MCDM: Multi-Criteria Decision Making Methods with R

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Abstract Selecting the best option from a set of alternatives is an ubiquitous problem nowadays. Multi-Criteria Decision Making Methods are mathematical tools designed to help in the decision process. These methods provide a ranking of the alternatives and the top ranked one is assumed to be the best option for the problem at hand. The R package **MCDM** provides four Multi-Criteria Decision Making methods: TOPSIS, VIKOR, Multi-MOORA and WASPAS that are widely used in the literature. In addition, the package provides a function *MetaRanking* that simultaneously runs all the methods and provides a ranking summary of the alternatives. We show the usage of the package with an illustrative example.

Introduction

Multiple-Criteria Decision Making (MCDM) methods are mathematical tools supporting decision makers to solve multicriteria decision problems (Raiffa and Keeney, 1976; Hwang and Yoon, 1981; Triantaphyllou, 2000; Mardani et al., 2015). MCDM methods are widely used in different areas, as economy (Steuer and Na, 2003; Bilbao-Terol et al., 2015), medicine (Baltussen and Niessen, 2006; Scherrer et al., 2015), renewable energy (Pohekar and Ramachandran, 2004; Sánchez-Lozano et al., 2014, 2015), or supply chain (Chan and Kumar, 2007; Ho et al., 2010; Lo and Sudjatmika, 2015), among others.

A typical MCDM problem consists in ranking a set of alternatives according to certain criteria. The set of alternatives as well as the criteria have to be well defined. Some criterion could be more important than another, and this importance is reflected assigning a weight to every criterion. A MCDM method processes these input information and assigns a numerical value to each alternative (a rating), from which a ranking could be easily derived. The top ranked alternative can be taken as the best option.

Many MCDM methods exists. For example, we can consider those that are based in pairwise comparisons, as the Analytic Hierarchy Process (AHP), which was introduce by Saaty (1980). Also, we can mention ELECTRE (Rogers et al., 2013) and PROMETHEE (Mareschal et al., 1984), which take into consideration preferences apart from the pairwise comparison. Others consider distances to ideal solutions, as TOPSIS (Chen et al., 1992) or VIKOR (Opricovic, 1998), which rank the alternatives according to the shortest distance to the “ideal” solution and the largest distance to the “anti-ideal” solution. Other methods are just based in aggregation operators, as WASPAS (Zavadskas et al., 2012), which combines the Weighted Sum Model and the Weighted Product Model (Triantaphyllou and Mann, 1989), or Multi-MOORA (Brauers and Zavadskas, 2010).

As far as we know, there is no package in the R repository that provides several MCDM methods for these kind of MCDM problems, so the aim of this work is to introduce an easy-to-use R package, called "**MCDM**", for solving them.

Our package provides four methods: TOPSIS, VIKOR, Multi-MOORA and WASPAS. There are three reasons supporting this selection: 1) they all rely in a normalization procedure to unify the values of the alternatives; 2) they need similar parameters to obtain the ranking, thus simplifying their usage and 3) they are widely use in the literature.

How the user should select which method to apply is an open question, and subject to study since many years (Triantaphyllou, 2000; Saaty and Ergu, 2015). That’s why we also provide an integrative function that runs all the available methods and provides meta-ranking constructed from the original rankings. In this way, the decision maker can have further support to select the best alternative.

The remainder of this paper is organized as follows. Section 2.2 provides a brief overview on MCDM, and describes the basic calculations of TOPSIS, VIKOR, Multi-MOORA and WASPAS. Section 2.3 describes the **MCDM** package in this work. Section 2.4 provides an illustrative example to show how the package works. Finally, Section 2.5 presents a summary of our work.

Multi-Criteria Decision Making Problem and Methods

The MCDM problem (Triantaphyllou, 2000) we consider here is composed by a set of alternatives, which represent the different choices available to the decision maker. It is assumed that the number of alternatives is finite, and the set is represented by $\{A_i | i = 1, 2, \ldots, m\}$, being m the number of the alternatives.

The alternatives are evaluated according to certain criteria. The criteria can have different domains, and may represent a cost (which is desirable to minimize) or a benefit (desirable to maximize). In addition, each criterion has assigned an importance weight (these weights are normalized to add up to one). The criteria are represented by $\{C_1, C_2, \ldots, C_n\}$ and the weights by $\{w_1, w_2, \ldots, w_n\}$, being n the number of the criteria.

These information is organized in a decision matrix ($M^{m \times n}$) as in Table 1, where each element x_{ij} represents the value of the alternative A_i with respect to the criterion C_j. The matrix M and the vector of weigths $W = \{w_1, w_2, \ldots, w_n\}$ are the fundamental inputs for a MCDM method.

MCDM	C_1	C_2	...	C_n
A_1	x_{11}	x_{12}	...	x_{1n}
A_2	x_{21}	x_{22}	...	x_{2n}
...	...	...	x_{ij}	...
A_m	x_{m1}	x_{m2}	...	x_{mn}

Table 1: Decision matrix of a MCDM.

As stated before our **MCDM** package provides four MCDM methods: TOPSIS, VIKOR, Multi-MOORA and WASPAS. The application of every method gives as output, a ranking of the alternatives.

Below, we will briefly describe these methods.

TOPSIS Method

TOPSIS stands for "Technique for Order Preference by Similarity to an Ideal Solution" (Chen et al., 1992). In order to rank the alternatives, it measures their distance to the positive and negative ideal solution. TOPSIS is composed by the following steps:

Step 1: since the criteria' domains could have different units, first it is necessary to normalize the decision matrix replacing every x_{ij} by n_{ij} using the following formula:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} (x_{ij})^2}} \tag{1}$$

where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

Step 2: Calculate the weighted normalized values as $v_{ij} = w_j * n_{ij}$, where w_j correspond to the weight of the j^{th} criterion, $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

Step 3: Calculate the ideal or reference solutions, which are the Positive Ideal Solution (PIS), A^+, and the Negative Ideal Solution (NIS), A^-, as follows:

$$\begin{aligned} (PIS) = A^+ = \{v_1^+, v_2^+, ..., v_j^+\} \\ (NIS) = A^- = \{v_1^-, v_2^-, ..., v_j^-\} \end{aligned} \tag{2}$$

where $v_j^+ = \max_i(v_{ij})$ and $v_j^- = \min_i(v_{ij})$ if the j^{th} criterion is benefit; and $v_j^+ = \min_i(v_{ij})$ and $v_j^- = \max_i(v_{ij})$ if the j^{th} criterion is cost, $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

Step 4: Calculate the distances from every alternative to the ideal solutions, being d_i^+ the distance to A^+, and d_i^- the distance to A^- as following:

$$\begin{aligned} d_i^+ = \left\{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2\right\}^{1/2}, i = 1, 2, ..., m; j = 1, 2, ..., n, \\ d_i^- = \left\{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2\right\}^{1/2}, i = 1, 2, ..., m; j = 1, 2, ..., n, \end{aligned} \tag{3}$$

which correspond to the m-dimensional Euclidean distance.

Step 5: Calculate the relative closeness to both ideal solutions as following:

$$R_i = \frac{d_i^-}{d_i^+ + d_i^-}, \tag{4}$$

where $i = 1, 2, \ldots, m$. If $R_i = 0$, then $d_i^- = 0$ that means it is the worst possible case. On the other

hand, if R_i = 1, then d_i^+ = 0 that means it is the best possible case. In general, $0 \leq R_i \leq 1$.
Step 6: Rank the alternatives according to R_i in descending order. The best alternative is the one with the highest R_i.

VIKOR Method

The *VIseKriterijumska Optimizacija I Kompromisno Resenje* (VIKOR) method Opricovic (1998) is, as TOPSIS, also based in the idea of the distances to "ideal solutions" (some differences exist between the methods, as stated in (Opricovic and Tzeng, 2004)).

VIKOR method follows these steps:

Step 1: Determine the best f_j^* and worst f_j^- values of each criterion as $f_j^* = \max_i(x_{ij})$ and $f_j^- = \min_i(x_{ij})$, if the j^{th} criterion is benefit, and as $f_j^* = \min_i(x_{ij})$ and $f_j^- = \max_i(x_{ij})$ if the j^{th} criterion is cost, $i = 1, 2, \ldots, m$ y $j = 1, 2, \ldots, n$.
Step 2: Normalize the x_{ij} values as follows:

$$n_{ij} = \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \tag{5}$$

where $i = 1, 2, \ldots, m$ y $j = 1, 2, \ldots, n$.
Step 3: Calculate the values S_i and R_i, $i = 1, 2, \ldots, m$ y $j = 1, 2, \ldots, n$:

$$S_i = \sum_{j=1}^{n} w_j * n_{ij}, \tag{6}$$

$$R_i = \max_j \left[w_j * n_{ij} \right] \tag{7}$$

Step 4: Calculate Q_i as follows:

$$Q_i = v \frac{(S_i - S^*)}{(S^- - S^*)} + (1 - v) \frac{(R_i - R^*)}{(R^- - R^*)} \tag{8}$$

where $S^* = \min_i(S_i)$, $S^- = \max_i(S_i)$, $R^* = \min_i(R_i)$, $R^- = \max_i(R_i)$, and $v \in$[0,1].
Parameter v balances the relative importance of indexes S and R.

Step 5: Sort Q in increasing order. The best ranked alternative is the one with the lowest value of Q.

Multi-MOORA Method

Multi-MOORA constructs a ranking departing from three calculations: the "Ratio System", the "Reference Point" and the "Full Multiplicative Form of Multiple Objectives" (Brauers and Zavadskas, 2010).

Ratio system

The first step is the normalization of the decision matrix. Normalization is done according to Eq. 1 and the values are denoted as n_{ij}. Then, the ratio y_i^* of every alternative is calculated as follows:

$$y_i^* = \sum_{j=1}^{g} n_{ij} * w_j - \sum_{j=g+1}^{n} n_{ij} * w_j \tag{9}$$

where $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, g$ are the benefit criteria and $j = g + 1, 2, \ldots, m$ are the cost criteria. A higher ratio y_i^* implies a better ranking of the alternative.

Reference point

Initially, a reference point r_j is calculated using the normalized values and the weights. It is defined as $r_j = \max_j(n_{ij} * w_j)$ if C_j is a benefit criteria, and as $r_j = \min_j(n_{ij} * w_j)$ if C_j is a cost criteria. Then, every alternative is assigned a value using the following metric:

$$\min_i(\max_j |r_j - n_{ij} * w_j|) \tag{10}$$

The lower the value, the better the alternative is.

Full multiplicative form

An additional value U_i is calculated for every alternative:

$$U_i = \frac{\prod_{j=1}^{g} n_{ij}^{w_j}}{\prod_{j=g+1}^{n} n_{ij}^{w_j}} \tag{11}$$

where $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, g$ are the benefit criteria and $j = g + 1, 2, \ldots, m$ are the cost criteria. Finally, the best ranked alternative according to the full multiplicative form is the one that has the highest value of U.

Final Ranking Construction

In order to construct the final ranking, Multi-MOORA calculates a fourth value "summary of rankings" sr_i for every alternative. This value is the sum of the positions of the alternatives in each one of the rankings previously mentioned.

Then, the final ranking is constructed sorting the alternatives in increasing order of sr_i.

WASPAS Method

The Weighted Aggregated Sum Product Assessment (WASPAS) method was first introduced in (Zavadskas et al., 2012) as a combination of two methods in order to increase the ranking accuracy. These methods are the Weighted Sum Model (WSM) and the Weighted Product Model (WPM) (Triantaphyllou and Mann, 1989). The authors proved that the accuracy of the combination of these methods is larger comparing to the accuracy of their isolated behavior.

WASPAS consists of the following steps.

Step 1: Normalization procedure: $n_{ij} = \frac{x_{ij}}{\max_i(x_{ij})}$ if the j^{th} criterion is benefit, and $n_{ij} = \frac{\min_i(x_{ij})}{x_{ij}}$ if the j^{th} criterion is cost, $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

Step 2: Calculate values according to WSM:

$$wsm_i = \sum_{j=1}^{n} n_{ij} * w_j, \tag{12}$$

where w_j is the weight of the j^{th} criterion, i=1,2,...,m and j=1,2,...,n.

Step 3: Calculate values according to WPM:

$$wpm_i = \prod_{j=1}^{n} n_{ij}^{w_j} \tag{13}$$

where w_j is the weight of the j^{th} criterion, $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

Step 4: by joining the WSM and WPM methods, we calculated the Weighted Aggregated Sum Product Assessment as follows:

$$W_i = \lambda * wsm_i + (1 - \lambda) * wpm_i \tag{14}$$

where $\lambda \in [0, 1]$, w_j is the weight of the j^{th} criterion, $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$. If λ = 0, the ranking is provided by WPM method, and if λ = 1, the ranking is provided by WSM method.

Step 5: finally, rank the alternatives according to W_i in descending order.

An R package implementing MCDM methods

The **MCDM** package offers R users a set of functions implementing the four MCDM methods described above, namely `TOPSIS`, `VIKOR`, `MMOORA` and `WASPAS`. In addition, the R package implements a function `MetaRanking` that executes the four methods and returns both, the individual rankings and a meta-ranking.

The call of the functions is as follows:

```
TOPSIS(decision,weights,cd),
VIKOR(decision,weights,cd,v),
MMOORA(decision,weights,cd),
WASPAS(decision,weights,cd,lambda),
MetaRanking(decision,weights,cd,lambda,v),
```

As it is easy to observe, three parameters are common to all the functions `decision,weights,cb`

- `decision`: is a $m \times n$ decision matrix of the problem.
- `weights`: is a vector of length n containing the importance weights associated with every criterion.
- `cb`: is also a vector of length n. `cb(i)='max'` if the criterion C_i is a benefit and `cb(i)='min'` if C_i is a cost
- `v`: is a real number between 0 and 1 corresponding to the v parameter of VIKOR method.
- `lambda`: is a real number between 0 and 1 corresponding to the λ parameter of WASPAS method.

When each function is called, a basic error checking procedure is done to assess that all the parameters exists, that the length of the vectors `weights` and `cb` is the same as the number of columns of the matrix, and that the sum of the values of the `weights` is equal to 1.

The functions return the ranking of the alternatives as data frame that contains, at least, the rating value of the corresponding method and the ranking of the alternatives. The number of columns returned depends on which method is called.

The output of the TOPSIS function is a data frame that contains the number of the alternative in the first column, the value of the R index in the second column, and the ranking of each alternative in the last column.

The output of the VIKOR function is a data frame that contains the number of the alternative in the first column, the value of the S index in the second column, the value of the R index in the third column, the value of the Q index in the fourth column, and the ranking of each alternative in the last column according to Q. With the values of S and R, the user is able to calculate the "advantage rate", if it is necessary.

The output of the Multi-MOORA function is a data frame that contains the number of the alternatives in the first column, the value of the *Ratio System* index in the second column, its corresponding ranking in the following column, the value of the *Reference point* index in the fourth column, its corresponding ranking in the following column, the value of the *Full multiplicative form* index in the sixth column, its corresponding ranking in the following column, and the ranking of Multi-MOORA in the last column.

The output of the WASPAS function is a data frame that contains the number of the alternative in the first column, the value of the W index in the second column, and the ranking of each alternative in the last column.

The output of the `MetaRanking` function is a data frame that contains the number of the alternatives in the first column, the ranking of the Multi-MOORA method in the second column, the ranking of the TOPSIS method in the third column, the ranking of the VIKOR method in the fourth column, the ranking of the WASPAS method in the fifth column and a ranking summary in the last column.

Illustrative example

In order to show the usage of the package we consider the problem of selecting a smartphone, where for each terminal we have available a set of characteristics (criteria). The information collected is shown in Table 2

The importance of the criteria is (from most importante to less important): price, battery capacity, weight, memory, screen and cameras resolution. We define the the following set of importance weights: so $w_1 = 0.1, w_2 = 0.25, w_3 = 0.1, w_4 = 0.15, w_5 = 0.05, w_6 = 0.05, w_7 = 0.3$. Table 2 also shows if each criterion is a benefit or cost.

Terminal	C_1 Screen Size	C_2 Battery (mAmp)	C_3 Internal RAM	C_4 Weight	C_5 Camera Resolution	C_6 Front Camera Resolution	C_7 Price
	'max'	'max'	'max'	'min'	'max'	'max'	'min'
A_1	5.5	2915	16	192	12	5	859
A_2	4.7	1810	16	143	12	5	749
A_3	5.7	3000	32	153	16	5	799
A_4	5.1	2600	32	132	16	5	699
A_5	5.0	2600	16	130	13	2	289
A_6	5.7	3450	64	178	12.3	8	449
A_7	5.2	2700	32	136	12.3	5	341
A_8	4.5	2470	16	115	8	5	170
A_9	5.5	3620	16	162	13	5	300
A_{10}	5.0	3120	16	144	13	5	260
A_{11}	5.2	2900	32	156	23	5	699
A_{12}	6.0	2930	16	187	13	13	399
A_{13}	5.2	2680	16	144	13	8	499
A_{14}	5.0	2200	16	131	13	5	250
A_{15}	5.2	3000	32	150	20	5	659
A_{16}	5.0	2500	8	145	8	0.9	140

Table 2: Every alternative represents a smartphone with the corresponding characteristics

This information is translated to R as follows:

```
decision = matrix(c(5.5,4.7,5.7,5.1,5,5.7,5.2,4.5,5.5,5,5.2,6,5.2,5,5.2,5,2915,1810,
3000,2600,2600,3450,2700,2470,3620,3120,2900,2930,2680,
2200,3000,2500,16,16,32,32,16,64,32,16,16,16,32,16,16,16,
32,8,192,143,153,132,130,178,136,115,162,144,156.5,187,
144,131,150,145,12,12,16,16,13,12.3,12.3,8,13,13,23,13,13,
13,20,8,5,5,5,5,2,8,5,5,5,5,5,13,8,5,5,0.9,859,749,799,699,
289,449,341,169.9,299.9,259.9,699,399,499,249.01,659,140),
16,7)
weights <- c(0.1,0.25,0.1,0.15,0.05,0.05,0.3)
cb <- c('max','max','max','min','max','max','min')
v <- 0.5
lambda <- 0.5
```

Please note that we have assigned $v = 0.5$ (for VIKOR) and $\lambda = 0.5$ (for WASPAS).

Once we have execute this code, the decision matrix obtained is:

```
[,1] [,2] [,3]  [,4] [,5] [,6]   [,7]
[1,]  5.5 2915   16 192.0 12.0  5.0 859.00
[2,]  4.7 1810   16 143.0 12.0  5.0 749.00
[3,]  5.7 3000   32 153.0 16.0  5.0 799.00
[4,]  5.1 2600   32 132.0 16.0  5.0 699.00
[5,]  5.0 2600   16 130.0 13.0  2.0 289.00
[6,]  5.7 3450   64 178.0 12.3  8.0 449.00
[7,]  5.2 2700   32 136.0 12.3  5.0 341.00
[8,]  4.5 2470   16 115.0  8.0  5.0 169.90
[9,]  5.5 3620   16 162.0 13.0  5.0 299.90
[10,]  5.0 3120   16 144.0 13.0  5.0 259.90
[11,]  5.2 2900   32 156.5 23.0  5.0 699.00
[12,]  6.0 2930   16 187.0 13.0 13.0 399.00
[13,]  5.2 2680   16 144.0 13.0  8.0 499.00
[14,]  5.0 2200   16 131.0 13.0  5.0 249.01
[15,]  5.2 3000   32 150.0 20.0  5.0 659.00
[16,]  5.0 2500    8 145.0  8.0  0.9 140.00
```

Next, we call the methods available in the package as follows:

```
TOPSIS(decision, weights, cb)
VIKOR(decision, weights, cb, v)
MMOORA(decision, weights, cb)
```

```
WASPAS(decision,weights,cb,lambda)
MetaRanking(decision, weights, cd, lambda, v)
```

The outputs of the functions are the following:

TOPSIS: the output is composed by the *R* index and the ranking of the alternatives.

Alt	R	Ranking
1	0.1924	15
2	0.1767	16
3	0.2773	14
4	0.3127	13
5	0.5866	8
6	0.6421	2
7	0.6181	5
8	0.6440	1
9	0.6228	4
10	0.6330	3
11	0.3316	12
12	0.5442	9
13	0.4467	10
14	0.5981	7
15	0.3663	11
16	0.6164	6

VIKOR: the output is composed by the *S*, *R* and *Q* indexes and the ranking of the alternatives.

Alt	S	R	Q	Ranking
1	0.7361	0.3000	0.9293	16
2	0.8007	0.2541	0.8929	15
3	0.5681	0.2749	0.6871	14
4	0.5807	0.2332	0.6035	13
5	0.4634	0.1408	0.2597	6
6	0.3514	0.1289	0.1093	3
7	0.4310	0.1270	0.1920	4
8	0.4400	0.1588	0.2760	7
9	0.3437	0.0915	0.0136	1
10	0.3943	0.0857	0.0553	2
11	0.5570	0.2332	0.5776	12
12	0.4626	0.1402	0.2574	5
13	0.5291	0.1497	0.3523	9
14	0.4915	0.1961	0.4193	10
15	0.5239	0.2165	0.5024	11
16	0.4798	0.1546	0.3098	8

Multi-MOORA: the output is composed by the *Ratio System* and its ranking, the *Reference Point* and its ranking, the *Full multiplicative form* and its ranking, and the Multi-MOORA ranking. The output has been edited for visualization purposes. We used the following abbreviations: "Rank1 = Ranking.1", "RefPoint = ReferencePoint", "Rank2 = Ranking.2", "MultForm = MultiplicativeForm", "Rank3 = Ranking.3" and "M-MooraRank = MultiMooraRanking".

Alt	RatioSystem	Rank1	RefPoint	Rank2	MultForm	Rank3	M-MooraRank
1	-0.0431	15	0.1025	16	0.6860	15	16
2	-0.0436	16	0.0868	14	0.6528	16	15
3	-0.0036	14	0.0939	15	0.7972	14	14
4	0.0040	13	0.0797	13	0.8095	13	13
5	0.0387	9	0.0445	8	0.9310	8	8
6	0.0827	1	0.0440	2	1.0389	2	1
7	0.0535	5	0.0297	1	0.9978	5	3
8	0.0560	4	0.0445	3	1.1101	1	2
9	0.0605	2	0.0445	4	1.0227	4	4
10	0.0572	3	0.0445	6	1.0370	3	5
11	0.0113	12	0.0797	12	0.8274	12	12
12	0.0439	6	0.0445	5	0.9221	9	7
13	0.0205	10	0.0511	9	0.8437	11	10
14	0.0415	7	0.0445	7	0.9763	7	6

```
15      0.0182      11      0.0740        11          0.8488     10            11
16      0.0399       8      0.0520        10          0.9863      6             9
```

WASPAS: the output is composed by the *W* index and the ranking of the alternatives.

```
Alt        W        Ranking
1         0.4537      15
2         0.4180      16
3         0.5213      13
4         0.5188      14
5         0.5760       8
6         0.6475       2
7         0.6043       6
8         0.6801       1
9         0.6325       5
10         0.6327       4
11         0.5327      11
12         0.5740       9
13         0.5291      12
14         0.5925       7
15         0.5434      10
16         0.6455       3
```

MetaRanking: from the previous function calls, it is clear that the rankings produced by every method are different. In a single call to the MetaRanking function we can obtain the rankings of each method, Multi-MOORA, TOPSIS, VIKOR and WASPAS. Besides this, the function returns a meta-ranking which combines the information of the positions that every alternative achieve in every individual ranking.

```
Alt MMOORA TOPSIS VIKOR WASPAS METARANKING
1     16     15    16     15          16
2     15     16    15     16          15
3     14     14    14     13          14
4     13     13    13     14          13
5      8      8     6      8           9
6      1      2     3      2           1
7      3      5     4      6           5
8      2      1     7      1           2
9      5      4     1      5           4
10      4      3     2      4           3
11     12     12    12     11          12
12      7      9     5      9           8
13     10     10     9     12          10
14      6      7    10      7           7
15     11     11    11     10          11
16      9      6     8      3           6
```

In this example, and according to the MetaRanking, the best alternatives are 6, 8 and 10. It is interesting to note the case for alternative 8. Under the VIKOR's ranking, it appears in the position 7, while the other methods assign it the positions 2, 1, 1.

This is a quite common problem and an open field of research as it was recently hihglighted in Saaty and Ergu (2015).

Summary

In this work we have presented an R package called **MCDM**, which is composed by four MCDM methods in order to solve MCDM problems. The MCDM methods that are implemented in this package are TOPSIS, VIKOR, Multi-MOORA and WASPAS, and they have been implemented as four different functions: `TOPSIS`, `VIKOR`, `MMOORA` and `WASPAS`, respectively. We have chosen these methods because they share the normalization procedure and they need very similar parameters. Also, and to partially address the problem of selecting an individual method, we provided a `MetaRanking` function which simultaneously runs all the available methods and returns a summary ranking.

To clarify how the package works, we have developed an example to show how the functions should be called and the output that provide each function.

We are confident that this package will be helpful for both practitioners and academics interested in practical applications and theoretical analyses of the MCDM methods.

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