Sensitivity Analysis of TOPSIS method for Stakeholders Ranking

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Abstract: Every decision-making process is influenced by each stakeholder, individually or collectively. The selection of stakeholders is a crucial step in any system development process that leads to the completion of the finished product. The weights assigned to each criterion by the stakeholders vary from those assigned by other stakeholders. These criteria are frequently used to pinpoint the participants in the evaluation process. Therefore, in order to properly evaluate the alternatives, it is crucial to have a thorough awareness of both the identification of stakeholders and their aims. The weight to be given to each criterion can be determined using a variety of techniques, including direct rating, the Borda count approach, and pairwise comparison. The weighting and pairwise comparison algorithms are both part of the Analytic Hierarchy Process (AHP), which handles the multi-actor characteristics. One set of the weights of the stakeholder criterion is measured using AHP, which performs a comparison on pairs of alternatives to calculate the weight values of the criteria using the eigenvector values. When the weights of the criteria are altered, there is a strong chance that the outcome could be significantly change by even a small deviation from the ideal value. Sensitivity analysis is a technique for examining how the final pattern will change if the original input data is changed or if the initial weights of the criteria are slightly different from previous values. The variation in the weight may take fixed form of modification or an repetitive procedure that approximates the weight's steadiness. The TOPSIS approach for ranking the active stakeholders is implemented after additional consideration of these estimated weights. With the help of vector normalization, the TOPSIS technique determines the stakeholders' relative importance based on their proximity to the ideal solution.

Keywords: Stakeholder, Ranking, Criteria, Sensitivity Analysis, AHP, TOPSIS

I. INTRODUCTION

The term "stakeholder" in this article refers to those who are affected by decisions in some way, whether it be financially or otherwise. Each stakeholder group specifies its own goals, which will serve as the standards by which the alternatives will be judged. Prioritizing the significance of stakeholder objectives or criteria should be the first phase of any development. Assessment becomes more difficult when there are too many stakeholders involved, and disregarding crucial goals while making decisions could jeopardize the implementation procedure [Macharis et al., 2009; Banville et al., 1998]. Banville et al. first introduced the idea of considering stakeholders in the process of multiple criteria decision analysis (MCDA). They contend that involving stakeholders at the outset of any analysis increases the effectiveness of the result. Researchers use a variety of techniques to rank stakeholders across various application sectors. Using a definite set of criteria, multi-criteria decision-making (MCDM) methods assess these many stakeholders. These criteria weights often reflect their influence on the decision. [Gaur et al. 2022]

Due to the managers' multiple needs and the associated stakeholders' differing perspectives, the project planning process becomes challenging [Yang et al., 2014; Mwesigwa et al., 2020]. To ensure a project's success, the connected stakeholders must be carefully handled. Finding the stakeholders and taking into account how they actively participate in the process is crucial. This study intends to employ a unique strategy using the AHP and TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) approaches. The AHP takes into account the pairwise comparison of attributes to calculate their weight values, and the TOPSIS technique provides a scalar number that concurrently examines the best and worst options for ranking the stakeholders, subsequently reducing the dependency on the decision-makers in the stakeholder evaluation process. The TOPSIS approach is used to solve a variety of issues, including selection issues and ranking, according to a review by Yap et al. (2019), as well as problems with project success evaluation based on specified criteria. Therefore, integrating these two MCDM approaches is appropriate for evaluating stakeholder influence.

All previous studies on TOPSIS made the identical assumptions regarding the data provided as input and the weights of the alternatives. Actually, estimating, prediction, and/or expert judgment are typically used to get the input data and parameter weights. The assessment results are unclear as a result of their constant inaccuracy and changeability. The TOPSIS method's sensitivity analysis has received few reports up to this point. In this current study the sensitivity of TOPSIS to weight change was discussed in detail. This study primarily has two goals: (1) demonstrating the viability and dependability of employing the TOPSIS approach for stakeholder ranking; and (2) determining how sensitive the TOPSIS method is to parameter weights.

LITERATURE REVIEW .II

Stakeholder analysis is a method or group of method to understand the activities, intents, relationships and objectives of the people and their organization. Additionally, it assesses the resources available and the impact they have on the decision-making and execution procedures [Varvasovszky et al. 2000]. The Multi Actor Multi-Criteria Analysis (MAMCA) developed by Macharis (2005) allows considering different stakeholders during the decision-making process and at the same time uses the AHP method as the basis of multi-criteria analysis. This method was applied to many projects related to strategic decision-making. Stakeholder analysis takes into account more than just the stakeholders' qualities in relation to the topic at hand, whether it be a project, policy, or organizational goal. It can also be used to forecast stakeholder alliances and depict current organizational linkages. If there is a short-term pragmatic goal, such as the implementation of a certain policy or project, the identification and evaluation of the type and strengths of these interactions can aid in devising strategies for managing the stakeholders [Varvasovszky et al. 2000]. Since it may be utilized as a key tool for managing and engaging with stakeholders, the classification of stakeholders based on their characteristics is a vital topic during stakeholder management [Bahadorestani et al., 2019]. Internal and external stakeholders have been separated into a variety of groups by a number of ideas and approaches [Di Maddaloni and Davis, 2017].

Stakeholder identification should be carried out at the start of any process to have a clear understanding of their relationships. Identification of key stakeholders is the first step in the process of stakeholder management, which also includes planning, and allocating resources to them, taking into account their requests, disseminating useful information, and assessing their project-related interests [Xia et al., 2018, Eskerod et al., 2015]. It is possible to take into account the issues from the previous stage of development throughout the planning and execution phase. When determining the project's complexity, the number of stakeholders involved is quite important. Directly affecting the project's complexity are their investments, involvement, agreements, and disagreements during the software development process. Primary, secondary, internal, external, and direct and indirect stakeholders are among the various stakeholder kinds. Due to their significant impact on the project's outcome, primary stakeholders have a direct impact on a project's success.

III. MCDM METHODS

When confronted with multiple choices, MCDM focuses a great deal on choosing the best course of action. These are the quantitative techniques used to simplify the system design and arrive at the final conclusion taking into account the contribution of various attributes and the number of decision-making stakeholders. The Analytic Hierarchy Process (AHP), the Analytic Network Process (ANP), the Weighted Sum Model (WSM), the Weighted Average Model (WA), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the Elimination and Choice Translating Reality (ELECTRE), the Simple Multi-Attribute Rating Technique Exploiting Ranks (SMARTER), and VIKOR, etc are among others. Different approaches are utilized to arrive at the solution, like linear and non-linear programming, and discrete optimization techniques, depending on the functional requirement.

In this study two of the important MCDM methods AHP and TOPSIS are considered. AHP is regarded as the fundamental decision-making technique and is used to solve issues in the fields of science, business, engineering, etc. AHP is used in many applications such as optimized Model selection, Software selection, Quality control systems, Project management evaluation, Selecting a software project management tool, and genetic algorithms, among others, due to its simplicity in analyzing the problems in the form of hierarchical structure and to provide an optimal solution using a simple comparison matrix approach. The AHP method is used for calculating the initial weight values of the criteria to provide as input to TOPSIS method to calculate the ranking of the stakeholders. The "Technique for Order Preference by Similarity to Ideal Solution" (TOPSIS), which chooses the best alternative with the smallest distances from the positive ideal solution and the largest distances from the negative ideal solution, is one of the well-known ranking approaches in MCDM. A research of TOPSIS and a review of its applications in the fields of supply chain management, design and engineering, business and management, health, safety, and environment management, among others, were published in 2012 by Behzadian et al. It is observed that the traditional TOPSIS technique uses crisp values whereas the majority of applications use linguistic variables and fuzzy sets with imprecise information.

A. Analytical Hierarchical Process (AHP)

Thomas Saaty proposed AHP in 1980 for decision making in multiple criteria conditions. The method decomposes the problems into a hierarchical structure, and then pairs of alternatives are compared to determine which users prefer. To create a matrix of comparison values, the values considered depends on the weights, as shown in Table 1. The inverse value is inserted in the transposed place. Normalized pairwise matrix is calculated and the criteria weights are calculated from the Eigen vector.

Table 1: Scale for comparison

Relative Importance of two entity	**Equivalent Numerical Value(s)**
Equal	1
Marginally strong	3
Strong	5
Very Strong	7
Extremely Strong	9
Intermediate values	2,4,6,8
Values for inverse comparison	Reciprocals

Table 2: Random Consistency Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The consistency index (CI) assesses the decision maker's inconsistent comparisons.

$$CI= (\lambda_{max}-n) / (n-1) \quad (1)$$

The maximum eigenvalue of the judgment matrix is given by λ_{max}, and n is the order of the matrix. The maximum Eigenvalue is given by the sum of the products of each eigenvector element and the sum of the columns of the reciprocal matrix [Al-Harbi, K. M. (2001)]. The consistency index of the randomly generated pairwise matrix, the random index (RI), is shown in Table 2 computed for $n \leq 10$. The value of CI is compared with the RI and is termed the consistency ratio (CR). According to Saaty, the value of CR should be less than 0.1 for a consistent decision.

$$CR=CI /RI= X< 0.1 \quad (2)$$

B. A Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

When multiple-attribute decision-making problems lacked explicit preference information, TOPSIS was developed as a solution. The method, which Hwang and Yoon first presented in 1981, successfully combines quantitative and qualitative data and uses an aggregation method to represent choices that are close to the optimal course of action. The method is based on Euclidian distance, and by utilizing vector normalization, it determines its closest and furthest distances from the positive and negative ideal solutions, respectively [Kukreja et al. 2012]. Around the past 30 years, scholars from all over the world have carried out a large number of TOPSIS-related studies, advancing TOPSIS theory and application. In many different disciplines, it has been extensively employed to resolve multiple-attribute decision-making issues. The following are the steps followed in the TOPSIS method (Mahmood Zadeh et al. 2007).

Step 1: Construct a matrix with definite criteria values. Convert all linguistic parameters into a point scale.

Step 2: Calculate the normalized decision matrix using equation 3.

$$rij = fij/\sqrt{\sum_{j=1}^{n} fij^2} \quad (3)$$

Where j=1, 2..n and i=1, 2..m, and f_{ij} is the performance value.

Step 3: The normalized decision matrix is multiplied by the appropriate weight to get the weighted normalized decision matrix.

$$Vij = Wij \times rij \quad (4)$$

W_j represents the weight of the j^{th} attribute.
Step 4: Calculate the ideal best V_j^+ and ideal worst value V_j^- .

$$V_j^+ = \{V1^+, V2^+ .. \ Vn^+\} = \langle Max\ Vij | j \in J, Min\ Vij | j \in J' \rangle \quad (5)$$

$$V_j^- = \{V1^-, V2^- .. \ Vn^-\} = \langle Min\ Vij | j \in J, Max\ Vij | j \in J' \rangle \quad (6)$$

J represents positive criteria and J' represents negative criteria.
Step 5: Separation measures are calculated using Euclidean distance from the ideal best and ideal worst values using the following equation.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (Vij - Vj^+)^2} \quad (7)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (Vij - Vj^-)^2} \quad (8)$$

i=1,2…n.
Step 6: Performance score is determined from the equation 9 and the results are ordered in descending order.

$$P_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (9)$$

The performance score value ranges from 0 to 1. Larger value of performance score signifies the better performance of the results.

IV. SENSITIVITY ANALYSIS

Sensitivity analysis is a method for determining how the final ranking will change if the input data or the original weights of the criteria are modified slightly. The original method is quite complex and computationally demanding if the value of any attribute changes. The weights of the criteria have been determined using a variety of techniques. But TOPSIS doesn't look at how the weight factors affect events. One technique for assessing the consequences of weight changes is sensitivity analysis [Jiří M. , 2019]. Sensitivity analysis is increasingly used in a wide range of engineering and scientific disciplines, including almost all jobs involving the processing of experimental data as well as countless tasks involving computer modeling and for simulation process. According to Saltelli et al. (1999), sensitivity is the ability to "determine how a particular numerical model depends on its input components," and is defined as [Saltelli et al., 2005]

$$S_i = \frac{\partial F}{\partial x_i} \quad (10)$$

Si is the sensitivity of the function *F* for change in x_i . *F* is defined as predefined multivariable function and x_i is a variable with values $x_1, x_2\, x_3 \ldots\, x_n$. The other definition of sensitivity analysis based on relative terms was given out by

$$S_i = \frac{\partial F}{\partial x_i} * \frac{x_i}{F} \quad (11)$$

When the independent variable exhibits one unit of relative variation, it literally refers to the dependent variable's relative variation. *F* is considered to be sensitive to the variation of x_i when $|S_i| > 1$ and insensitive to the variation of xi when $|S_i| < 1$ [Li, Peiyue, et al. 2013]. According to researcher Triantaphyllou et al. definition of sensitivity with relative terms is more insightful compared to absolute concepts [Triantaphyllou et al. 1997]. Sensitivity analysis is an important step in many studies across a variety of disciplines, especially when trying to solve problems involving several criteria for decision-making, including simulating very complex physical systems that could react in a number of different ways. Sensitivity analysis can also be used to pinpoint uncertainty in complex systems [Zheng and Bennett, 2002]. A comprehensive assessment of the sensitivity and uncertainty analysis of large-scale systems was provided in the Ionescu-Bujor et al. paper from

2004. Since the input data for a multiple-criteria decision-making problem are frequently erroneous and dynamic, the decision makers were interested in determining if their choice results would remain stable and how they would alter if the input data were updated. Sensitivity testing thus turns into a useful method for evaluating the consistency of decision-making results [Ionescu-Bujor et al., 2004].
Several multi-criteria decision-making methodologies were compared by Triantaphyllou (2000), who also provided a sensitivity analysis method for these methods [Triantaphyllou (2000)]. Awasthi et al. employed fuzzy TOPSIS in 2011 and carried out a sensitivity study to assess how the weights of the criterion would impact the outcomes [Awasthi et al., 2011] . Li, Peiyue, et al. presented study with different weights of parameter and how the assessment results would get effected. Total fourteen schemes gives the detailed analysis of sensitivity for the variation of each weight. The results tabulated changes with increase and decrease of weights [Li, Peiyue, et al. ,2013]. Three novel types of sensitivity analysis were used in the work that Wolter et al. published. They assessed the ranking's sensitivity to certain criteria adjustments, the impact of changes in the criteria's scores, and the minimal weight modification needed to shift the alternative rank. The results were explained using simulation experiment [Wolters et al., 1995].

The objective of the sensitivity analysis methodology was to identify the degree to which each attribute was affected by the outcomes for every ranking method. This degree implies that there might have been some relationship between an attribute According to Kusumadewi and Hartati (2007) research, the TOPSIS approach consistently has the high correlation coefficient values, and as the ranking change is increased, this correlation value rises. According to their experimental findings, TOPSIS method is better method for group decision making..

V. CASE STUDY

In this study five different stakeholders are considered who are directly involved in the process: End users and beneficiaries, Technical Engineer of product development, Business engineer, System developer, an External stakeholder outside the client company, such as regulatory bodies, legal officials, and surrounding communities. Let five stakeholders involved in the process be D = $\{S_1, S_2, S_3, S_4, S_5\}$ respectively. The five criteria used for stakeholder ranking are Investment in the project (INV), Technical Details (TD) of the project to be developed, Business knowledge (BK), Organization capabilities (OC), and Time spent (TS) in the project represented as C = $\{C_1, C_2, C_3, C_4, C_5\}$ respectively.

The project may receive financial support or a resource facility. In this illustration, it is taken into account as an investment made for the project's development. Working together as a team, Technical Details is attempting to reflect the technical difficulties of the required implementation as assessed by cost, time, risk, and difficulty in execution (Iyas Ibriwesh et.al. 2019). The stakeholders' perspective on how to boost the project's efficiency and profitability is represented by business knowledge. The organizational competencies are the skills that a company uses to complete its tasks, carry out its business plans, and please its clients. Time spent refers to the overall amount of time invested in comprehending the project's goal and successfully delivering the system requirements. Assume that C1 is a non-beneficiary and that the project's C2, C3, C4, and C5 are beneficiary qualities. In the first example, the criteria weights are calculated using the AHP approach, and in the subsequent four scenarios for sensitivity analysis, the criteria weights are assumed to follow a different pattern.

Table 3: Calculation of Consistency Index (CI)

	C1	C2	C3	C4	C5	Weighted Sum Value	Weighted Sum Value / CW
C1	1	3	2	6	5	2.410	5.422
C2	0.33	1	3	2	4	1.281	5.274
C3	0.5	0.33	1	1	3	0.736	5.079
C4	0.17	0.50	1	1	2	0.568	5.270
C5	0.2	0.25	0.33	0.5	1	0.312	5.199
						λ_{max}	5.249

$$CI= (5.238-5) / (5-1) = 0.059$$

To calculate the weights from AHP method first the comparison values are taken from Saaty's scale is shown in Table 1. The weight values of the criteria are calculated using AHP method and the consistency of the results are checked using the consistency index. This gauges how consistently the decision-maker compares different factors. CI is calculated as given in equation 1.

Table 4: Input to TOPSIS for stakeholder Ranking

Stakeholders	C1	C2	C3	C4	C5
S1	50000	90	95	98	1800
S2	10000	95	75	80	2700
S3	15000	40	57	40	960
S4	5000	80	30	20	1500
S5	25000	95	90	95	3000
CW	0.445	0.243	0.145	0.108	0.060

The calculated CI compared with the RI and the consistency ratio (CR) is derived. The CR value is 0.053 which is less than 0.1 shows that the value allotted for the criteria in the matrix is appropriate and the results of criteria weights are consistent.

Table 5: Ranked Stakeholders using weights From AHP

Stakeholders	PS
S2	0.879
S4	0.808
S3	0.690
S5	0.589
S1	0.230

Consider range-based values for all five criteria given by different stakeholders as shown in Table 4. The value of the performance score (PS) decides the ranking of the stakeholders. A higher performance score (PS) value means the response is further from the negative ideal solution and closer to the ideal solution. According to the analysis Table 5 shows stakeholders are ranked in the order of S2, S4, S3, S5 and S1.

Table 6: Equal weights to all the Attributes

Stakeholders	PS
S2	0.829
S5	0.723
S4	0.534
S3	0.476
S1	0.464

Table 7: 50% to Beneficiary Attributes and 50% to Non-Beneficiary Attributes

Stakeholders	PS
S2	0.880
S4	0.814
S3	0.714
S5	0.579
S1	0.185

To study the sensitivity analysis, the study continued by adjusting the weights of the criteria. The instance discussed in this research is far more unique and intricate than studies conducted in the past using other techniques. The work followed by changing the weights of beneficiary and non-beneficiary attributes. Four different cases are discussed. Table 6 shows the results of the first case with equal weights for all attributes.

Table 8: 60% to Beneficiary Attributes and 40% to Non-Beneficiary Attributes

Stakeholders	PS
S2	0.871
S4	0.746
S3	0.664
S5	0.603
S1	0.254

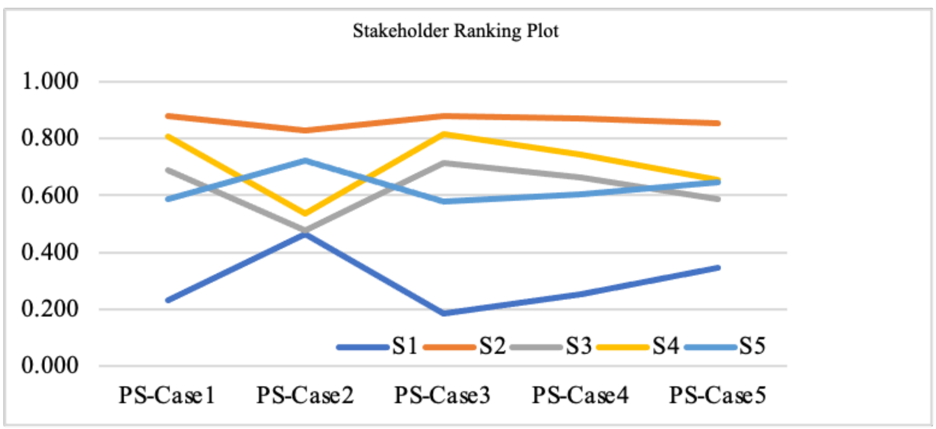
Table 9: 70% to Beneficiary Attributes and 30% Non-Beneficiary Attributes

Stakeholders	PS
S2	0.854
S4	0.656
S5	0.647
S3	0.587
S1	0.344

Next case with 50% weights for beneficiary attributes and non-beneficiary attributes. Following that, 60% to beneficiary attributes and 40% went to non-beneficiary attributes, and next case 70% to beneficiary attributes and 30% to non-beneficiary attributes in the final case.

Table 10: Final results with different cases of weight assignments

Stakeholders	PS-Case1	PS-Case2	PS-Case3	PS-Case4	PS-Case5
S1	0.230	0.464	0.185	0.254	0.344
S2	0.879	0.829	0.88	0.871	0.854
S3	0.690	0.476	0.714	0.664	0.587
S4	0.808	0.534	0.814	0.746	0.656
S5	0.589	0.723	0.579	0.603	0.647



Graph 1: Stakeholder Ranking based on Performance score

When the weights are changed under the aforementioned circumstances, the sample order continues to fluctuate. This details the selection of stakeholders with different weight values. The graph in the study demonstrates that the sensitivity analysis provided a different perspective for the selection and for ranking the stakeholders. Graph 1 depicts the steady value of S2's performance score with various criteria values. The alternative option is restricted in the different case study, which details the selection in a broader context. The stakeholders' ranking helps in considering the requirements for the development of the system in the smarter way. The results of the case study indicate that the stakeholder's ranking is not solely determined by their investment in the project. It is the combination of the multiple criteria that enables them to be included in the project analysis.

VI. CONCLUSION

The TOPSIS method's sensitivity analysis to parameter weights was the primary focus of the current investigation. The weight of the parameter and the input data both have the potential to add uncertainty into the results. As a result, it is still challenging to fully understand how sensitive TOPSIS is to input data and parameter weight. The relationship between the different criteria are not taken into account by the conventional MCDM approaches, and the ambiguous justification for inclusion was also missed. Additionally, although the criteria are thought of as independent, they are dependent on particular feedback in real-world problems. If all the weights are modified at once, the sensitivity analysis will become far more difficult to do manually and potentially even impossible. The case study and theoretical analysis show that the TOPSIS methodology for ranking applications is a practical and reliable method when it comes to the sensitivity analysis of weights. The final evaluation results can maintain a high level of sensitivity to weight variation while remaining relatively stable within the specified range. It is reasonable to assume that the discussion of TOPSIS's sensitivity to the input data for the ranking will be equally complex, possibly much more so than is reasonable. The majority of projects involve different stakeholders, such as users, managers, developers, etc., to actively participate. Setting stakeholder priorities assists in deciding on various functional areas during the development process. The inclusion of stakeholders at the beginning of the process is always taken into consideration, as the solution is more acceptable, but their engagement is limited in real-time to further minimize the complexity of the development process.

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