4$, in the order of their importance in relation with each individual criterion, according to his/her judgement. This ranking, according to AHP methodology, is done by writing a 4x4 matrix, B, for each criterion, C1, C2 and C3 (Table 4 -

Matrix B –C1÷C3), because we have m=4 alternatives, that are entered on the rows and columns of this type of matrix. Any entry on row "j" and column "k" of such matrix is termed, like in the previous case, p_{jk}, where, in this case, j= 1÷m; and m=4; k=1÷m and m=4;

Table 3 - Matrix A (3x3)

j/k (j=3,k=3)	C1=Technical evidences	C2=Economic evidences	C3=Ecological evidences
c1= Technical evidences			
c2= Economic evidences			
c3= Ecological evidences			

Table 4 - Matrix B (4x4) –C1÷C3

j/k (j=4,k=4)	AltRT1	AltRT2	AltRT3	AltRT4
AltRT1				
AltRT2				
AltRT3				
AltRT4				

Each evaluator fills in these matrices, called matrices of pair comparison, using scale Saaty, shown in Table 5.

Table 5 – Scale of importance of the score from column 1, given using the Saaty scale

Intensity of importance - p_{jk} value given to the lexical evaluations	Definition
1	Equal importance
3	Slightly more important
5	Moderately more important
7	Much more important
9	Absolutely more important
2, 4, 6, 8	Intermediary values between two adjacent evaluations, signifying the an importance evaluated at half way of the value difference (in the opinion of each evaluator/decision-maker) between a previous score and the next score, having the above-mentioned significances.
Reciprocals of the above figures different from zero: 1/n	

In order to show their for the best of the two criteria, or for the best of the two alternatives, the evaluators score, according to Saaty scale, each criterion/each alternative, by comparison with another criterion/another alternative with which they are compared within a pair comparison, and this is done in each cell of the above matrices. Each p_{jk} entry from a matrix, A or B type, shows how important is “j” criterion/alternative from row “j”, when compared to “k” criterion/alternative from column “k”; the magnitude of this importance is scored on the Saaty scale (1 ÷9). Whole numbers are used, 1÷9, and their reciprocals that correspond to the judgements of value made by the evaluators/decision-makers.

The score has the significance shown in Table 5, for the different judgements of value expressed lexically by the evaluators/decision-makers.

RESULTS AND DISCUSSION

Evaluator 1 produced the matrix of pair comparisons for the proportion of the three types of criteria (A=3x3 matrix), shown in Table 6, below.

Table 6 – Matrix A –Evaluator I

j/k (j=3,k=3)	C1= Technical evidences type Y object	C2= Economic evidences type Y object	C3= Ecological evidences type Y object
C1= Technical evidences type X object	1	3 → ↑	3
C2= Economic evidences type X object	1/3	1	2
C3= Ecological evidences type X object	1/3	½	1

Reading the matrix of pair comparisons drawn up by Evaluator 1 for two objects (type X and Y), which are compared between them, both of them representing criteria, is done in the direction shown by the arrow. Row 1, column 2: criterion C1 (object X) of the Technical evidences is “slightly more important” than criterion C2 (object Y) of the Economic evidences (i.e. $p_{X,Y}$ = $p_{1,2}$=3).

This evaluation is in good agreement with the evaluation from row 2, column 1: criterion C2 (object X) of the Economic evidences is “slightly less important” than criterion C1 (object Y) of the Technical evidences (i.e. $p_{X,Y}$ = $p_{2,1}$=1/3).

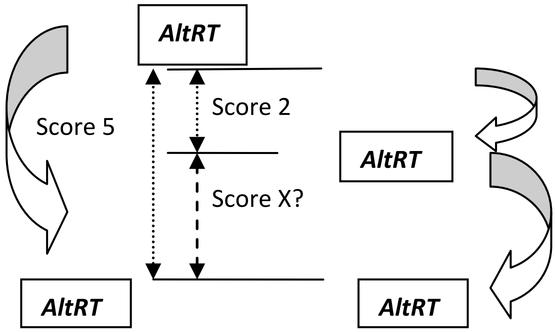
Row 1, column 3: criterion C1 of the Technical evidences is “slightly more important” than the criterion of the Ecological evidences (i.e. $p_{X,Y}$ = $p_{1,3}$=3). This evaluation is in good agreement with the evaluation from row 2, column 1: criterion C3 of the Ecological evidences is “slightly less important” than criterion C1 of the Technical evidences (i.e. $p_{X,Y}$ = $p_{3,1}$=1/3).

It must be noted that the rows from the main diagonal represent the comparison of two objects that have similar importance for the accomplishment of the objective. In this case of the Saaty scale, we have the example of the case when an object is compared with itself (Row 1, Column 1). For evaluator 1, it means comparing the technical criterion C1 (type X object from the row of the matrix) with the technical criterion C1 (type Y object from the column of the matrix). This comparison produces the score of "1" of the Saaty scale. When the dominance of an object over another object is cancelled, because "object X = object Y", it is obvious that they have an equal contribution to the accomplishment of the objective, so that this type of comparison is scored with the value/intensity of 1, i.e., equal importance for the accomplishment of the objective. Any score above 1 (whole numbers) means a higher dominance of an object over the other one, on this relative scale of importance. The lower dominance is shown as seen above, by fraction numbers. This matrix is processed according to the Saaty algorithm, producing the following proportions of Evaluator 1 for the three criteria: w^{I}_{C1}=0.594, w^{I}_{C2}=0.249, w^{I}_{C3}=0.157. The sum of these proportions must be 1. See the research paper for the detailed algorithm used by the automatic calculation sheets.

The same algorithm is also applied to the proportion of the alternatives when Evaluator 1 produces three, type-B, comparison matrices, that compare, two by two, the four alternatives, AltRT1÷AltRT4, according to each criterion, C1, C2 and C3. Thus, a matrix of pair comparison in relation with criterion C1, a matrix of pair comparison in relation with criterion C2, and a matrix of pair comparison in relation with criterion C3 are produced. These are input into the AHP calculation algorithm. Inconsistencies may appear in the initial evaluations, as shown in the case below. The evaluation can be resumed in order to check the consistency. The method accepts small inconsistencies, not higher than 10%, and provides an algorithm of verification for these inconsistencies, as shown in Figure 2.

Below is the example of Evaluator 1, who produced the first type-B matrix of pair comparisons (Table 4 – Matrix B (4x4) – C1), and who resumed the evaluation due to reasons of inconsistency, thus generating a second matrix of pair comparisons. This matrix has been subsequently processed and produced the ranking proportions for the alternatives in relation with criterion C1, shown in column w_i of the same figure.

The initial matrix from the following form has been re-evaluated resulting the left side matrix. Within the context of the entire initial assessment matrix the following comment justifies the re-evaluation, to achieve consistency: if alternative AltRT2 is better than AltRT3 assessed with the score 5 and the alternative AltRT2 is slightly better than alternative 4, being assessed with the score 2 on the same Saaty Scale, then AltRT4 cannot be assessed better then AltRT3, i.e. with score 6, superior to the score of 5 received by alternative AltRT2 when it has been compared to AltRT3.



Note: AltRT4 can not be evaluated in relation with AltRT3 with the score of 6 = which would mean a major dominance higher then 5 (essential dominance), because of its less good position compared to AltRT2, which has been evaluated with the score of 5 by the same evaluator, using the same criteria and the same scale.

Reviewed matrix- Evaluator 1 – written in decimal format

Initial matrix – Evaluator 1

In the calculations shown in Figure 2, the right side matrix is the initial matrix that has been reviewed and produced the left side matrix, which has acceptable consistency that can validate the used method. The comments explain the reason for reviewing. If alternative AltRT2 is better than alternative AltRT3, with score 5 (meaning essential/strong importance), and if alternative AltRT2 is better, with score 2 (meaning slightly better) than alternative AltRT4, then, alternative AltRT4, which is poorer than alternative AltRT2, cannot be better compared to the same reference, AltRT3, with a score of 6 (higher than 5), than AltRT2 is, under the conditions of the same evidences that support the ranking of the four alternatives one compared to the other.

Eval_I_A(4x4)	Alt RT1	Alt RT2	Alt RT3	Alt RT4		Alt RT1	Alt RT2	Alt RT3	Alt RT4
Alt RT1	1	1/8	1/5	1/7	Alt RT1	1	1/8	1/5	1/7
Alt RT2	8	1	6	2	Alt RT1	8	1	5	2
Alt RT3	5	1/6	1	1/5	Alt RT1	5	1/5	1	1/6
Alt RT4	7	1/2	5	1	Alt RT1	7	1/2	6	1

↓

Reviewed matrix -Evaluator 1 – written in decimal format

AHP Algorithm – automatic computing sheets dedicated to consistency evaluation. When the value of 1 appears in the column "Evaluation consistency", the evaluation is consistent.

$CI=(\lambda_{max}-n)/(n-1)$ CR

$CR=CI/RI$

	A(4x4)				n	4		w_i	$\sum_{i=1,4}$ AW)i/ Wi	λ_{max}	CI	CR	RI	Consis tency *
Eval_I_A (4x4)	Alt RT1	Alt RT2	Alt RT3	Alt RT4		1/4								
Alt RT1	1.000	0.125	0.200	0.143		0.004	0.245	0.040	4.319					
Alt RT2	8.000	1.000	6.000	2.000		96.000	3.130	0.517	4.157					
Alt RT3	5.000	0.165	1.000	0.2000		0.167	0.639	0.106	4.370					
Alt RT4	7.000	0.500	5.000	1.000		17.500	2.045	0.338	4.165					
							6.059		17,011	4.2581	0.08427	0.09363	0.9000	1

*1: consistent; 0: inconsistent

Figure 2 –AHP computing algorithm determining the proportions in column w_i on the basis of the reviewed comparison matrix, and on consistency verification for Evaluator 1.

The final evaluation of Evaluator 1 for the four alternatives in relation to the three criteria, weighted with w_1=0.594, w_2=0.249, w_3=0.157 is shown below, in Figure 4.

	Criterion Weight				
	C1	C2	C3		
Alternatives	0.594	0.249	0.157	Final Score Evaluator 1	Alternative Hierarchy Evaluator 1
AltRT1	0.040	0.260	0.296	0.135	IV
AltRT2	0.517	0.045	0.483	0.394	I
AltRT3	0.106	0.609	0.092	0.229	III
AltRT4	0.338	0.085	0.129	0.242	II

Figure 4 – Calculation for the final weight given by Evaluator 1 according to AHP algorithm and to the Saaty scale, in relation with the evidences for the four alternatives assigned to the three categories of weighted criteria

Evaluator 1 ranked first solution SN 2 (AltRT2), which: lowered most of all four formulation the total cholesterol in the egg yolk and in the liver; where the egg yolk is rich in omega 3 polyunsaturated fatty acids (highest amounts of the four formulations); where over 70 % of the microbiological indicators ecologically relevant to the environmental impact improve the environmental protection by their decrease, compared to the control; and where 50 % of the microbiological indicators ecologically relevant to the environmental impact improve the environmental protection by their decrease, compared to the control. For this evaluator it mattered less that this solution is the most expensive.

The other two evaluators of the panel made similar evaluations, using the procedure shown for Evaluator 1, using their own judgements (Figures 5 and 6)

The final ranking obtained from the average score for each alternative produced by each evaluator, taking into account the agreed criteria, was the following: the top two alternatives are AltRT2 (formulation E2) with a total average of 0.402, and AltRT4 (formulation E4) with a total average of 0.233.

	Criterion Weight				
	C1	C2	C3		
Alternatives	0.051	0.287	0.078	Final Score Evaluator 2	Alternative Hierarchy Evaluator 2
AltRT1	0.051	0.259	0.293	0.130	IV
AltRT2	0.519	0.041	0.557	0.385	I
AltRT3	0.092	0.621	0.062	0.242	III
AltRT4	0.337	0.079	0.088	0.244	II

Figure 5 – Calculation for the final weight given by Evaluator 2 according to AHP algorithm and to the Saaty scale, in relation with the evidences for the four alternatives assigned to the three categories of weighted criteria

	Criterion Weight				
	C1	C2	C3		
Alternatives	0.493	0.196	0.311	Final Score Evaluator 3	Alternative Hierarchy Evaluator 3
AltRT1	0.059	0.317	0.282	0.179	IV
AltRT2	0.479	0.057	0.579	0.427	I
AltRT3	0.120	0.519	0.057	0.179	III
AltRT4	0.342	0.108	0.081	0.215	II

Figure 6 – Calculation for the final weight given by Evaluator 3 according to AHP algorithm and to the Saaty scale, in relation with the evidences for the four alternatives assigned to the three categories of weighted criteria

CONCLUSIONS

AHP method allows:

- Improving the objectivity of the decisions due to the existence of a previously-agreed common set of evaluation criteria.
- Higher transparency of the decisions, allowing to review the evaluation and to check its consistency.
- Making group decisions in good time, with each evaluator/decision-maker expressing his/her own judgement by the weight given to the previously-agreed criteria.

The final ranking shows that the best two alternatives are AltRT2 (formulation E2) with a total average of 0.402, and AltRT4 (formulation E4) with a total average of 0.233.

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