

Correlated Criteria in Decision Models: Recurrent Application of TOPSIS Method

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Abstract

The purpose of multicriteria decision models is to help decision maker to evaluate each alternative and to rank them in descending order of performance. A problem can appear when the criteria are not independent. This study explores the effect of multicollinearity between criteria in decision making with the technique for order preference by similarity to ideal solution (TOPSIS) and proposes an algorithm to resolve this problem. The algorithm was based on the application of the TOPSIS method several times until all the components are uncorrelated. The algorithm was applied on two examples from medical field to demonstrate its effectiveness. After we applied the proposed algorithm on two examples the index result from TOPSIS was equal correlated with all the criteria.

Keywords: TOPSIS method; Diabetes mellitus type 2; Multicollinearity.

Introduction

Problems of decision making where the evaluation of possible alternatives with different criteria are widespread today not only in the economy. To resolve a situation and choose that alternative which is optimal in terms of evaluation criteria is a problem not only important but also difficult.

We consider the multiattribut decision models because it may have applications in the medical field [1-6]. Multi-criteria methods were used in the medical fields in combination with Shanon entropy [7-8], fuzzy teory [9], artificial intelligence algorithms [10] or neural networks [11].

From the multiattribut decision making methods we chose TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method because it can be use not only to determin the best alternative, but it can be use for ranking the alternatives.

In TOPSIS method the best alternative is considered the alternative that minimizes the distance to the ideal solution. The ideal solution is the solution that maximizes all the maximum criteria and minimizes all the minimum criteria. The optimal alternative is the alternative for which the distance to ideal solution is minimal [12]. Hwang and Yoon introduced this method in 1981 [13]. TOPSIS method was used in medical field by several authors [14-20]. We found only two studies in medical field were the authors applied TOPSIS method for rank risk factors: in bronchial asthma [19] and in post kidney transplant diabetes mellitus [20]. TOPSIS method takes in account the characteristics of the factors: risk or protection factor and amplitude of their influence [20].

The assumptions of the TOPSIS method are independence and non-correlation between attributes [21]. This assumption frequently is violated and then the evaluations done using TOPSIS

in presence of multicollinearity can be wrong [22].

The aim of our study was to explore the effect of multicollinearity between two or more criteria in a decision making model with TOPSIS and to found a solution for the multicollinearity problem.

Material and Method

TOPSIS Method

We have, generally, m indicators (symptoms, characteristics, criteria) $C_j, j=\overline{1,m}$ of the same condition (disease, problem, state) and n alternative solutions $V_i, i=\overline{1,n}$. In the following, we present the algorithm steps [12].

- Step 1. Construct the matrix of consequences $A = [a_{ij}], i = \overline{1,n}, j = \overline{1,m}$
- Step 2. Construct the matrix of normalized consequences $R = [r_{ij}], i = \overline{1,n}, j = \overline{1,m}$.
- Step 3. Construct the weighted-normalized matrix $V = [v_{ij}]$ with the criteria importance coefficients: $W=[w_j], j = \overline{1,m}$, the weights of each criteria $C_j, j = \overline{1,m}$, where:

$$v_{ij} = w_j \cdot r_{ij}, i = \overline{1,n}, j = \overline{1,m}$$

- Step 4. Define the positive ideal solution vector V^+ and the negative ideal solution vector V^- (the vector for minimal value of alternatives if the criteria is a minimal criteria or the maxim value of alternatives if the criteria is a maxim criteria) thus:

$$V^+ = (v_1^+, v_2^+, \dots, v_m^+), V^- = (v_1^-, v_2^-, \dots, v_m^-)$$

where:

$$v_j^+ = \begin{cases} \max_{1 \leq i \leq n} \{v_{ij}\}, & \text{when } C_j \text{ is a maximum criteria} \\ \min_{1 \leq i \leq n} \{v_{ij}\}, & \text{when } C_j \text{ is a minimum criteria} \end{cases}$$

and

$$v_j^- = \begin{cases} \max_{1 \leq i \leq n} \{v_{ij}\}, & \text{when } C_j \text{ is a maximum criteria} \\ \min_{1 \leq i \leq n} \{v_{ij}\}, & \text{when } C_j \text{ is a minimum criteria} \end{cases}$$

- Step 5. The calculation of distance between the i alternative and the positive ideal alternative V^+ and the calculation of distance between the i alternative and the negative ideal alternative V^- :

$$S_{i+} = \left[\sum_{j=1}^m (v_{ij} - v_j^+)^2 \right]^{1/2}, i = \overline{1,n} \quad (1)$$

$$S_{i-} = \left[\sum_{j=1}^m (v_{ij} - v_j^-)^2 \right]^{1/2}, i = \overline{1,n} \quad (2)$$

- Step 6. The determination of the index to positive ideal solution:

$$In_i = \frac{S_{i-}}{S_{i+} + S_{i-}}, i = \overline{1,n}$$

An alternative V_i is more near to V^+ the more In_i is close to 1.

A number of distance metrics can be applied. TOPSIS2 is a variant where distance was

measured in least absolute value terms. Another commonly used metric is the Tchebychev metric, where the minimum maximum difference is the basis for selection [23].

Problem of Collinearity

We define collinearity of the criteria as a linear relationship between two criteria. Two criteria are perfectly collinear if there is an exact linear relationship between them. If X, Y are two criteria with $x_i, i=1, n$ respectively $y_i, i=1, n$ values for each alternatives, then there exist parameters a and b such that, for all alternatives i , we have [24]:

$$y_i = a + bx_i \tag{3}$$

In this case the Pearson coefficient of correlation is $r=1.00$ or $r=-1.00$. (3) is the regression line equations.

We define multicollinearity as a situation in which two or more criteria are in a high linear relationship. Two or more criteria are perfectly multicollinear if there is an exact linear relationship between them. If Y is the dependent criteria and $X_j, j=1, m$ are m independent criteria, $y_i, i=1, n$ respectively $x_{ij}, i=1, n, j=1, m$ values for each alternative, then there exists parameters a and $b_j, j=1, m$ such that, for all alternatives i , we have [24]:

$$y_i = a + b_1x_{i1} + b_2x_{i2} + \dots + b_mx_{im} .$$

Example 1. We took data from 500 patients with diabetes mellitus type 2 recorded at Center of Diabetes, Nutrition and Metabolic Diseases, Cluj-Napoca, Romania. The TOPSIS method could be applied in this particular case for the ranking of patients in order to predict the risk for the complications of diabetes mellitus like: retinopathy, diabetic nephropathy and neuropathy. Three parameters that can be taken into account in predicting risk in this case are glycaemia, cholesterol and LDL-cholesterol. All the criteria in our example were maximum criteria. We choose these three parameters because they meet our requirements.

Mathematical model: Let be X, Y, Z three criteria (glycaemia, cholesterol and LDL-cholesterol) with $x_i, i=1, 500$ respectively $y_i, i=1, 500, z_i, i=1, 500$, values for each alternatives (patients with diabetes mellitus). The Pearson coefficients of correlation were $r(X,Y)=0.003, r(X,Z)=-0.03$ respectively $r(Y,Z)=0.89$.

- Phase 1. We applied TOPSIS for two independent criteria X, Y (weights: $w_x=1, w_y=1$). We noted the results $In(X,Y)_i, i=1, 500$.

The Pearson coefficients of correlation were $r(In(X,Y),X)=0.71$ and $r(In(X,Y),Y)=0.70$. Both of criteria have the same participation in the composition of index In .

- Phase 2. We applied TOPSIS for three criteria X, Y and Z ($w_x=1, w_y=1, w_z=1$). We noted the results $In(X,Y,Z)_i, i=1, 500$.

The Pearson coefficients of correlation were $r(In(X,Y,Z),X)=0.59, r(In(X,Y,Z),Y)=0.78$ and $r(In(X,Y,Z),Z)=0.74$.

- Phase 3. We applied TOPSIS for two independent criteria X, Y ($w_x=1, w_y=2$). We noted the results $In(X,Y)_i, i=1, 500$.

The Pearson coefficients of correlation were $r(In(X,Y),X)=0.51$ and $r(In(X,Y),Y)=0.85$.

From this example we can formulate the following proposition:

Proposition. If $C_j, j=1, m$ criteria, where $C_k, k=1, p$ are independent criteria with $w_k, k=1, p$ weights; $C'_l, l=1, s$ are pairs of perfectly collinear criteria, $w'_l, l=1, s$ weights, $p+s=m$, then the result of TOPSIS method $In_i, i=1, n$ is the same as the results of a model with the same $C_k, k=1, p$ criteria with the weights $w_k, k=1, p$, and $C'_l, l=1, \frac{s}{2}$ (one of each pairs of perfectly collinear

criteria) with the weights $w_1 = \sqrt{1 + b^2}$, $l = 1, \frac{s}{2}$, where $b, l = 1, \frac{s}{2}$ are the coefficients of regression line.

Demonstration. If $s=2$ and C_1' perfectly correlated with C_2' then, from (1) and (3), S_{i+} become:

$$S_{i+} = \left\{ \sum_{k=1}^p (v_{ik} - v_k^+)^2 + (v'_{i1} - v_1^+)^2 + [a + bv'_{i1} - (a + bv_1^+)]^2 \right\}^{1/2} =$$

$$= \left[\sum_{k=1}^p (v_{ik} - v_k^+)^2 + (v'_{i1} - v_1^+)^2 + b^2(v'_{i1} - v_1^+)^2 \right]^{1/2} = \left[\sum_{k=1}^p (v_{ik} - v_k^+)^2 + (v'_{i1} - v_1^+)^2(1 + b^2) \right]^{1/2}$$

Analog for S_{i-} .

Let $w_k=1, k=1, p$ and $w'_1=t$ then:

$$S'_{i+} = \left[\sum_{k=1}^p (w_k v_{ik} - w_k v_k^+)^2 + (w'_1 v'_{i1} - w'_1 v_1^+)^2 \right]^{1/2} = \left[\sum_{k=1}^p (v_{ik} - v_k^+)^2 + t^2(v'_{i1} - v_1^+)^2 \right]^{1/2}.$$

Analog for S'_{i-} .

Thus $S_{i+} = S'_{i+}$ if $t = \sqrt{1 + b^2}$. Analog for $S_{i-} = S'_{i-}$.

Thus $In_i = In'_i$ if $t = \sqrt{1 + b^2}$.

Example 2. We took data from 304 patients with diabetes mellitus type 2 recorded at Center of Diabetes, Nutrition and Metabolic Diseases, Cluj-Napoca, Romania. For this example we use five parameters to simulate our algorithm (Patients were different than the first example). The TOPSIS method can be apply in this particular case for the ranking of patients similar with [19-20, 25]. For criteria $C_j, j=1,5$ we consider abdominal circumference, cholesterol, triglyceride, systolic blood pressure and diastolic blood pressure. All the criteria in our example were maximum criteria. We choose these parameters because they meet our requirements.

- Phase 2. We applied TOPSIS for the criteria $C_j, j=1,5$ (weights=1 for all criteria). We noted the results $In_i, i=1,304$. The Pearson coefficients of correlation were $r(In, C_1)=0.21, r(In, C_2)=0.51, r(In, C_3)=0.56, r(In, C_4)=0.69$ and $r(In, C_5)=-0.71$.

Solution

We propose the next algorithm:

Step 1. Compute the Pearson correlation matrix $r_{ij}, i, j=1, m$ between $C_j, j=1, m$;

Step 2. $\max=0$;

Step 3. Get $r_{kl}=\max$ from $r_{ij}, i, j=1, m \setminus r_{ij}, i=j$, where $i, j=1, m$;

Step 4. If $|r_{kl}| \geq 0.25$ then begin

$In(C_k, C_l) = \text{Apply TOPSIS}(C_k, C_l)$;

Replace C_k with $In(C_k, C_l)$;

Standardize C_k ;

Delete C_j ;

$m=m-1$;

if $m=1$ then Stop;

Go to Step 1.

end;

else Stop.

Where "apply TOPSIS(C_k, C_l)" means the application of TOPSIS for two criteria C_k and C_l . We took the cut-off from the empirical appreciations (Colton rules [24]).

Results

We applied the algorithm in the case of the **example 1**. We had three criteria X, Y, Z ($C_j, j=1,3$ (glycaemia, cholesterol and LDL cholesterol) and 500 alternatives (patients with diabetes mellitus).

First iteration

- Step 1. The Pearson correlation matrix was presented in table 1.

Table 1. The Pearson correlation matrix $r_{ij}, i=1,3, j=1,3$ between criteria X, Y, Z ($C_j, j=1,3$)

	Glycaemia	Cholesterol	LDL-cholesterol
Glycaemia	1.00	0.003	-0.03
Cholesterol	0.003	1.00	0.89
LDL-cholesterol	-0.03	0.89	1.00

- Step 2. $\max=0$;
- Step 3. $\max=r_{32}=0.89$;
- Step 4. We applied TOPSIS method for C_2 and C_3 . We found $In(C_2,C_3)$. The Pearson coefficient of correlation $r(In(C_2,C_3),C_2)=0.97$ and $r(In(C_2,C_3),C_3)=0.97$. We replaced C_2 with $In(C_2,C_3)$. We deleted C_3 . $m=2$. We repeated Step 1.

Second iteration

- Step 1. The Pearson correlation matrix was presented in Table 2.

Table 2. The Pearson correlation matrix $r_{ij}, i=1,2, j=1,2$ between criteria X, $In(C_2,C_3)$

	Glycaemia	$In(C_2,C_3)$
Glycaemia	1.00	-0.02
$In(C_2,C_3)$	-0.02	1.00

- Step 2. $\max=0$; Step 3. $\max=r_{21}=-0.02$; Step 4. Stop.
The problem of the collinearity was resolved, thus TOPSIS method can be applied.
Phase 4. We applied TOPSIS for two independent criteria X, $In(Y,Z)$ ($w_x=1, w_{in}=1$). We noted the results $In(X,In)_i, i=1,500$.

The Pearson coefficients of correlation were $r(In(X,In),X)=0.73$, $r(In(X,In),Y)=0.66$ and $r(In(X,In),Z)=0.64$.

We applied the algorithm in the case of **second example**. We had five criteria $C_j, j=1,5$ (abdominal circumference, cholesterol, triglyceride, systolic blood pressure and diastolic blood pressure) and 304 alternatives (patients with diabetes mellitus).

First iteration

- Step 1. The Pearson correlation matrix was presented in Table 3.

Table 3. The Pearson correlation matrix $r_{ij}, i=1,5, j=1,5$ between criteria $C_j, j=1,5$

	Abdominal circumference	Cholesterol	Triglyceride	Systolic blood pressure	Diastolic blood pressure
Abdominal circumference	1.00	0.24	-0.08	-0.09	-0.10
Cholesterol	0.24	1.00	0.30	0.01	-0.01
Triglyceride	-0.08	0.30	1.00	0.16	0.16
Systolic blood pressure	-0.09	0.01	0.16	1.00	0.62
Diastolic blood pressure	-0.10	-0.01	0.16	0.62	1.00

- Step 2. $\max=0$; Step 3. $\max=r_{54}=0.62$;
- Step 4. We applied TOPSIS method for C_5 and C_4 . We found $In(C_4, C_5)$. The Pearson coefficient of correlation $r(In(C_4, C_5), C_4)=0.87$ and $r(In(C_4, C_5), C_5)=0.92$. We replaced C_4 with $In(C_4, C_5)$. We deleted C_5 . $m=4$. We repeated Step 1.

Second iteration

- Step 1. The Pearson correlation matrix was presented in Table 4.

Table 4. The Pearson correlation matrix r_{ij} , $i=\overline{1,4}$, $j=\overline{1,4}$ between criteria $C_1, C_2, C_3, In(C_4, C_5)$

	Abdominal circumference	Cholesterol	Triglyceride	$In(C_4, C_5)$
Abdominal circumference	1.00	0.24	-0.08	-0.10
Cholesterol	0.24	1.00	0.30	0.00
Triglyceride	-0.08	0.30	1.00	0.18
$In(C_4, C_5)$	-0.10	0.00	0.18	1.00

- Step 2. $\max=0$; Step 3. $\max=r_{32}=0.30$;
- Step 4. We applied TOPSIS method for C_2 and C_3 . We found $In(C_2, C_3)$. The Pearson coefficient of correlation $r(In(C_2, C_3), C_2)=0.86$ and $r(In(C_2, C_3), C_3)=0.89$. We replaced C_2 with $In(C_2, C_3)$. We deleted C_3 . $m=3$. We repeated Step 1.

Third iteration

- Step 1. The Pearson correlation matrix was presented in table 5.

Table 5. The Pearson correlation matrix r_{ij} , $i=\overline{1,3}$, $j=\overline{1,3}$ between criteria $C_1, In(C_2, C_3), In(C_4, C_5)$

	Abdominal circumference	$In(C_2, C_3)$	$In(C_4, C_5)$
Abdominal circumference	1.00	0.08	-0.10
$In(C_2, C_3)$	0.08	1.00	0.13
$In(C_4, C_5)$	-0.10	0.13	1.00

- Step 2. $\max=0$;
- Step 3. $\max=r_{21}=0.13$;
- Step 4. Stop

The problem of the collinearity was resolved, thus TOPSIS method can be applied.

Phase 4 (for example 2). We applied TOPSIS for three independent criteria $C_1, In(C_2, C_3), In(C_4, C_5)$ (weights=1 for all criteria). We noted the results In_i , $i=\overline{1,3}$. The Pearson coefficients of correlation were $r(In, C_1)=0.58$, $r(In, C_2)=0.63$, $r(In, C_3)=0.55$, $r(In, C_4)=0.42$ and $r(In, C_5)=0.42$.

Discussion

In example 1 criterion X was not correlated with the other two criteria Y and Z, but Y was strong correlated with Z. The index result from TOPSIS (Phase4) was more correlated with Y $r(In(X, Y, Z), Y)=0.78$ and Z $r(In(X, Y, Z), Z)=0.74$, than with X $r(In(X, Y, Z), X)=0.59$. Even if X and Y were not perfectly correlated they influenced the results.

In example 2 criterion C_1 was not correlated with the other four criteria. The index result from TOPSIS (Phase4) was more correlated with C_2-C_5 ($r(In, C_2)=0.51$, $r(In, C_3)=0.56$, $r(In, C_4)=0.69$ and $r(In, C_5)=-0.71$), than with C_1 ($r(In, C_1)=0.21$).

After we applied the purposed algorithm the index result from TOPSIS (Phase4) was equal correlated with all the criteria (for first example $r(In(X, In), X)=0.73$, $r(In(X, In), Y)=0.66$ and

$r(\text{In}(X,\text{In}),Z)=0.64$; for second example $r(\text{In},C_1)=0.58$, $r(\text{In},C_2)=0.63$, $r(\text{In},C_3)=0.55$, $r(\text{In},C_4)=0.42$ and $r(\text{In},C_5)=0.42$). Our algorithm fulfilled its purpose in the case of our examples.

Jorge et al. resolved the problem of collinearity by replacing the traditional Euclidian distance to the ideal solution with malahanobis distance [21]. Monavvarian et al. used analytic network process to evaluate weights for dependent criteria and applied TOPSIS with these weights [26-27]. The analytic network process is a general theory in the ratio scale that measures influence, based on a methodology that deals with dependence and feedback [28]. Liberatore et al. emphasized that analytic hierarchy process can be applied successfully in the medical field [29].

Tong et al. used principal component analysis to obtain a set of uncorrelated components from the set of criteria and then applied TOPSIS method to determine the alternative that optimized the distance to ideal solution [30].

In our study we applied TOPSIS method in a recurrent manner until the coefficients of correlation were less than 0.25. The disadvantage of our algorithm is that we took the cut-off from the empirical appreciations (Colton rules [24]) and is not necessary that a correlation less than 0.25 not influence the results of TOPSIS method. This cut-off 0.25 is debatable. It remained for further study to establish a better way to end the algorithm.

The algorithm can be used for weights different then 1.

The proposed algorithm has a strong empirical justification relying on examples. It remained for further study to compare the algorithm proposed in this paper with different methods.

Conclusion

The proposed algorithm can solve the problem of multicollinearity between criteria in the problem of decision making. The purpose of our algorithm was to apply recurrent the TOPSIS method until the correlations between components are reduced below a threshold.

List of abbreviations

TOPSIS = Technique for Order Preference by Similarity to Ideal Solution

Conflict of Interest

The authors declare that they have no conflict of interest.

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