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An Aggregation Function Based on Pairwise Comparisons

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Abstract: *Multiple-Criteria Decision Aid (MCDA) has long been considered in a single decision-making framework. Nowadays, the need to take into account several contradictory opinions handled by several decision-makers arises. Thus, researchers are interested in multi-criteria problems involving several decision-makers. In this context, to solve the classification problem, we propose an aggregation model based on the geometric mean and the comparison score on the considered criteria. Comparisons with two methods, AHP and TOPSIS, are performed on numerical data. It is clear that the proposed aggregation function is better depending on the complexity of the calculation and the computation time. Further research in this field is proposed.*

Keywords: *Aggregation Function, Group Decision, Multi-Criteria Decision Aiding, Ranking Problem.*

1. Introduction

It is always difficult and complex to decide with consistency when an objective set is given. Decision-makers are often faced with decision-making situations in which several points of view (objectives or criteria) must be considered simultaneously [1]. Decision-making is the study of identifying and choosing alternatives to find the best solution based on different factors while considering decision-makers' expectations [2].

Also, as noted [2], any decision is made in an environment, which is defined as a collection of information, alternatives, values and preferences available at the time the decision is to be made. The most difficult point in decision-making is the multiplicity of used criteria to judge alternatives. These objectives are often conflicting and, in most cases, different groups of decision-makers are involved in the process.

Indeed, decision-making goes beyond the framework of the mono-decision-maker [3]. The current trend is for a group of people concerned by the expertise on the decision. The different perspectives of the decision-makers (DM) must be taken into account in order to arrive at a consensual decision. The choice between alternatives is reached by a process that aims to aggregate individual preferences into a collective preference. According to [4], aggregation functions are usually defined and used to combine and summarize several numerical values into one, so that the final result of the aggregation takes into account, in a prescribed manner, all individual values.

In this article, we present a new method of aggregation and its application on a multi-decision-maker problem.The multiplicity of decision-makers shows the collective importance of decision-making within organizations [5]. Indeed, each decision-maker has his or her judgment to make in relation to the action. Then, we obtain a collective classification from which a consensual result is calculated.

2. Outlines of AFPC

The AFPC (Aggregation Function Based on Pairwise Comparisons) method is based on comparisons between the performances of the alternatives on each of the considered criteria. It is astonishingly simple but produces results as satisfactory as those produced by the highest rated aggregation functions.

2.1 Description of the method

The method is based on the ranking obtained by comparing the actions in pairs. An action x with a score greater than another action gets 2 points. There would be 0 point. In case of a tie, the two actions each 1 point.

The weights of the criteria are the geometric means of the weights assigned by the decision-makers on each criterion.

$$\varphi(a_i) = \sum_{\substack{j=1 \\ j \neq i}}^{n} \sum_{k=1}^{l} g_k . u_{ij}^k$$

Where:

g_k : Is the weight of criterion k

u_{ij}^k : Is the sum of the points obtained by the action a_i with respect to the other actions a_j for the criterion k

$$u_{ij}^k = \begin{cases} 2 \ \text{if} a_i^k > a_j^k \\ 1 \ \text{if} \ a_i^k = a_j^k \\ 0 \ \text{if} a_i^k < a_j^k \end{cases}$$

2.2 Complexity

$\forall \ k, n \ \in N$, for a comparison in pairs 2 to 2 on k alternative and n criteria, we have $\forall$ actions, $(\left[\frac{n.(n-1)}{2}\right] * k)$ comparisons.

The complexity of our method is therefore$\mathcal{O}(n^2)$, a polynomial complexity of order 2.

3. Didactic Examples

3.1 Example [6]

A multi-criterion problem where the solution that surpasses the others must be accepted by as many people as possible, and must not be rejected too clearly, even by a single one. Each decision- maker builds the judgment matrix to retain the best product among 4 products, saying what is best compared to other products.

Table 1. *Judgment Matrix for DM 1*

	Price	Life	Odor	Drying	Harm
Weight	6	3	2	4	3
P_1	6	5	2	4	5
P_2	5	6	3	3	4
P_3	7	5	4	6	3
P_4	6	4	5	3	6

Table 2. Judgment Matrix for DM 2

	Price	Life	Odor	Drying	Harm
Weight	7	5	3	3	4
P_1	7	6	2	3	3
P_2	6	5	2	5	3
P_3	5	7	3	6	4
P_4	5	4	4	4	3

Table 3. *Judgment Matrix for DM 3*

	Price	Life	Odor	Drying	Harm
Weight	6	4	2	3	3
P_1	6	5	2	4	4
P_2	7	6	3	5	3
P_3	6	5	4	3	5
P_4	5	4	3	6	4

Resolution

- The average weights for criteria are the geometric mean of the weights in relation to the following criteria:

  Price (C1) : 6.3

  Life (C2) : 3.9

  Odor (C3) : 2.3

  Drying (C4) : 3.3

  Harm (C5) : 3.3

  a. Ranking matrix by actions

  b. Note: Grays are the *ex aequos.*

Decision maker 1:

C1	C2	C3	C4	C5
P3	P2	P4	P3	P4
P1	P1	P3	P1	P1
P4	P3	P2	P2	P2
P2	P4	P1	P4	P3

Decision maker 2:

C1	C2	C3	C4	C5
P1	P3	P4	P3	P3
P2	P1	P3	P2	P1
P3	P2	P1	P4	P2
P4	P4	P2	P1	P4

Decision maker 3:

C1	C2	C3	C4	C5
P2	P2	P3	P4	P3
P1	P1	P2	P2	P1
P3	P3	P4	P1	P4
P4	P4	P1	P3	P2

c. Analysis of criteria against Decision Maker 1

- Comparison of the products against the criterion C1

	P1	P2	P3	P4	Total
P1	-	2	0	1	3
P2	0	-	0	0	0
P3	2	2	-	2	6
P4	1	2	0	-	3

- Comparison of the products against the criterion C2

	P1	P2	P3	P4	Total
P1	-	0	1	2	3
P2	2	-	2	2	6
P3	1	0	-	2	3
P4	0	0	0	-	0

- Comparison of the products against the criterion C3

	P1	P2	P3	P4	Total
P1	-	0	0	0	0
P2	2	-	0	0	2
P3	2	2	-	0	4
P4	2	2	2	-	6

- Comparison of the products against the criterion C4

	P1	P2	P3	P4	Total
P1	-	2	0	2	4
P2	0	-	0	1	1
P3	2	2	-	2	6
P4	0	1	0	-	1

- Comparison of the products against the criterion C5

	P1	P2	P3	P4	Total
P1	-	2	2	0	4
P2	0	-	2	0	2
P3	0	0	-	0	0
P4	2	2	2	-	6

d. Analysis of criteria against Decision Maker 2

- Comparison of the products against the criterion C1

	P1	P2	P3	P4	Total
P1	-	2	2	2	6
P2	0	-	2	2	4
P3	0	0	-	1	1
P4	0	0	1	-	1

- Comparison of the products against the criterion C2

	P1	P2	P3	P4	Total
P1	-	2	0	2	4
P2	0	-	0	2	2
P3	2	2	-	2	6
P4	0	0	0	-	0

- Comparison of the products against the criterion C3

	P1	P2	P3	P4	Total
P1	-	1	0	0	1
P2	1	-	0	0	1
P3	2	2	-	0	4
P4	2	2	2	-	6

- Comparison of the products against the criterion C4

	P1	P2	P3	P4	Total
P1	-	0	0	0	0
P2	2	-	0	2	4
P3	2	2	-	2	6
P4	2	0	0	-	2

- Comparison of the products against the criterion C5

	P1	P2	P3	P4	Total
P1	-	1	0	1	2
P2	1	-	0	1	2
P3	2	2	-	2	6
P4	1	1	0	-	2

e. Analysis of criteria against Decision Maker 3

- Comparison of the products against the criterion C1

	P1	P2	P3	P4	Total
P1	-	0	1	2	3
P2	2	-	2	2	6
P3	1	0	-	2	3
P4	0	0	0	-	0

- Comparison of the products against the criterion C2

	P1	P2	P3	P4	Total
P1	-	0	1	2	3
P2	2	-	2	2	6
P3	1	0	-	2	3
P4	0	0	0	-	0

- Comparison of the products against the criterion C3

	P1	P2	P3	P4	Total
P1	-	0	0	0	0
P2	2	-	0	1	3
P3	2	2	-	2	6
P4	2	1	0	-	3

- Comparison of the products against the criterion C4

	P1	P2	P3	P4	Total
P1	-	0	2	0	2
P2	2	-	2	0	4
P3	0	0	-	0	0
P4	2	2	2	-	6

- Comparison of the products against the criterion C5

	P1	P2	P3	P4	Total
P1	-	2	0	1	3
P2	0	-	0	0	0
P3	2	2	-	2	6
P4	1	2	0	-	3

f. Matrix of scores obtained by the duels

Action	DM	C1	C2	C3	C4	C5	TOTAL
		6.3	**3.9**	**2.3**	**3.3**	**3.3**	
P1	**DM 1**	3	3	0	4	4	
	DM 2	6	4	1	0	2	
	DM 3	3	3	0	2	3	
Total by criterion		**12**	**10**	**1**	**6**	**9**	**166.4**
Action	**DM**	**C1**	**C2**	**C3**	**C4**	**C5**	**TOTAL**
		6.3	**3.9**	**2.3**	**3.3**	**3.3**	
P2	**DM 1**	0	6	2	1	2	
	DM 2	4	2	1	4	2	
	DM 3	6	6	3	4	0	
Total by criterion		**10**	**14**	**6**	**9**	**4**	**174.3**
Action	**DM**	**C1**	**C2**	**C3**	**C4**	**C5**	**TOTAL**
		6.3	**3.9**	**2.3**	**3.3**	**3.3**	
P3	**DM 1**	6	3	4	6	0	
	DM 2	1	6	4	6	6	
	DM 3	3	3	6	0	6	
Total by criterion		**10**	**12**	**14**	**12**	**12**	**221.2**
Action	**DM**	**C1**	**C2**	**C3**	**C4**	**C5**	**TOTAL**
		6.3	**3.9**	**2.3**	**3.3**	3.3	
P4	**DM 1**	3	0	6	1	6	
	DM 2	1	0	6	2	2	
	DM 3	0	0	3	6	3	
Total by criterion		**4**	**0**	**15**	**9**	**11**	**125.7**

g. Calculation of the coefficient of repartition

	Totalbycriterion	Order of choice	Coefficient of repartition
P1	166.4	3	24%
P2	174.3	2	25%
P3	221.2	1	32%
P4	125.7	4	18%

The best product is product 3 (P3) for which the best total return function is 221.2.

3.2 Example [7]

A decision-maker group must choose a service provider from a group of partners in order to find the best of them.

The problem is to choose a partner from the following list:

P1= Nippon Paint KK

P2= Courtaulds Coatings Holding

P3= Kansai Paint

P4= International Paint

P5= US Set of Navy

The set of criterion is:

C1= Product quality

C2= Technology

C3= Time

C4= Cost

Table 1. *Judgment Matrix for DM 1*

	Product Quality	Technology	Time	Cost
Weights	3	4	3	5
Nippon Paint KK	6	8	9	4
Courtaulds Coatings	4	5	6	7
International Paints	7	6	8	4
Kansai Paint	6	8	4	7
US Sec Of Navy	5	4	7	6

Table 2. *Judgment Matrix for DM 2*

	Product Quality	Technology	Time	Cost
Weights	4	3	2	5
Nippon Paint KK	7	5	3	8
Courtaulds Coatings	3	6	8	4
International Paints	6	8	4	3
Kansai Paint	5	4	6	7
US Sec Of Navy	2	3	7	5

Table 3. Judgment Matrix for DM 3

	Product Quality	Technology	Time	Cost
Weights	4	5	3	5
Nippon Paint KK	8	3	6	7
Courtaulds Coatings	6	5	7	3
International Paints	5	8	4	2
Kansai Paint	4	7	3	6
US Sec Of Navy	7	6	5	8

Resolution

- The average weights of each criterion is the geometric mean of the weights against the criteria below:

  C1= 3.6

  C2= 3.9

  C3= 2.6

  C4= 5

  a. Ranking matrix by actions

Note: Grays are the *ex aequos*.

Decision-maker 1:

C1	C2	C3	C4
P3	P1	P1	P2
P1	P4	P3	P4
P4	P3	P5	P5
P5	P2	P2	P1
P2	P5	P4	P3

Decision-maker 2:

C1	C2	C3	C4
P1	P3	P2	P1
P3	P2	P5	P4
P4	P1	P4	P5
P2	P4	P3	P2
P5	P5	P1	P3

Decision-maker 3 :

C1	C2	C3	C4
P1	P3	P2	P5
P5	P4	P1	P1
P2	P5	P5	P4
P3	P2	P3	P2
P4	P1	P4	P3

b. Analysis of criteria against Decision Maker 1

- Comparison of the products against the criterion C1

	P1	P2	P3	P4	P5	Total
P1	-	2	0	1	2	5
P2	0	-	0	0	0	0
P3	2	2	-	2	2	8
P4	1	2	0	-	2	5
P5	0	2	0	0	-	2

- Comparison of the products against the criterion C2

	P1	P2	P3	P4	P5	Total
P1	-	2	2	1	2	7
P2	0	-	0	0	2	2
P3	0	2	-	0	2	4
P4	1	2	2	-	2	7
P5	0	0	0	0	0	0

- Comparison of the products against the criterion C3

	P1	P2	P3	P4	P5	Total
P1	-	2	2	2	2	8
P2	0	-	0	2	0	2
P3	0	2	-	2	2	6
P4	0	0	0	-	0	0
P5	0	2	0	2	-	4

- Comparison of the products against the criterion C4

	P1	P2	P3	P4	P5	Total
P1	-	0	1	0	0	1
P2	2	-	2	1	2	7
P3	1	0	-	0	0	1
P4	2	1	2	-	2	7
P5	2	0	2	0	-	4

c. Analysis of criteria against Decision Maker 2

- Comparison of the products against the criterion C1

	P1	P2	P3	P4	P5	Total
P1	-	2	2	2	2	8
P2	0	-	0	0	2	2
P3	0	2	-	2	2	6
P4	0	2	0	-	2	4
P5	0	0	0	0	-	0

- Comparison of the products against the criterion C2

	P1	P2	P3	P4	P5	Total
P1	-	0	0	2	2	4
P2	2	-	0	2	2	6
P3	2	2	-	2	2	8
P4	0	0	0	-	2	2
P5	0	0	0	0	0	0

- Comparison of the products against the criterion C3

	P1	P2	P3	P4	P5	Total
P1	-	0	0	0	0	0
P2	2	-	2	2	2	8
P3	2	0	-	0	0	2
P4	2	0	2	-	0	4
P5	2	0	2	2	-	6

- Comparison of the products against the criterion C4

	P1	P2	P3	P4	P5	Total
P1	-	2	2	2	2	8
P2	0	-	2	0	0	2
P3	0	0	-	0	0	0
P4	0	2	2	-	2	6
P5	0	2	2	0	-	4

d. Analysis of criteria against Decision-Maker 3

- Comparison of the products against the criterion C1

	P1	P2	P3	P4	P5	Total
P1	-	2	2	2	2	8
P2	0	-	2	2	0	4
P3	0	0	-	2	0	2
P4	0	0	0	-	0	0
P5	0	2	2	2	-	6

- Comparison of the products against the criterion C2

	P1	P2	P3	P4	P5	Total
P1	-	0	0	0	0	0
P2	2	-	0	0	0	2
P3	2	2	-	2	2	8
P4	2	2	0	-	2	6
P5	2	2	0	0	0	4

- Comparison of the products against the criterion C3

	P1	P2	P3	P4	P5	Total
P1	-	0	2	2	2	6
P2	2	-	2	2	2	8
P3	0	0	-	2	0	2
P4	0	0	0	-	0	0
P5	0	0	2	2	-	4

- Comparison of the products against the criterion C4

	P1	P2	P3	P4	P5	Total
P1	-	2	2	2	0	6
P2	0	-	2	0	0	2
P3	0	0	-	0	0	0
P4	0	2	2	-	0	4
P5	2	2	2	2	-	8

e. Matrix of scores obtained by the duels

Action	DM	C1	C2	C3	C4	TOTAL
		3.6	3.9	2.6	5	
NPK	DM 1	5	7	8	1	
	DM 2	8	4	0	8	
	DM 3	8	0	6	6	
Amount by criterion		**21**	**11**	**14**	**15**	**229.9**
Action	**DM**	**C1**	**C2**	**C3**	**C4**	**TOTAL**
		3.6	**3.9**	**2.6**	**5**	
CC	DM 1	0	2	2	7	
	DM 2	2	6	8	2	
	DM 3	4	2	8	2	
Amount by criterion		**6**	**10**	**18**	**11**	**162.4**
Action	**DM**	**C1**	**C2**	**C3**	**C4**	**TOTAL**
		3.6	**3.9**	**2.6**	**5**	
IP	DM 1	8	4	6	1	
	DM 2	6	8	2	0	
	DM 3	2	8	2	0	
Amount by criterion		**16**	**20**	**10**	**1**	**166.6**
Action	**DM**	**C1**	**C2**	**C3**	**C4**	**TOTAL**
		3.6	**3.9**	**2.6**	**5**	
KP	DM 1	5	7	0	7	
	DM 2	4	2	4	6	
	DM 3	0	6	0	4	
Amount by criterion		**9**	**15**	**4**	**17**	**186.3**
Action	**DM**	**C1**	**C2**	**C3**	**C4**	**TOTAL**
		3.6	**3.9**	**2.6**	**5**	
USN	DM 1	2	0	4	4	
	DM 2	0	0	6	4	
	DM 3	6	4	4	8	
Total by criterion		**8**	**4**	**14**	**16**	**160.8**

f. Calculation of the coefficient of repartitions

	Sumbycriterion	Order of choice	Coefficient of repartition
P1	**229.9**	**1**	**25.3%**
P2	**162.4**	**4**	**17.9%**
P3	**166.6**	**3**	**18.4%**
P4	**186.3**	**2**	**20.6%**
P5	**160.8**	**5**	**17.8%**

The best partner is NIPPON PAINT KK for which the best return function is 229.9.

3.3 Example

We want to make a wise choice on three smartphones (Nokia Lumia, Samsung Galaxy S6 et Alcatel Pixi2).

This choice depends on two criteria: the price and longevity of battery (autonomy of battery). The decision maker believes that the price is more important than the longevity.

In this choice of the best phone, the price criterion at to minimize, longevity at to maximize. The information gathered on the market is as follows:

	Price in $	Longevity in hours
Nokia Lumia	600	72
Samsung Galaxy S6	1050	144
Alcatel Pixi2	150	48

Example 3.a

- The Analytic Hierarchy Process method (AHP) gives the results below:

	Price	Longevity	
Weights	0.833	0.167	Value For Money(VFM)
Nokia Lumia	0.268	0.239	0.263
Samsung Galaxy S6	0.117	0.635	0.202
Alcatel Pixi2	0.615	0.136	0.535

The last column tells us that Alcatel Pixi2 is the best alternative. By using the usual order on the real, we have the following ranking:

Alcatel Pixi2 > Nokia Lumia > Samsung Galaxy S6

Example 3.b

We will solve this example above in (3.a) by the AFPC method:

	Price	Longevity
Nokia Lumia	600	72
Samsung Galaxy S6	1050	144
Alcatel Pixi2	150	48

The set of criterion is:

- Price = C1
- Longevity = C2

We shorten the names of our different Smartphones to have a presentable table:

- Nokia Lumia = NOK
- Samsung Galaxy S6=SAM
- Alcatel Pixi2= ALC

- Weight of the criteria taking into account the scale of values on the judgment of the decision maker between price and longevity.

	Price	Longevity	Geometric Average
Price	1	5	2.236
Longevity	1/5	1	0.447

- Comparison in pairs between smartphones in relation to price, which is a criterion to be minimized.
    - NOK < SAM score of 2 points and 0 at the opposite
    - NOK > SAM score of 0 point and 2 at the opposite
    - NOK < SAM score of 0 point and 2 at the opposite

We can summarize the scores of our comparisons in the table below:

	NOK	SAM	ALC	TOTAL
NOK	-	2	0	2
SAM	0	-	0	0
ALC	2	2	-	4

- Comparison in pairs between smartphones in relation to longevity, which is a criterion to be maximized
    - NOK < SAM score of 0 point and 2 at the opposite
    - NOK > SAM score of 2 points and 0 at the opposite
    - NOK > SAM score of 2 points and 0 at the opposite

We can summarize the scores of our comparisons in the table below:

	NOK	SAM	ALC	TOTAL
NOK	-	0	2	2
SAM	2	-	2	4
ALC	0	0	-	0

- Matrix of scores obtained by the duals

	Price	Longevity		
Weight	2.237	0.447	Score	**Coefficient of repartition**
Nokia Lumia	2	2	5.367	33%
Samsung Galaxy S6	0	4	1.789	11%
Alcatel Pixi2	4	0	8.944	56%

Nokia Lumia score is obtained by:

2*2.37 + 2*0.447 = 5.367and so forth for the others.

We can conclude the following:

Alcatel Pixi2 > Nokia Lumia > Samsung Galaxy S6

By exploiting the Java code on an HP ProBook 4540s, the AFPC method converges more quickly in 31 Milliseconds and AHP 78 Milliseconds.

4. Concluding Remarks

Through Multi-Criteria Decision Aid, approaches have been developed to help groups seeking a common solution.

The aggregation function presented in this paper combines geometric mean concepts and a score on all paired comparisons. Indeed, given the non-compensatory effect of the geometric mean, it seems well indicated for this kind of problems because our method is non-compensatory.

We have come to show that with the AFPC method, we can solve a Multicriteria problem with Multi decision maker like Mono decision maker. To assess the reliability and convergence of AFPC, we have confronted it with methods such as AHP, TOPSIS and the ELECTRE series to have the same results and also confirm that AFPC converges faster than AHP and TOPSIS.

We believe that AFPC has yet to prove itself and be compared with the most common methods.

The Studenttest as the coefficient of correlation have shown that the results of our different methods are in perfect correlations.

With the data used in our study and the discrepancies between our methods and the data of our studies are random, that is, not significant.

The AFPC method remains open for a study in the direction of the fuzzy set and why not talk about fuzzy AFPC?

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