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A Trade-off Ranking Method: Case of Extreme Solutions Redundancy

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ABSTRACT

In the trade-off ranking (TOR) method, the determination of the extreme solution (ES) is the main step before ranking the alternatives. ES reflects the best value of one criterion in a conflicting multi-criteria problem. However, the redundancy in selecting the ESs occurs because of the redundancy in some of the criteria values. Based on the stated problem, an improved TOR method is introduced in this paper to cater the redundant ES problem. An example is used from the literature to test the improvisation. The result indicates the implementation of the TOR method provides a better solution since it satisfies two conditions which are the highest value for different weights and the least compromise values in average weights. This verifies the reasonableness and effectiveness of the TOR method.

1. Introduction

Many Multi-Criteria Decision-Making (MCDM) methods have undergone modification or improved methods processes [1,2]. The evolution process is fitted to the situation or problem that is being solved in certain cases. Though the trade-off ranking (TOR) method is still new, the evolution process is also experienced by the TOR method which will be discussed in this paper.

Due to the newness of this method, there is still a lack of study involving the method. A study was done by Jaini *et al.*, [3] that used the TOR method to solve the MCDM problem with conflicting criteria in the vehicle routing problem to get the best solution and minimize the trade-off among the criteria. Besides the uses of the TOR method alone, a study was done by Ibrahim *et al.*, [4] that integrated the TOR with the Shapley value solution concept in cooperative game theory, acronymized as the S-TOR method. An improvement concerning the weights of the criteria was considered based on the fairness concept in the Shapley value solution concept.

The problem highlighted by the TOR method is a case of redundancy in the extreme solutions (ES). Redundancy is a repetition of identical values in a set of data. In this paper, repetition occurs in the same criterion where the problem in selecting ESs arises concerning the maximum or minimum criteria.

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The redundancy of ESs has raised an issue on choosing which ES for TOR calculation must be chosen for the next calculation steps. The ES is the base for the TOR method before the next calculation process proceeds. Therefore, this paper aims to improve the TOR method for the case of redundant ESs. In addition, this paper contributes to the TOR method in the MCDM framework with an improvement regarding the redundant ESs with some modifications to the procedures. Hence, a variant of the TOR method is developed.

The rest of the paper is organized as follows: The literature on the TOR method is presented in the next section. Then, the TOR method is briefly discussed, followed by the proposed methodology of the improved TOR method. Later, a few case studies of redundant ESs with different and average weights are solved using the improved TOR method. Lastly, the conclusion is discussed.

2. Literature Review

MCDM is a process of solving real-case problems according to some criteria to find the best solution among several available alternatives. Many methods have been improved for the study in MCDM. One of the methods that has undergone improvement is the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Wang and He [1] proposed two improvements to conventional TOPSIS. The first improvement for TOPSIS was the response of nominal-the-best that this type of procedure does not require selecting from the alternatives since the positive ideal solution is the target itself. The second improvement was the purpose of robust design and the root of mean square error.

Besides that, Kuo [2] also studied the TOPSIS method and proposed an improvement since TOPSIS contains adequacy in the ranking index. TOPSIS method selects the alternatives based on the closest and farthest distances from the positive and negative ideal solutions, respectively. The ranking index in the conventional TOPSIS method disregards the weights of an alternative from its positive and negative ideal solutions, and this will be a lack in the TOPSIS method as it has no preferences by the decision-makers. Therefore, a new ranking index was proposed by adapting the alternative with its positive and negative ideal solutions as cost and benefit criteria respectively.

It is a challenging undertaking to choose suitable MCDM methods and also its variants for specific problems, especially those methods that need some improvements from time to time. A comparison study was done by Chakraborty [5] that showed TOPSIS and modified TOPSIS methods to help researchers distinguish between these two methods. Besides TOPSIS and its variants, some methods experienced improvements or modifications, such as the previous studies [6] and [7] that were not within its method but integrated into other methods.

Lin *et al*., [6] mentioned that the conventional Analytic Hierarchy Process (AHP) that limits to the 9-value scale of Saaty is difficult for decision-makers regarding the relative importance relationship on the criteria. Therefore, they proposed AHP using a Genetic Algorithm to recover the real number weights of criteria and prepared a function for improving the consistency ratio of the pairwise comparisons. In addition, Ke *et al*., [7] proposed the DEA method with fuzzy mathematics. This model prevails over the objective factors in the conventional DEA model and caters to fuzzy input and fuzzy output sets.

Among numerous MCDM methods, TOR which was proposed by Jaini [8], is still new to this field and may be exposed to some improvements. To apply the TOR method, the process needs alternatives, criteria, and weight for each criterion to solve the conflicting problems. The TOR method uses the distance from an alternative to the other alternatives to determine the ranking. The ranking determination in the TOR method depends on the sum of the distances between those alternatives. The distance reflects the degree of trade-off between the solutions. Recall the aim of this study, it is reasonable to improve some steps in the TOR method for the case of redundant ESs. To answer this question, this paper proceeds to the next section for further study and explanation.

3. Trade-Off Ranking Method

TOR method was proposed and developed by Jaini [8]. Generally, the main principle of the TOR method is to provide a solution with less compromising than the other alternatives. The determination of the TOR method ranking depends on the sum of the distances between those alternatives. The distance represents the degree of trade-off between the solutions. At the beginning of the TOR method, the distance among alternatives is used to decide the ranking. Later, the method was revised to find the extreme solutions (as the best outcomes) for each criterion that came out with two levels of selection before rank that will be discussed further for the conventional TOR method algorithm.

Jaini and Utyuzhnikov [9] first introduced that the trade-off between the objectives is inevitable due to the constraints that make the optimal solution nonunique called as Pareto solution. The paper mentioned that the Pareto solution appeared as the ranking problem since it was unconsidered by any preferences. Therefore, the TOR method, as a new algorithm was proposed as a new ranking solution that has a unique value. The idea was originally based on the method to minimize the trade-off level among the solutions so that the ranking later will reflect the least compromised Pareto solutions. The minimization of the trade-off solutions can be attained by computing the distances among points in the objective space.

Jaini and Utyuzhnikov [10] studied the TOR method in a conflicting multi-criteria problem. In the paper, the alternatives were determined to satisfy all the criteria for finding a compromise solution. The idea of the anchor point for each alternative in the single-objective problem, a solution called an extreme solution is introduced in the TOR method. The selection of ESs as a reference point as it gives the best solution in a single-criterion problem. Then, the best solution is taken as a reasonable compromise solution in the conflicting criteria problem with the minimum value of the degree of trade-off, DT_1. Besides DT_1, the DT_2 indicates the total distances of an alternative to the others for the second level of selection. The TOR method is based on the smaller value of the distance that represents a less compromised solution or less degree of trade-off among those alternatives. The paper concluded that the TOR method is the least compromise solution as the calculation of the ESs and the other alternatives so the TOR method can be the best approach as the best compromise option using the differences among the alternatives.

Assuming that there are A alternatives, C criteria and represent the performance of criterion j in terms of alternative i and w_j represents the weight of a criterion, where $i=1,2,...,a; j=1,2,...,c$. Table 1 shows the decision matrix for the MCDM problem.

Table 1
The decision matrix

	Criterion				
Weight	W_1	W_2	W_3	...	W_c
Alternative	C_1	C_2	C_3	⋯	C_c
A_1	P_{11}	P_{12}	P_{13}	⋯	P_{1c}
A_2	P_{21}	P_{22}	P_{23}	⋯	P_{2c}
A_3	P_{31}	P_{32}	P_{33}	⋯	P_{3c}
⋮	⋮	⋮	⋮	⋮	⋮
A_a	P_{a1}	P_{a2}	P_{a3}	⋯	P_{ac}

The conventional TOR method algorithm to compute the distance between alternatives is as follows:

Step 1: The standardization of the performance criterion j in the alternative i, P_{ij} using the formula:

$$f_{ij} = \frac{P_{ij} - \min_j P_{ij}}{\max_j P_{ij} - \min_j P_{ij}}, i = 1,2,...,a, j = 1,2,...,c. \tag{1}$$

Step 2. Determination of the criteria objectives either maximum or minimum.

Step 3. Determination of the extreme solutions, $ES_k^*, k = 1,2,...,c,$ using the formula:

$$ES_k^* = \left\{\min_{1 \le i \le a} f_{ij}\right\}, j = 1,2,...,c, \text{ for the cost criteria, or}$$
$$ES_k^* = \left\{\max_{1 \le i \le a} f_{ij}\right\}, j = 1,2,...,c, \text{for the benefit criteria.} \tag{2}$$

Step 4. The computation of the distance between an alternative with every extreme solutions using the formula:

$$d_{TOR1}\left(ES_k^*, A^\alpha\right) = \left[\sum_{j=1}^{c}\left(f_{kj}, f_{\alpha j}\right)^2\right]^{1/2}, \alpha = 1,2,...,a, k = 1,2,...,c. \tag{3}$$

Step 5. The computation of the degree of trade-off, DT_1 between an alternative with all extreme solutions using the formula:

$$DT_{1_{A^\alpha}} = \sum_{j=1}^{c}\left[w_j \times d_{TOR1}\left(ES_k^*, A^\alpha\right)\right], \alpha = 1,2,...,a, k = 1,2,...,c. \tag{4}$$

where w_j is the weight or importance of the j^{th} criterion.

Step 6. Rank the best alternative with the lowest value of DT_1. If at least two alternatives have the same values of DT_1, proceed iteration to Step 7. Otherwise, stop.

Step 7. The computation of the distance between an alternative with every other alternatives using the formula:

$$d_{TOR2}\left(A^\alpha, A^\beta\right) = \left[\sum_{j=1}^{c}\left(\overline{P}_{\alpha j} - \overline{P}_{\beta j}\right)^2\right]^{1/2}, \alpha, \beta = 1,2,...,a, \tag{5}$$

where $\overline{P_{ij}}$ the weighted performance of an alternative i in criterion j

$$\overline{P_{ij}} = w_j \times f_{ij}, i = 1,2,...,a, j = 1,2,...,c. \tag{6}$$

Step 8. The computation of the degree of trade-off, DT_2 between an alternative with all other alternatives using the formula:

$$DT_{2_{A^{\alpha}}} = \sum_{i=1}^{a} \left[d_{TOR2} \left(A_{\alpha}, A_i \right) \right], \alpha = 1,2,...,a. \tag{7}$$

Step 9. Rank the best alternative with the lowest value of DT_2.

3. Improved Trade-Off Ranking Method for Extreme Solution Redundancy

The conventional TOR method steps explained in previous section will give a reasonable result as it compromises the trade-off solution. However, the redundancy in choosing ESs as in Step 3 needs to be improved since the ES represents the best alternative concerning one criterion. Thus, if the value of some of the alternatives in one criterion is equally the best, there exists a problem in choosing one alternative to be the ES for that criterion. Therefore, the improved Step 3 for the conventional TOR method is introduced in this section.

The method, generally, differs at redundant ES. If the ES is redundant, the weights as either different or average need to be considered. However, note that, if the ES is not redundant, the steps can proceed as the conventional TOR method itself. The suggested Step 3 to solve the redundancy in choosing ESs is planned as follows:

Step 3(a). Determination of the extreme solutions, $ES_k^*, k = 1,2,...,c,$ using the formula:

$ES_k^* = \left\{ \min_{1 \le i \le a} f_{ij} \right\}, j = 1,2,...,c,$ for the cost criteria, or
$ES_k^* = \left\{ \max_{1 \le i \le a} f_{ij} \right\}, j = 1,2,...,c,$ for the benefit criteria.

If the ES is redundant on that criterion, then

Step 3(b). Refer to the highest weight among all criteria. The ES is an alternative with the highest value of criterion in that particular weight between the redundant options. If the options are still redundant, refer to the next highest weight, and repeat the selection process.

Step 3(c). If the weights are equal, then the ES is an alternative with the best value in most criteria between the redundant options. In this case, it is wise to rank the alternatives based on each conflicting criterion in advanced.

Step 3(d). If the options for ES of a criterion are still redundant in Steps 3(b) and 3(c), calculate the difference in value between the redundant options and the best value in the examined criterion, either in the highest or average weights. The ES is an alternative with the least difference among the redundant options.

Step 3(e). If every steps above are fail, then the ES is chosen randomly between the redundant options.

In the next section, the case study on both the highest and average weights is explained.

4. Numerical Experiments

The case studies for redundant ESs are presented in this section. The problem and data are extracted from the previous study [11] where four criteria have been taken into account in the international cooperation in Iran. The criteria are Empowerment Level $(C1)$, Supplying Risk $(C2)$, Strategic Relation $(C3)$ and Future Opportunities $(C4)$. Since the paper used the game theory method, there are three Nash equilibria with combined strategies result from [11] which then are considered as three alternatives in MCDM. The alternatives are $S_{A3} - S_{B4}$ (Collaboration Level – Co-Evolving), $S_{A4} - S_{B3}$ (Risk Management – Supply Chain Re-Conceptualization) and $S_{A4} - S_{B4}$ (Risk – Management – Co-Evolving).

Table 2 shows the decision matrix raw data to be used for standardization for both different and average weights cases later. Then, the improved TOR method will be implemented.

Table 2
The decision matrix raw data is obtained from the previous study [11]

	$C1$ (Max)	$C2$ (Min)	$C3$ (Max)	$C4$ (Max)
$S_{A3} - S_{B4}$	7.000	6.143	6.857	6.143
$S_{A4} - S_{B3}$	6.143	5.286	6.286	7.000
$S_{A4} - S_{B4}$	6.286	6.571	6.857	6.143

4.1 Redundant Extreme Solutions with Different Weights

This subsection presents the case study for the redundant ESs with different weights. Table 3 is the normalized data, calculated from the Table 2 using Eq. (1). Table 3 shows the ES redundancy in one of the criteria, $C3$. Thus, the ES of criterion $C3$ is obtained using the improved TOR method, Steps 3(a)-(e), whichever necessary.

Table 3
The normalized decision matrix data with different weights

	$C1$ (Max)	$C2$ (Min)	$C3$ (Max)	$C4$ (Max)
Weight	0.3	0.5	0.1	0.1
$S_{A3} - S_{B4}$	1.000	0.667	1.000	0.000
$S_{A4} - S_{B3}$	0.000	0.000	0.000	1.000
$S_{A4} - S_{B4}$	0.167	1.000	1.000	0.000

Note that, since the two redundant maximum values are 1.000 in $C3$ for the maximum goal, the determination of the extreme solution will be referred to the improved TOR method. Since the weights are different, the improved TOR method starts the determination of the ES in $C3$ by Step 3(b), referring to the highest weight among all criteria. In this case, $C2$ has the highest weight (0.5) compared to the others. Thus, the ranking will be prioritized by following the minimum goal for this criterion which ranks the alternatives from the smallest to the highest values. In $C2$, the smallest value is 0.000. However, the redundant ES in $C3$ does not relative to $S_{A4} - S_{B3}$ in $C2$. Next, the second smallest value in $C2$ is 0.667 where the second rank is $S_{A3} - S_{B4}$. Hence, $S_{A3} - S_{B4}$ is chosen as the ES in $C3$ whereas ES is the alternative with the highest value of criterion in that particular weight between the redundant options.

After calculating the data in Table 3 via Eq. (3) and Eq. (4), the ranking result using the TOR method with different weights is given in Table 4.

Table 4
The ranking result via the improved TOR method with different weights

Trade-Off	$S_{A3}-S_{B4}$	$S_{A4}-S_{B3}$	$S_{A4}-S_{B4}$
Ranking	2	1	3

Table 4 shows that $S_{A4}-S_{B3}$ is the best ranking for different weights followed by the second and third ranks which are $S_{A3}-S_{B4}$ and $S_{A4}-S_{B4}$, respectively. The alternative $S_{A4}-S_{B3}$ has the best value in $C2$ (highest weight criterion) compared to $S_{A3}-S_{B4}$ and $S_{A4}-S_{B4}$. Therefore, $S_{A4}-S_{B3}$ is more prioritized than the other two alternatives.

4.2 Redundant Extreme Solutions with Average Weights

This subsection presents the case study for redundant ES with average weights. Therefore, Table 5 is created for the average weight value for each criterion by using the same data in Table 2. Similar steps to TOR method are implemented.

Table 5
The normalized decision matrix data with average weights – case I

	$C1$ (Max)	$C2$ (Min)	$C3$ (Max)	$C4$ (Max)
Weight	0.25	0.25	0.25	0.25
$S_{A3}-S_{B4}$	1.000	0.667	1.000	0.000
$S_{A4}-S_{B3}$	0.000	0.000	0.000	1.000
$S_{A4}-S_{B4}$	0.167	1.000	1.000	0.000

For this case, the Steps 3(a) and 3(b) cannot be applied since there are redundant ES in $C3$ and the weights are equal for all criteria. Thus, Step 3(c) of the improved TOR method is applied where if the weights are average, then the determination of the ES is required to be chosen with the best value in most criteria between the redundant options. In this case, all criteria have the average weights which are 0.25. In $C1$, the best value of the alternative $S_{A3}-S_{B4}$ is 1.000. Meanwhile, $S_{A4}-S_{B3}$ has the best value for the minimum goal $C2$ which is 0.000. Again, the redundant ES in $C3$ does not relative to $S_{A4}-S_{B3}$ in $C2$. Thus, the second smallest best value is 0.667 whereas this second ranking in $C2$ is $S_{A3}-S_{B4}$. Lastly, the best value for $C4$ to choose the ES is 1.000, which is alternative $S_{A4}-S_{B3}$. Even though $C4$ is redundant for first and third alternatives but that is not taken into consideration since the best value is the highest. Since most of the criteria are best in alternative $S_{A3}-S_{B4}$, therefore alternative $S_{A3}-S_{B4}$, is chosen as the ES in $C3$. The situation here can be depicted as in Table 6.

Table 6
The ranking for each alternative concerning each criterion

	$C1$ (Max)	$C2$ (Min)	$C3$ (Max)	$C4$ (Max)
Weight	0.25	0.25	0.25	0.25
$S_{A3}-S_{B4}$	1	2	1	2
$S_{A4}-S_{B3}$	3	1	3	1
$S_{A4}-S_{B4}$	2	3	1	2

After calculating the data in Table 5 via Eq. (3) and Eq. (4), however, the values of $S_{A3}-S_{B4}$ and $S_{A4}-S_{B3}$ are both equally ranked first. Thus, the method proceeds to the Step 7 until Step 9 via the Eq. (5) to Eq. (7). Then, the rank of the best alternatives with the lowest value of DT_2 is used. The ranking result using the TOR method with average weights is given in Table 7.

Table 7
The ranking result via the improved TOR method with average weights – case I

Trade-Off	$S_{A3}-S_{B4}$	$S_{A4}-S_{B3}$	$S_{A4}-S_{B4}$
Ranking DT_1	1	1	3
Ranking DT_2	2	3	1

Table 7 shows that $S_{A4}-S_{B4}$ is the best ranking for average weights followed by the second and third ranks which are $S_{A3}-S_{B4}$ and $S_{A4}-S_{B3}$, respectively. The alternative $S_{A4}-S_{B4}$ is the best option since it has the least compromise traits to all criteria compared to $S_{A3}-S_{B4}$ and $S_{A4}-S_{B3}$. In the case of average weights, the Decision Maker does not have specific preference towards the criteria, thus taking consideration of the least compromise alternative is the best option in dealing with the conflicting multi-criteria problem or the set of Pareto solutions. The least compromise means that the best alternative is on par with all other alternatives, having a value in each criterion that is not too much different than others. Note that, $S_{A3}-S_{B4}$ is ranked second for both different and average weights. The distance position of the alternative $S_{A3}-S_{B4}$ among all alternatives is consistent in all criteria between different and average weights. Consider another MCDM problem with data as in Table 8.

Table 8
The normalized decision matrix data with average weights – case II

	$C1$ (Max)	$C2$ (Min)	$C3$ (Max)	$C4$ (Max)
Weight	0.25	0.25	0.25	0.25
$S_{A3}-S_{B4}$	1.000	0.667	1.000	0.000
$S_{A4}-S_{B3}$	0.000	1.000	0.000	1.000
$S_{A4}-S_{B4}$	0.167	0.000	1.000	0.000

Again, the problem has redundant ES in criteria $C3$. However, the ES cannot be determined by the Step 3(c) in improved TOR since the redundant options $S_{A3}-S_{B4}$ and $S_{A4}-S_{B4}$ have equally best value in $C1$ and $C2$, respectively, while equally worst in $C4$. In this case, Step 3(d) is implemented. In $C1$, the alternative $S_{A3}-S_{B4}$ holds the best criterion value, while alternative $S_{A4}-S_{B4}$ has $0.833\ (=1-0.167)$ difference in value with the best value. On the other hand, in $C2$, the alternative $S_{A4}-S_{B4}$ holds the best criterion value, while alternative $S_{A3}-S_{B4}$ has $0.667\ (=0.667-0)$ difference in value with the best value. Thus, it is wise to choose the first option, $S_{A3}-S_{B4}$, due to the least compromise condition to the best value in each criterion. The ranking results for MCDM problem in Table 8 is given in Table 9.

Table 9
The ranking result via the improved TOR method with average weights – case II

Trade-Off	$S_{A3}-S_{B4}$	$S_{A4}-S_{B3}$	$S_{A4}-S_{B4}$
Ranking	1	3	2

4. Conclusion

An improved TOR method has been proposed in this paper to cater to the ESs redundancy problem. Illustrated examples from the literature were used for the further steps of implementation in solving ESs problem. The implementation result showed that the improved TOR method satisfies the conventional TOR method on the priority of the highest criteria weights and the compromise in average weights which verifies the reasonableness and effectiveness of this improved method.

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