Flaws of Quantification Method as applied to Software Requirements Prioritization

M. Shanmuganathan [1] and K. Kajendran [2]
[1] Assistant Prof(G-I), Dept of C.S.E, Panimalar Engineering College,
[2] Associate Prof., Dept of C.S.E, Panimalar Engineering College,

***Abstract* - This paper deals with decision-making using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) , one of the Multi- Criteria Decision-Making (MCDM) methods, which was originally developed by Hwang and Yoon in 1981with further developments by Yoon in 1987 and Hwang, Lai and Liu in 1993. It is a goal based approach for finding the alternative that is closest to the optimal solution . In this method, alternatives are graded based on optimal solution or alternative similarity. Optimal solution is a solution that is the best or perfect from any aspect that does not exist practically and tries to approximate it. Basically, for measuring similarity of an alternative to optimal level and non-optimal, we consider distance of the alternative from optimal and non-optimal solution. It explains the usefulness of TOPSIS in decision-making, quantification of data, solving complex problems, besides touching upon some basic concepts, ideas, benefits, and drawbacks of TOPSIS. The paper includes : I.Introduction, II. Algorithm of TOPSIS, III. Numerical Example, IV. Phenomenon of Rank Reversal, V. Conclusion, and VI. References .**

Keywords : Multi-Criteria Decision-Making, Technique for Order Preference by Similarity to Ideal Solution , Decision-Making, Rank Reversal.

I. INTRODUCTION :

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is an easily understandable, and a systematic Multi-Criteria Decision-Making (MCDM) technique , which was introduced by Hwang and Yoon in the year 1981[1][2][4][8][9][10] with further developments by Yoon in 1987 and Hwang[11][12], Lai and Liu in 1993[5]. This technique is based on the concept that the chosen alternative should have the shortest distance from the positive optimal solution and the longest distance from the negative optimal solution. If an alternative is more similar to optimal solution , it has a higher grade[11] This principle has been also suggested by Zeleny (1982) and Hall(1989) and it has been enriched by Yoon(1987) and Hwang,Lai and Liu (1993).It defines m x n matrix, m alternatives and n criteria and assigns priority to alternatives. It is purely a goal based approach for finding the alternative that is closest to the ideal solution . It is simple to use and takes into account all types of criteria (subjective and objective). It reduces a huge complex problem into a more structured format and facilitates a more practical approach. The computation processes are straight-forward. It is applied in many Engineering , Scientific, and other commercial fields[6]. A Decision-Maker, who can understand the entire domain of the problem and who has the knowledge of the domain, can use this method without any difficulty. Thus TOPSIS can be considered to be one of the Multi-Criteria Decision-Making Methods for solving certain complex problems.

II. ALGORITHM OF TOPSIS:

The basic TOPSIS technique consists of the following steps :

Step (1) : Construct m x n matrix for alternative performance with respect to criteria available, m denotes the number of alternatives and n denotes number of criteria. The structure of the matrix can be expressed as

C1 C2 . . Cn

$$D = \begin{array}{c|cccc} & & & & \\ A1 & x_{11} & x_{12} & .. & x_{1n} \\ A2 & x_{21} & x_{22} & .. & x_{2n} \\ & . & . & . & . \\ Am & x_{m1} & x_{m2} & .. & x_{mn} \end{array}$$

Where Ai denotes the possible alternatives i = 1 .. m , Cj denotes the possible criteria relating to alternative performance j=1..n, X_{ij} is an exact value indicating the performance rating of each alternative Ai with respect to each criterion C_j

Step (2) : Calculate the normalized m x n matrix $R(=r_{ij})$. The normalized value r_{ij} is calculated as

$r_{ij} = x_{ij} / \sqrt{(\Sigma x_{ij}^2)}$ for i=1 ..m, j=1 .. n

Step(3) : Calculate the weighted normalized matrix by multiplying the normalized decision matrix by its associated weights. The weighted normalized value V_{ij} is calculated as $V_{ij} = W_j r_{ij}$, for i=1 ..m, j=1 .. n where w_j represents the weight of the j^{th} criterion

Step(4) : Determine the ideal and negative ideal solutions

$V^+ = \{V_1^+, \ldots\ldots\ldots, Vn^+\} = \{(\max V_{ij} \mid j \in J), (\min V_{ij} \mid j \in J^1)\}$

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$V^- = \{V_1^-, \ldots\ldots\ldots, Vn^-\} = \{(\min V_{ij} \mid j \in J), (\max V_{ij} \mid j \in J^1)\}$
Where J is associated with benefit criteria and J^1 is associated with cost criteria

Step(5) : Calculate the separation measures, using the m – dimensional shortest distance. The separation of each alternative from the ideal solution (D_i^+) is given as $D_i^+ = \sqrt{(\Sigma(V_{ij} - V_j^+)^2}$, i=1..m, j=1..n. Similarly, the separation of each alternative from the negative ideal solution (D_i^-) is as follows

$D_i^- = \sqrt{(\Sigma(V_{ij} - V_j^-)^2}$, i=1..m, j=1..n

Step(6) : Determine the relative closeness to the ideal solution and rank the preferences. The relative closeness of the alternative Ai with respect to V^+ can be expressed as $C_i = D_i^- / (D_i^+ + D_i^-)$, i=1….m , where Ci index value lies between 0 and 1. The higher the index value, the better the performance of the alternatives will be.

Step(7) : Rank the preference Order

III. NUMERICAL EXAMPLE

This paper demonstrates that the decision-maker(software developer) wants to choose a sequence from a set of feasible requirements - Requirement -1(R1), Requirement- 2(R2), Requirement- 3(R3), Requirement- 4(R4) against criteria Criterion-1(C1), Criterion-2(C2) and Criterion-3(C3).

Start of TOPSIS method :

Step (1) : Construct m x n matrix for alternative performance with respect to criteria available, m denotes the number of alternatives (R1, R2, R3, R4) and n denotes number of criteria (C1,C2,C3). In this step the decision-maker's use the linguistic weighting variables to assess the importance of the criteria. They use the linguistic rating variables to evaluate the rating of alternatives with respect to each criterion. The human feelings are converted into numbers inorder to construct a matrix. The linguistic variables are converted into numerical values by using a 10 point scale

VL	Very Low	0	VP	Very Poor	0	VL	Very Slow	0
L	Low	1	P	Poor	1	L	Slow	1
ML	Medium Low	3	MP	Medium Poor	3	ML	Medium Slow	3
M	Medium	5	F	Fair	5	M	Fair	5
MH	Medium High	7	MG	Medium Good	7	MH	Medium Fast	7
H	High	9	G	Good	9	H	Fast	9
VH	Very High	10	VG	Very Good	10	VH	Very Fast	10

The following table gives a list of alternatives and their respective criteria. Table 1 shows various alternatives and their respective criteria

The structure of the matrix can be expressed as

Table 1

Alternatives	C1	C2	C3
R1	7	9	8
R2	8	7	8
R3	9	6	8
R4	6	7	6

Step (2) : To normalize m x n matrix $R(=r_{ij})$. The normalized value r_{ij} is calculated as $r_{ij} = x_{ij} / \sqrt{(\Sigma x_{ij}^2)}$ for i=1 ..m, j=1 .. n , It is shown in Table 2

Table 2

Alternatives	C1	C2	C3
R1	0.462	0.614	0.530
R2	0.527	0.477	0.530
R3	0.593	0.409	0.530
R4	0.396	0.477	0.397

Step (3): Calculate the weighted normalized matrix by multiplying the normalized decision matrix by its associated weights. The weights of the criteria are assigned as 40% for C1, 30 % for C2, and 30 % for C3. This is based on decision-maker's expertise as indicated in Table 3. The weighted normalized value V_{ij} is calculated as $V_{ij} = W_j r_{ij}$, for i=1 ..m, j=1 .. n as shown in Table 4 where w_j represents the weight of the jth criterion

Table 3

Weight(W_i)	0.4	0.3	0.3
Alternatives	C1	C2	C3
R1	0.462	0.614	0.530
R2	0.527	0.477	0.530
R3	0.593	0.409	0.530
R4	0.396	0.477	0.397

Table 4

Alternatives	C1	C2	C3
R1	0.185	0.184	0.159
R2	0.211	0.143	0.159
R3	0.237	0.123	0.159
R4	0.158	0.143	0.119

Step (4) : Determine the positive and negative ideal solutions .
For positive ideal solution is shown in Table 5

Table 5 $V^+ = \{0.237, 0.184, 0.119\}$

Alternatives	C1	C2	C3
R1	0.185	**0.184**	0.159
R2	0.211	0.143	0.159
R3	**0.237**	0.123	0.159
R4	0.158	0.143	**0.119**

For negative ideal solution is shown in Table 6

Table 6 $V^1 = \{0.160, 0.123, 0.159\}$

Alternatives	C1	C2	C3
R1	0.185	0.184	**0.159**
R2	0.211	0.143	0.159
R3	0.237	**0.123**	0.159
R4	**0.158**	0.143	0.119

Step(5) : Calculate the separation measures, using the m – dimensional shortest distance. The separation of each alternative from the positive ideal solution (Di^+) is shown in Table 7 , $Di^+ = \sqrt{(\Sigma(Vij - Vj^+)^2}$, i=1..m, j=1..n

Table 7

Alternatives	C1	C2	C3	$\sqrt{(\Sigma(V_{ij} - V_j^+)^2}$
R1	$(0.185 - 0.237)^2$	$(0.184 - 0.184)^2$	$(0.159 - 0.119)^2$	0.066
R2	$(0.211 – 0.237)^2$	$(0.143 - 0.184)^2$	$(0.159 - 0.119)^2$	0.063
R3	$(0.237 - 0.237)^2$	$(0.123 - 0.184)^2$	$(0.159 - 0.119)^2$	0.073
R4	$(0.158 - 0.237)^2$	$(0.143 - 0.184)^2$	$(0.119 - 0.119)^2$	0.089

Similarly, the separation of each alternative from the negative ideal solution (D_i^-) is shown in Table 8,
$D_i^- = \sqrt{(\Sigma(V_{ij} - V_j^-)^2}$, i=1..m,j=1..n

Table 8

Alternatives	C1	C2	C3	$\sqrt{(\Sigma(V_{ij} - V_j^-)^2}$
R1	$(0.185 - 0.158)^2$	$(0.184 - 0.123)^2$	$(0.159 - 0.159)^2$	0.067
R2	$(0.211 – 0.158)^2$	$(0.143 - 0.123)^2$	$(0.159 - 0.159)^2$	0.057
R3	$(0.237 - 0.158)^2$	$(0.123 - 0.123)^2$	$(0.159 - 0.159)^2$	0.079
R4	$(0.158 - 0.158)^2$	$(0.143 - 0.123)^2$	$(0.119 - 0.159)^2$	0.045

Step(6) : Determine the relative closeness to the ideal solution . The relative closeness of the alternative A_i with respect to V^+ can be expressed as $C_i = D_i^- / (D_i^+ + D_i^-)$, i = 1….m where C_i index value lies between 0 and 1. The higher the index value, the better the performance of the alternatives will be.

Table 9

Alternatives	$C_i = D_i^- / (D_i^+ + D_i^-)$
R1	0.067/(0.066+0.067) = 0.504
R2	0.057/(0.063+0.057) = 0.475
R3	0.079/(0.073+0.079) = 0.520
R4	0.045/(0.089+0.045) = 0.336

Step (7) : Rank the preference Order
Overall relative closeness and Rank of alternatives is shown in Table 10

Table 10

Alternatives	Result	Rank
R1	0.504	2
R2	0.475	3
R3	0.520	1
R4	0.336	4

R3>R1>R2>R4

(IV)Phenomenon of Rank Reversal :

As already mentioned TOPSIS suffers from the drawback of rank reversal. If a new alternative (new requirement) R5 is added, then the following will be the judgement matrix, with four alternatives in terms of criterion: If the new alternative R5 is added which is similar to R3, then The following will be the judgement matrix, with five alternatives in terms of criterion shown in Table 11

Step (1) :

Table 11

Alternatives	C1	C2	C3
R1	7	9	8
R2	8	7	8
R3	9	6	8
R4	6	7	6
R5	9	6	8

Step (2) : To normalize m x n matrix $R(=r_{ij})$. The normalized value r_{ij} is calculated as $r_{ij} = x_{ij} / \sqrt{(\Sigma x_{ij}^2)}$ for i=1 ..m, j=1 .. n , It is shown in Table 12

Table 12

Alternatives	C1	C2	C3
R1	0.397	0.568	0.468
R2	0.454	0.442	0.468
R3	0.510	0.379	0.468
R4	0.340	0.442	0.351
R5	0.510	0.379	0.468

Step (3): Calculate the weighted normalized matrix by multiplying the normalized decision matrix by its associated weights. The weights of the criteria are assigned as 40% for C1, 30 % for C2, 30 % for C3. This is based on decision-maker's expertise as indicated in Table 3. The weighted normalized value V_{ij} is calculated as $V_{ij} = W_j r_{ij}$, for i=1 ..m, j=1 .. n as shown in Table 13 where w_j represents the weight of the j^{th} criterion

Table 13

Weight(Wj)	0.4	0.3	0.3
Alternatives	C1	C2	C3
R1	0.397	0.568	0.468
R2	0.454	0.442	0.468
R3	0.510	0.379	0.468
R4	0.340	0.442	0.351
R5	0.510	0.379	0.468

Table 14

Alternatives	C1	C2	C3
R1	0.159	0.170	0.140
R2	0.182	0.133	0.140
R3	0.204	0.114	0.140
R4	0.136	0.133	0.105
R5	0.204	0.114	0.140

Step (4) : Determine the positive and negative ideal solutions

For positive ideal solution is shown in Table 15

Table 15 $V^+ = \{0.204, 0.170, 0.105\}$

Alternatives	C1	C2	C3
R1	0.159	**0.170**	0.140
R2	0.182	0.133	0.140
R3	**0.204**	0.114	0.140
R4	0.136	0.133	**0.105**
R5	0.204	0.114	0.140

For negative ideal solution is shown in Table 16

Table 16 $V^1 = \{0.136, 0.114, 0.140\}$

Alternatives	C1	C2	C3
R1	0.159	0.170	**0.140**
R2	0.182	0.133	0.140
R3	0.204	**0.114**	0.140
R4	**0.136**	0.133	0.105
R5	0.204	0.114	0.140

Step(5) : Calculate the separation measures, using the m – dimensional shortest distance. The separation of each alternative from the positive ideal solution (D_i^+) is shown in Table 17 , $D_i^+ = \sqrt{(\Sigma(V_{ij} - V_j^+)^2}$, i=1..m, j=1..n

Table 17

Alternatives	C1	C2	C3	$\sqrt{(\Sigma(V_{ij} - V_j^+)^2}$
R1	$(0.159 - 0.204)^2$	$(0.170 - 0.170)^2$	$(0.140 - 0.105)^2$	0.057
R2	$(0.182 - 0.204)^2$	$(0.133 - 0.170)^2$	$(0.140 - 0.105)^2$	0.055
R3	$(0.204 - 0.204)^2$	$(0.114 - 0.170)^2$	$(0.140 - 0.105)^2$	0.066
R4	$(0.136 - 0.204)^2$	$(0.133 - 0.170)^2$	$(0.105 - 0.105)^2$	0.077
R5	$(0.204 - 0.204)^2$	$(0.114 - 0.170)^2$	$(0.140 - 0.105)^2$	0.066

Similarly, the separation of each alternative from the negative ideal solution (D_i^-) is shown in Table 18, $D_i^- = \sqrt{(\Sigma(V_{ij} - V_j^-)^2}$, i=1..m, j=1..n

Table 18

Alternatives	C1	C2	C3	$\sqrt{(\Sigma(V_{ij} - V_j^-)^2}$
R1	$(0.159 - 0.136)^2$	$(0.170 - 0.114)^2$	$(0.140 - 0.140)^2$	0.061
R2	$(0.182 - 0.136)^2$	$(0.133 - 0.114)^2$	$(0.140 - 0.140)^2$	0.050
R3	$(0.204 - 0.136)^2$	$(0.114 - 0.114)^2$	$(0.140 - 0.140)^2$	0.068
R4	$(0.136 - 0.136)^2$	$(0.133 - 0.114)^2$	$(0.105 - 0.140)^2$	0.040
R5	$(0.204 - 0.136)^2$	$(0.114 - 0.114)^2$	$(0.140 - 0.140)^2$	0.068

Step(6) : Determine the relative closeness to the ideal solution . The relative closeness of the alternative A_i with respect to V^+ can be expressed as $C_i = D_i^- / (D_i^+ + D_i^-)$, i=1….m where C_i index value lies between 0 and 1. The higher the index value, the better the performance of the alternatives will be. It is shown in Table 19.

Table 19

Alternatives	$C_i = D_i^- / (D_i^+ + D_i^-)$
R1	0.061/(0.057+0.061) = 0.517
R2	0.050/(0.055+0.050) = 0.476
R3	0.068/(0.066+0.068) = 0.507
R4	0.040/(0.077+0.040) = 0.342
R5	0.068/(0.066+0.068) = 0.507

Step (7) : Rank the preference Order

Overall relative closeness and Rank of alternatives is shown in Table 20

Table 20

Alternatives	Result	Rank
R1	0.517	1
R2	0.476	3
R3	0.507	2
R4	0.342	4
R5	0.507	2

R1 > R3= R5 > R2 > R4

V. CONCLUSION :

TOPSIS is one of the Multi-Criteria Decision-Making methods (MCDM) and it has been applied in different fields despite certain drawbacks . In this numerical example discussed above when four alternatives are considered, the rank becomes R3 > R1 > R2 > R4 for the first empirical analysis. When a new alternative R5 is added to an existing alternative which is similar to R3, then, the rank becomes R1 > R3 = R5 > R2 > R4. This paper clearly indicates that rank reversal exists when new alternatives are added to or deleted from an existing alternatives. According to literature available on TOPSIS, the linguistic variables are converted into numerical values. In other words, Human feelings are converted into numbers, i.e., quantified in order to suit this scale[7]. Human feelings differ from person to person. Psychologically, human feelings cannot quantify [3]. Despite certain drawbacks, this method cannot be ignored because this technique provides an easy, understandable, proper, straight forward computation besides being a systematic and meaningful method for academic community to make better decisions.

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