Health-care Supplier Selection using Hybrid Multi-criteria Decision Making Methods : A Case Study from Morocco

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Research

Keywords: Healthcare, MCDM, BWM, AHP, TOPSIS, Sensitivity analysis

Posted Date: January 27th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1152849/v1>

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RESEARCH

Health-care Supplier Selection using Hybrid Multi-criteria Decision Making Methods : A Case Study from Morocco

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Abstract

Several studies have been conducted in the context of selecting the best supplier. In literature, the supplier selection problem has been widely studied using different approaches. Multi Criteria decision making(MCDM) is one of the frequently exploited tools for achieving this study. Health-care sector represents a vital priority for decreasing risks. However, it is rarely treated by the research community. In this work, we present three hybrid multi-criteria methods (Analytic hierarchy process-technique for order preference by similarity to ideal solution) AHP-TOPSIS, (Pythagorean fuzzy analytic hierarchy process-technique for order preference by similarity to ideal solution (PFAHP-TOPSIS) and Best worst method-technique for order preference by similarity to ideal solution(BWM-TOPSIS)) for making the efficient health-care supplier selection. This study is mainly composed of two stages: the first one consists of calculating of the weight priority of each criterion and sub-criterion using AHP, BWM, and PFAHP methods, while the second stage aims to integrate the weights priorities for making the ranking of the alternatives using TOPSIS method. Moreover, we present the sensitivity analysis for the three integrated tools to evaluate the ranking of suppliers under the variation of the weights of criteria. This study was conducted in a public hospital from Marrakech city.

Keywords: Healthcare; MCDM; BWM; AHP; TOPSIS; Sensitivity analysis

Introduction

In the last years, several studies have been directed to supplier selection problem. However, supplier healthcare is rarely treated. The aged population and the apparition of new diseases increased everyday, which imposes our focus on medical sector. MCDM tools are widely used for making ranking of alternatives in different fields as social, economic and industry. Great works have been proposed for resolving the supplier selection problem, we review some recent research works: In [1], authors have proposed AHP-TOPSIS tool to select the optimal collecting strategy for Taiwan photovoltaic industry (TPI). AHP method is exploited for calculating the criteria weights and TOPSIS is used as ranking tool for making the optimal selection. In [2], authors designed a novel model and an algorithm to resolve the buyers decision problem. Moreover, this work studied the method optimality, where it is proved that the obtained results are near to the optimal solution. Another optimal methodology has been designed In [3], for resolving the supplier selection problem. This work combined a fuzzy multi-objective and optimization tools. In [4], authors

proposed another work that treats the supplier selection problem. This research work aimed at various technologies are widely used as essential tools for health monitoring like medical sensors. Even though, various tools have been integrated into hospitals for assisting the hospital staff, this problem is still persists. Motivated by these reasons, we present an efficient healthcare supplier selection in Morocco. From our knowledge, this the first work aimed at studying the supplier selection of healthcare supplier in Morocco. The main contribution of this work is the study of the most critical sector using MCDM. We have exploited three integrated tools for making an effective selection, where the criteria weights are calculated using two strong methods. Moreover, we present the sensitivity analysis of the proposed methods to validate the results consistency. This paper is organized as follows: the second section presents the main contributions of this paper. The third section explains the different multi-criteria tools exploited for making the present study. The fourth section presents the case study, where the illustrative example and the sensitivity analysis are explored in details. The fifth section summarizes this work.

Authors' contributions

Several reviewed works resolve the problem of the supplier selection using individual or hybrid MCDM techniques. Even though various research works have been designed, supplier selection for the healthcare sector is not considered as important human goal. However, the increase of the aged population and diseases impose the research community to make more significant efforts. In this paper, we propose the use of three combined multi-criteria decision-making tools for resolving this problem. Recently, TOPSIS method has shown its efficiency for the supplier selection problem. However, its process can't calculate the weights of criteria. Hence, we have applied the integrated methods to complete and fill the gaps of TOPSIS method. We have exploited AHP, PFAHP and BWM for calculating the weights of criteria and then use the generated weights as inputs of TOPSIS for ranking the available suppliers. The integrated multi-criteria tools have shown their efficiency for making the alternatives selection [5].

MCDM methods

In our daily and professional life, we are in front of making the right decisions. MCDA [6] [7] represent an important science that allows us making decisions. It is exploited in different fields such as economics and mathematics and social science, which provide the apparition of several methods for finding the most adapted solution to the situation studied. Roy(1981) [8] have categorize the decision problems in four categories: the choice problem that has the main goal of selecting the best element among a subset of elements. The second type is the sorting problem which focuses on sorting options into ordered groups named categories. This regrouping is done in order to reduce the options number. The third type is the ranking problem consists of ordering options from best to worst. The forth type is the description problem which has the main goal of describing options for understanding the problem characteristics. Our problem is selecting the efficient elements for routing data. Consequently, our case is the selection or choice problem and TOPSIS method is adapted to our case and we use AHP, PFAHP, and BWM models for defining the

different criteria weights. This section presents the different multi-criteria methods, which are exploited for making this study: AHP, BWM, PFAHP, and TOPSIS. We use AHP, PFAHP and BWM for calculating the weights of criteria that are integrated with TOPSIS tool for making the ranking of alternatives. To validate the AHP-TOPSIS, PFAHP-TOPSIS, and BWM-TOPSIS health-care supplier selection, we compared the three hybrid methods using the sensitivity analysis phase. All multi-criteria methods are explained in details in the next sub-sections.

Description of the AHP model

AHP method represents a well known MDMM method that attracts the research community due to its simplicity. It allows the representation of the multi-criteria decision problem as hierarchical problem. Then, it makes the pair wise comparison for defining the priorities that are exploited for calculating the weights of criteria. The next step represents a comparison step, where the elements are compared using the importance values. Table 1 depicts the scale of pair-wise comparison. The third step aims to calculate the adequate Eigenvectors to the maximal Eigen values for defining factors relative importance.

The last step aims to verify the judgments consistency : a comparison to Consistency Index(CI) and Consistency Ratio(CR) is done according to the following formulas:

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

Where λ_{max} is the Eigen value, which corresponds to the pair-wise comparisons matrix and n is the number of the compared elements. CR is calculated by this equation [9]:

$$CR = \frac{CI}{RCI} \quad (2)$$

Where RCI corresponds to the random CI that vary according to the number of criteria considered for the decision problem as shown in Table 2

The pair-wise comparison is revised after the evaluation of the values of CR: it is required to revise the pair-wise comparison if the CR more than 0.1.

BWM

BWM [10] represents a multi-criteria method that is frequently used for calculating the weights of criteria. In this section, we present the different steps of this method: Step1: Define the most essential criteria for the decision problem. All criteria are grouped in the set $C = (c_1, c_2, \dots, c_n)$, that is used for achieving the selection problem.

Step2: BWM is based on two key criteria: the best criterion (the most important one) and the worst criterion (the least preferable) for the decision study.

Step3: In this step, we are asked to determine the preference of the best criterion compared to the remaining criteria using a value between 1 and 9. Each value represents a significant preference where 1 is an equal preference and 9 is the most

important score. This results to the following vector:

$A_{Bst} = (a_{b1}, a_{b2}, a_{b3}, \dots, a_{bn})$, where a_{bi} represent the preference of the best criterion Bst over criterion i.

Step4: Determine the preference of the worst criterion compared to the remaining criteria using a value between 1 and 9. . This results to the following vector:

$A_{wst} = (a_{1W}, a_{2W}, a_{3W}, \dots, a_{nW})^T$, where a_{iW} is the preference of criterion i over the worst one (W).

Step 5: This step consists of calculating the optimal values of the different criteria weights. The main objective of the BWM is to find the set of criteria weights, where the constraint of optimality is satisfied. In this step, $|\frac{W_b}{W_j} - a_{bj}|$ and $|\frac{W_j}{W_w} - a_{jW}|$ have to be minimized for each criterion i. Searching the optimal solution lead to resolve the following minmax problem:

$$\min \max_j \left\{ \left| \frac{W_j}{W_w} - a_{jW} \right|, \left| \frac{W_b}{W_j} - a_{bj} \right| \right\} \quad (3)$$

, $s.t.$

$$\sum_j W_j = 1$$

$$W_j \geq 0, \text{ for all } j.s.$$

To simplify equation(3), the optimal problem can be rewritten as:

$$\min \epsilon \quad (4)$$

, $s.t.$

$$\left| \frac{W_b}{W_j} - a_{bj} \right| \leq \epsilon, \text{ for all } j.s.$$

$$\left| \frac{W_j}{W_w} - a_{jW} \right| \leq \epsilon, \text{ for all } j.s.$$

$$\sum_j W_j = 1$$

$$W_j \geq 0, \text{ for all } j.s.$$

0.1 PFAHP method

Pythagorean fuzzy sets

The intuitionistic fuzzy sets technique has been designed to adress the uncertainty of several decision problems. These sets are mainly based on the membership functions, non-membership function and hesitancy degree. However, it can not resolve the situation, where the value of the membership and non-membership exceed 1. To resolve this situation, Pythagorean fuzzy sets have been proposed as a variant of the intuitionistic fuzzy sets. In Pythagorean fuzzy sets, unlike the intuitionistic fuzzy sets, the sum of membership and non-membership degrees can be bigger than

1 while the sum of squares cannot. Definition 1 shows this situation.

Definition 1: Let a set X be a universe of discourse. A Pythagorean fuzzy set P is an object having the form:

$$P = \{ \langle x, P(\mu_p(x), V_p(x)) \mid x \in X \rangle \} \quad (5)$$

where $\mu_p(x) : X \rightarrow [0, 1]$ represents the degree of membership and $V_p(x) : X \rightarrow [0, 1]$ defines the degree of non-membership of the element $x \in X$ to P , respectively, and for each $x \in X$, it holds:

$$0 \leq \mu_p(x)^2 + V_p(x)^2 \leq 1 \quad (6)$$

for any PFS P and $x \in X$, $\pi_p(x) = \sqrt{1 - \mu_p^2(x) - V_p^2(x)}$ is called the degree of indeterminacy of x to P .

Definition 2 Let $\beta_1 = P(\mu_{\beta_1}, V_{\beta_1})$ and $\beta_2 = P(\mu_{\beta_2}, V_{\beta_2})$ and $\lambda > 0$ two Pythagorean fuzzy numbers, then the operations on these two Pythagorean fuzzy numbers are defined as follows (Zeng et al. 2016; Zhang and Xu 2014):

$$\beta_1 \oplus \beta_2 = P(\sqrt{\mu_{\beta_1}^2 + \mu_{\beta_2}^2 - \mu_{\beta_1}^2 \mu_{\beta_2}^2}, V_{\beta_1} V_{\beta_2}) \quad (7)$$

$$\beta_1 \otimes \beta_2 = P(\mu_{\beta_1} \mu_{\beta_2}, \sqrt{V_{\beta_1}^2 + V_{\beta_2}^2 - V_{\beta_1}^2 V_{\beta_2}^2}) \quad (8)$$

$$\lambda \beta_1 = P(\sqrt{1 - (1 - \mu_{\beta_1}^2)^\lambda}, (V_{\beta_1})^\lambda), \lambda > 0 \quad (9)$$

$$\beta_1^\lambda = P((\mu_{\beta_1})^\lambda, \sqrt{1 - (1 - V_{\beta_1}^2)^\lambda}), \lambda > 0 \quad (10)$$

Definition3 Let $\beta_1 = P(\mu_{\beta_1}, V_{\beta_1})$ and $\beta_2 = P(\mu_{\beta_2}, V_{\beta_2})$ and $\lambda > 0$ two Pythagorean fuzzy numbers, a nature quasi-ordering on the Pythagorean fuzzy numbers is expressed as follows:

$\beta_1 \geq \beta_2$ if and only if $\mu_{\beta_1} \geq \mu_{\beta_2}$ and $V_{\beta_1} \leq V_{\beta_2}$ a score function is proposed to compare two Pythagorean fuzzy numbers as follows:

$$s(\beta_1) = (\mu_{\beta_1})^2 - (V_{\beta_1})^2 \quad (11)$$

Definition 4 Based on the score functions proposed above, the following laws are defined to compare two Pythagorean fuzzy numbers:

If $s(\beta_1) < s(\beta_2)$, then $\beta_1 < \beta_2$

If $s(\beta_1) > s(\beta_2)$, then $\beta_1 > \beta_2$

If $s(\beta_1) = s(\beta_2)$, then $\beta_1 = \beta_2$

PFAHP and related linguistic terms

The process of the PFAHP method is composed of different steps, which are presented as follows:

Step1: it is mainly based on the construction of the compromised pairwise comparison matrix $A(A_{ik})_{m \times m}$ using the scale designed by (ref15), as shown in Table : Step2: This step consists of calculating the difference matrices $D = (d_{ik})_{m \times m}$ between the lowest and the highest values of the membership and non-membership functions as follows:

$$d_{ik_L} = \mu_{ik_L}^2 - V_{ik_U}^2 \quad (12)$$

$$d_{ik_U} = \mu_{ik_U}^2 - V_{ik_L}^2 \quad (13)$$

Step3: This step is based on calculating the interval multiplicative matrix $S = (S_{ik})_{m \times m}$ by the equations (14 and 15):

$$S_{ik_L} = \sqrt{1000^{d_L}} \quad (14)$$

$$S_{ik_U} = \sqrt{1000^{d_U}} \quad (15)$$

Step4 : This step consists of determining the value of $\tau = (\tau_{ik})_{m \times m}$ by the use of the equation (16):

$$\tau_{ik} = 1 - (\mu_{ik_U}^2 - \mu_{ik_L}^2) - (V_{ik_U}^2 - V_{ik_L}^2) \quad (16)$$

Step5: Multiplying the value of τ_{ik} by the matrix $S = (S_{ik})_{m \times m}$ to obtain the matrix of weights, $T = (T_{ik})_{m \times m}$ and normalizing the matrix using the equation 17:

$$T_{ik} = \left(\frac{S_{ik_L} + S_{ik_U}}{2} \right) \tau_{ik} \quad (17)$$

Step6: Calculate the normalized weights W_i by the use of equation 18:

$$W_i = \frac{\sum_{k=1}^m t_{ik}}{\sum_{i=1}^m \sum_{k=1}^m t_{ik}} \quad (18)$$

TOPSIS method

TOPSIS [11] [12] is among the frequently used multi-criteria methods for resolving the supplier selection problem. Its process is based on the selection of the alternative according to its distance from both ideal and anti-ideal solutions. The best alternative has the shortest distance from the ideal solution and the farthest value from the anti-ideal solution. The main steps of this method are described below:

Step1: determine the actions' preferences; in our case we use AHP, PFAHP, and BWM to calculate all criteria weights. Then, give the decision matrix corresponding to the decision problem: r_{ij} where $i = 1, \dots, m$ and $j = 1, \dots, n$.

Normalize the previous matrix using the following formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^n x_{ij}^2}} \text{ for } i = 1, \dots, m \text{ and } j = 1, \dots, n \quad (19)$$

Step2: Calculate the weighted normalized matrix by multiplying the previous matrix by the associated weights. We use the following formula:

$$v_{ij} = Wt_j \cdot r_{ij} \quad (20)$$

Step 3: In this step, we compare the values calculated previously with both negative and positive solutions. The next equation expressed the ideal action (A^+):

$$A^+ = v_1^+, v_2^+, \dots, v_n^+ = (\max_i v_{ij} | j \in S_b) (\min_i v_{ij} | j \in S_c) \quad (21)$$

The negative ideal action A^- is expressed as follows:

$$A^- = v_1^-, v_2^-, \dots, v_n^- = (\min_i v_{ij} | j \in S_b) (\max_i v_{ij} | j \in S_c) \quad (22)$$

Where S_b and S_c denote the sets of the benefit criteria and the cost criteria respectively.

Step4: consists of measuring the separation distances (S_i^+ and S_i^-) of all actions to the positive and the negative points using the following equations:

$$S_i^+ = \sqrt{\sum_{j=1}^n (v_j^+ - v_{ij})^2}; i = 1, \dots, m \text{ and } j = 1, \dots, n \quad (23)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_j^- - v_{ij})^2}; i = 1, \dots, m \text{ and } j = 1, \dots, n \quad (24)$$

Step5: This step represents a validation step, where the closeness value is calculated on the basis of the previous distances, using the equation shown below:

$$C_i = \frac{S_i^-}{S_i^- + S_i^+}; i = 1, \dots, m \quad (25)$$

The obtained closeness value should be between 0 and 1. The closeness of this value to 1 means that the solution is nearest to the positive solution and farthest from the negative solution.

Case study

This section represents our illustrative example. This study follows different steps, which are detailed as follows:

Step1: The first step consists of representing the supplier selection problem as hierarchical problem where the most essential criteria and their sub-criteria are determined. The main criteria and sub-criteria are depicted in Table 4. . This phase initiates the decision process for the next step.

Step2: In this step, we construct the pair wise comparison matrices according to

the previous decision hierarchy.

sed on varying two criteria weights and fixing the other criteria weights. Figure shows the sensitivity analysis for the current study.

Step3: This phase influences directly the supplier selection; it is based on determining the weights of criteria using PFAHP and BWM methods. To achieve this step correctly, we have interviewed experts from the hospital where the case study was realized. The evaluation of the supplier selection is performed using the Saaty's 9-point scale. Then, we exploit the process of the PFAHP method for calculating the weights of criteria and their associated sub-criteria. Then, we use the BWM tool to recalculate the different weights.

Step 4: Hybridization of MCDM approaches

This step consists of making the ranking phase using two hybrid multi-criteria methods: PFAHP-TOPSIS and BWM-TOPSIS. We integrate the weights of all criteria and sub-criteria calculated by PFAHP for ranking the alternatives using PFAHP-TOPSIS. Similarly, we integrate the weights calculated by BWM in TOPSIS method for ranking alternatives by the hybrid BWM-TOPSIS tool.

Step5: This step represents a validation phase. We study the consistency of the two integrated methods using the sensitivity analysis. This phase is based on varying two criteria weights and fixing the other criteria weights.

Supplier selection using the integrated AHP-TOPSIS

In Table 3, we illustrate the preferences of each main criterion. These values are exploited for making the pairwise comparison step, Table 6. shows the values obtained in this step. After calculating all consistency rates, we conclude that the matrices calculated are consistent because the consistency value of each criteria or sub-criteria is inferior to 0.1 (with the values of 0.08,0.03,0.04,0.019, 0.047 and 0.019 respectively) . In Table 5, we regroup the global weights that are exploited as inputs for the following ranking phase. Global weights are calculated by multiplying the local weights by the weight of the correspondent main criteria. For example, for sub-criteria C11, the local weight is 0.44, and for the first criterion, the local weight is 0.63. Therefore, the overall weight of C11 is $0.44 * 0.63 = 0.27$. After calculating all criteria weights using AHP model, we use these generated weights for ranking the available alternatives. We present the Input values of TOPSIS method in Table 6

This section aims to rank the alternatives using TOPSIS technique, we present in Table 7 the weighted normalized matrix obtained by multiplying each column with its associated weight using equations: (19) and (20). For each criterion, we calculate the positive and negative ideal solutions (A^+ , A^-) using equations: (21) and (22). Ranking step is performed using equations: (23) and (24) and (25). Table 8 depicts the final evaluation of alternatives, it can be visually seen that supplier 5 represents the best supplier.

Supplier selection using the integrated BWM-TOPSIS

in this section, we calculate the criteria preferences using BWM tool. The first step consists of the determination of the preferences values of all criteria comparatively

to the best and the worst criterion. Table 9 and Table 10 show the importance values of the criteria considered for this study compared to the best and the worst criterion respectively. the followed step is resolving the optimal problem for finding the optimal weights of the different criteria. Table 11 depicts the optimal values of the study preferences. Table 12 shows the different global weights of criteria using BWM. After calculating the global weights of criteria using BWM, we use the generated preferences as inputs of TOPSIS method for ranking the suppliers. Table 13 shows the normalized weighted matrix obtained by the use of the integrated BWM-TOPSIS tool. The following step consists of calculating the distances for ranking the alternatives. Table 14 depicts the ranking step.

Supplier selection using the integrated PFAHP-TOPSIS

For the PFAHP process, the linguistic variables given in Table 15 are used and converted into corresponding interval-valued Pythagorean fuzzy numbers. After, the pairwise comparison matrix for the main criteria is given in Table 15 . The difference matrix D and Interval multiplicative matrix S are also given in Table 16, and Table 17 respectively. Finally, the normalized priority weights of main criteria are computed as shown in Table18 . Similar procedure is implemented for subcriteria and the results are presented in Table 18. After calculating all criteria weights using the PFAHP model, we use these generated weights for ranking the available alternatives. We present the Input values of TOPSIS method in Table 19. This section aims to rank the alternatives using TOPSIS technique, we present in Table 20. the weighted normlized matrix obtained by multiplying each column with its associated weight using equations:(19) and (20). For each criterion, we calculate the positive and negative ideal solutions (A^+ , A^-) using equations:(21) and (22). Table 21 shows the ranking of the available suppliers.

Sensitivity Analysis

Sensitivity analysis represents a strong tool for making the validation of ranking' results for the three hybrid models: AHP-TOPSIS, BWM-TOPSIS, and PFAHPTOPSIS tools. The main objective of this section is making the evaluation of alternatives under the variation of the criteria weights. We have studied different cases, where we have permuted two weights and kept the original values of the other weights. In each case, we followed the different steps of the hybrid models. Table22, Table24, and Table26 represent the different cases for AHP-TOPSIS, BWM-TOPSIS and PFAHP-TOPSIS respectively. In Table 22, Table 24, and Table 26 , we regroup the results obtained for all cases for the AHP-TOPSIS, the BWM-TOPSIS, and the PFAHP-TOPSIS tools respectively. From sensitivity analysis results(Table 23, Table 25, and Table 27), we observe that supplier5 is the most effective supplier compared to the remaining suppliers, this is justified by its highest values for the benefice criteria and its lowest values for the cost criteria .On the other hand, the supplier1 has the worst rank compared to the remaining suppliers, this is due to its highest values for the cost criteria while it has the lowest values for the benefice criteria. It is clearly shown that the main case is an original ranking of the suppliers. Also, Supplier5 keeps its highest rank in the studied cases compared to the remaining suppliers. Moreover, Supplier5 keeps the highest score even if we consider equal weights to criteria (last case). Consequently, we can conclude that our decision making process is insensitive to criteria weights.

Conclusion

In the last years, several research works have been directed in the context of the supplier selection due to its strong importance. However, only some works have treated the health-care sector and this sector needs more significant efforts. In Morocco, health-care sector suffers from various complications and the supplier selection is one of them. Hence, we have studied the supplier selection in a Moroccan hospital, where the most essential criteria have been considered in the present case study. In this work, we have calculated the preference of the different criteria using two methods: PFAHP and BWM. Then, we have integrated these methods in TOPSIS approach for making the right and the optimal ranking of suppliers. To validate the results of the proposed integrated tools for resolving the decision problem, we have studied the sensitivity analysis of both tools considering different cases. The present study has some limitations that can be resolved in future research works: 1) This study focuses on only Marrakech city. However, the same methodology can be applied to various Moroccan cities. 2) In this study, we use the integrated PFAHP-TOPSIS and BWM-TOPSIS approaches for making the health-care supplier selection. Future works can use other MCDM tools such as ANP, DEMATEL. . . 3) As another future work, we intend to implement this work' results to select the best supplier in other hospitals using the criteria and their sub-criteria.

Declarations

Ethics approval and consent to participate
'Not applicable'

Consent for publication
'Not applicable'

Competing interests
The authors declare that they have no conflicts of interest..

Funding
'Not applicable'

Authors' contributions
All authors contribute equally in this paper

Acknowledgements
'Not applicable'

Authors' information
'Not applicable'

Availability of data and materials
'Not applicable'

Abbreviations

MCDM: Multi Criteria decision making
AHP-TOPSIS: Analytic hierarchy process-technique for order preference by similarity to ideal solution
PFAHP-TOPSIS: Pythagorean fuzzy analytic hierarchy process-technique for order preference by similarity to ideal solution
BWM-TOPSIS: Best worst method-technique for order preference by similarity to ideal solution
CI: Consistency Index
CR: Consistency Ratio

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Tables

Table 1 Importance scale in AHP

Relative Importance	Meaning
1	Equal
3	Weak
5	Strong
7	Demonstrated over the others
9	Absolute

Table 2 RCI values

Criteria number	RCI values
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Table 3 Matrix of Global Importance Criteria

Criteria	C1	C2	C3	C4	C5	Weights
C1	1	3	3	7	3	0.44
C2	0.33	1	0.14	1	0.33	0.07
C3	0.33	7	1	3	3	0.28
C4	0.14	1	0.33	1	1	0.08
C5	0.33	3	0.33	1	1	0.12

Table 4 Pairwise comparison matrix for Sub-criteria

Sub-criteria	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43	C51	C52	C53	Local weights
C11	1	5	3													0.63
C12	0.20	1	0.33													0.11
C13	0.33	3	1													0.26
C21				1	3	7										0.64
C22				0.33	1	5										0.28
C23				0.14	0.20	1										0.07
C31							1	5	9							0.74
C32							0.20	1	3							0.18
C33							0.11	0.33	1							0.07
C41										1	5	7				0.72
C42										0.20	1	3				0.19
C43										0.14	0.33	1				0.082
C51													1	3	9	0.66
C52													0.33	1	5	0.26
C53													0.11	0.20	1	0.06

Table 5 Global weights for criteria and sub-criteria

Criteria	Level1	Sub-criteria	Level2
Quality	0.44	C11	0.27
		C12	0.043
		C13	0.11
Reliability	0.07	C21	0.05
		C22	0.02
		C23	0.005
Cost	0.28	C31	0.21
		C32	0.05
		C33	0.02
Real time	0.08	C41	0.06
		C42	0.015
		C43	0.006
Technology	0.12	C51	0.081
		C52	0.032
		C53	0.007

Table 6 Input values of TOPSIS method

Criteria	Weights	Supplier1	Supplier2	Supplier3	Supplier4	Supplier5
C11	0.27	3	5	9	7	9
C12	0.043	3	5	5	5	7
C13	0.11	5	3	3	7	9
C21	0.05	5	5	5	5	3
C22	0.02	7	7	5	5	5
C23	0.005	5	5	5	4	3
C31	0.21	3	3	4	3	7
C32	0.05	7	7	9	5	9
C33	0.02	7	7	7	5	7
C41	0.06	5	5	5	7	3
C42	0.015	3	3	3	5	3
C43	0.006	5	5	5	3	5
C51	0.081	5	5	5	4	3
C52	0.032	3	3	3	5	5
C53	0.007	5	5	5	7	7

Table 7 Weighted normalized matrix obtained by the AHP-TOPSIS tool

Criteria	Supplier1	Supplier2	Supplier3	Supplier4	Supplier5	P	A ⁺	A ⁻
C11	0.05	0.086	0.155	0.120	0.155	+	0.15	0.05
C12	0.01	0.017	0.0173	0.017	0.024	+	0.02	0.01
C13	0.041	0.025	0.025	0.058	0.075	+	0.07	0.025
C21	0.023	0.023	0.023	0.023	0.014	-	0.014	0.023
C22	0.01	0.01	0.007	0.007	0.007	-	0.007	0.01
C23	0.002	0.002	0.002	0.002	0.0015	-	0.001	0.002
C31	0.065	0.065	0.087	0.065	0.153	+	0.15	0.065
C32	0.020	0.020	0.026	0.014	0.026	-	0.014	0.026
C33	0.009	0.009	0.009	0.0067	0.0094	+	0.009	0.0067
C41	0.026	0.026	0.026	0.0036	0.0156	-	0.015	0.036
C42	0.0057	0.0057	0.0057	0.009	0.0057	-	0.005	0.009
C43	0.002	0.0028	0.0028	0.0017	0.0028	-	0.001	0.0028
C51	0.04	0.04	0.04	0.032	0.024	-	0.02	0.04
C52	0.01	0.01	0.01	0.017	0.017	+	0.017	0.01
C53	0.002	0.002	0.002	0.0037	0.0037	+	0.003	0.002

Table 8 Alternatives ranking using AHP-TOPSIS

	S_i^+	S_i^-	C_i	Rank
Supplier1	0.142	0.021	0.129	5
Supplier2	0.124	0.037	0.231	4
Supplier3	0.086	0.106	0.551	2
Supplier4	0.098	0.078	0.442	3
Supplier5	0.011	0.148	0.92	1

Table 9 Matrix of Global Importance Criteria compared to the Best Criterion

Best to others	Quality	Reliability	Cost	Real time	Technology
Quality	1	7	3	6	5

Table 10 Matrix of Global Importance Criteria compared to the Worst criterion

Others to the worst	Reliability
Quality	7
Reliability	1
Cost	6
Real time	5
Technology	4

Table 11 Matrix of the optimal weights

Criteria	Quality	Reliability	Cost	Real time	Technology
Optimal weight	0.49	0.05	0.21	0.10	0.12

Table 12 Global weights for criteria and sub-criteria

Criteria	Level1	Sub-criteria	Level2
Quality	0.49	C11	0.35
		C12	0.09
		C13	0.034
Reliability	0.05	C21	0.039
		C22	0.007
		C23	0.003
Cost	0.21	C31	0.165
		C32	0.029
		C33	0.012
Real time	0.10	C41	0.07
		C42	0.021
		C43	0.007
Technology	0.12	C51	0.079
		C52	0.031
		C53	0.008

Table 13 Weighted normalized matrix for BWM-TOPSIS tool

Criteria	Supplier1	Supplier2	Supplier3	Supplier4	Supplier5	P	A^+	A^-
C11	0.067	0.118	0.20	0.156	0.20	+	0.20	0.067
C12	0.023	0.039	0.039	0.039	0.054	+	0.054	0.023
C13	0.0129	0.007	0.007	0.018	0.023	+	0.023	0.007
C21	0.186	0.186	0.186	0.186	0.11	-	0.11	0.186
C22	0.0037	0.0037	0.0026	0.002	0.002	-	0.002	0.003
C23	0.0015	0.0015	0.0015	0.0015	0.0009	-	0.0009	0.0015
C31	0.051	0.051	0.068	0.051	0.12	+	0.12	0.051
C32	0.02	0.012	0.015	0.008	0.015	-	0.008	0.015
C33	0.005	0.005	0.005	0.004	0.005	+	0.005	0.004
C41	0.03	0.03	0.03	0.042	0.018	-	0.018	0.042
C42	0.008	0.008	0.008	0.013	0.008	-	0.008	0.013
C43	0.003	0.003	0.003	0.002	0.003	-	0.002	0.003
C51	0.039	0.03	0.039	0.031	0.023	-	0.023	0.039
C52	0.01	0.01	0.01	0.017	0.017	+	0.017	0.01
C53	0.003	0.003	0.003	0.004	0.0042	+	0.0042	0.003

Table 14 Alternatives ranking using BWM-TOPSIS

	S_i^+	S_i^-	C_i	Rank
Supplier1	0.172	0.0147	0.078	5
Supplier2	0.138	0.049	0.26	4
Supplier3	0.096	0.136	0.58	2
Supplier4	0.115	0.092	0.44	3
Supplier5	0.007	0.174	0.96	1

Table 15 The pairwise comparison matrix for the main criteria

	C1	C2	C3	C4	C5
C1	([0.197, 0.197], [0.197, 0.197])	([0.550, 0.650], [0.350, 0.450])	([0.550, 0.650], [0.350, 0.450])	([0.800, 0.900], [0.100, 0.200])	([0.550, 0.650], [0.350, 0.450])
C2	([0.350, 0.450], [0.550, 0.650])	([0.197, 0.197], [0.197, 0.197])	([0.100, 0.200], [0.800, 0.900])	([0.197, 0.197], [0.197, 0.197])	([0.350, 0.450], [0.550, 0.650])
C3	([0.350, 0.450], [0.550, 0.650])	([0.800, 0.900], [0.100, 0.200])	([0.197, 0.197], [0.197, 0.197])	([0.550, 0.650], [0.350, 0.450])	([0.550, 0.650], [0.350, 0.450])
C4	([0.100, 0.200], [0.800, 0.900])	([0.197, 0.197], [0.197, 0.197])	([0.350, 0.450], [0.550, 0.650])	([0.197, 0.197], [0.197, 0.197])	([0.197, 0.197], [0.197, 0.197])
C5	([0.350, 0.450], [0.550, 0.650])	([0.550, 0.650], [0.350, 0.450])	([0.350, 0.450], [0.550, 0.650])	([0.197, 0.197], [0.197, 0.197])	([0.197, 0.197], [0.197, 0.197])

Table 16 The difference matrix

	C1	C2	C3	C4	C5
C1	([0.000, 0.000])	([0.100, 0.300])	([0.100, 0.300])	([0.600, 0.800])	([0.100, 0.300])
C2	([-0.300, -0.100])	([0.000, 0.000])	([-0.800, -0.600])	([0.000, 0.000])	([-0.300, -0.100])
C3	([-0.300, -0.100])	([0.600, 0.800])	([0.000, 0.000])	([0.100, 0.300])	([0.100, 0.300])
C4	([-0.800, -0.600])	([0.000, 0.000])	([-0.300, -0.100])	([0.000, 0.000])	([0.000, 0.000])
C5	([-0.300, -0.100])	([0.100, 0.300])	([-0.300, -0.100])	([0.000, 0.000])	([0.000, 0.000])

Table 17 The interval multiplicative matrix

	C1	C2	C3	C4	C5
C1	([1.000, 1.000])	([1.413, 2.818])	([1.413, 2.818])	([7.943, 15.849])	([1.413, 2.818])
C2	([0.355, 0.708])	([1.000, 1.000])	([0.063, 0.126])	([1.000, 1.000])	([0.355, 0.708])
C3	([0.355, 0.708])	([7.943, 15.849])	([1.000, 1.000])	([1.413, 2.818])	([1.413, 2.818])
C4	([0.063, 0.126])	([1.000, 1.000])	([0.355, 0.708])	([1.000, 1.000])	([1.000, 1.000])
C5	([0.355, 0.708])	([1.413, 2.818])	([0.355, 0.708])	([1.000, 1.000])	([1.000, 1.000])

Table 18 Global weights for criteria and sub-criteria

Main criteria	Weights(Level1)	Sub-criteria	Local weights	Global weights(Level2)
Quality	0.38	C11	0.57	0.22
		C12	0.142	0.05
		C13	0.279	0.106
Reliability	0.07	C21	0.65	0.046
		C22	0.27	0.019
		C23	0.066	0.004
Cost	0.35	C31	0.84	0.296
		C32	0.101	0.035
		C33	0.052	0.018
Real time	0.08	C41	0.76	0.065
		C42	0.153	0.013
		C43	0.08	0.006
Technology	0.11	C51	0.77	0.08
		C52	0.18	0.02
		C53	0.042	0.004

Table 19 Input values of TOPSIS method for PFAHP

Criteria	Weights	Supplier1	Supplier2	Supplier3	Supplier4	Supplier5
C11	0.57	3	5	9	7	9
C12	0.142	3	5	5	5	7
C13	0.27	5	3	3	7	9
C21	0.65	5	5	5	5	3
C22	0.27	7	7	5	5	5
C23	0.066	5	5	5	4	3
C31	0.84	3	3	4	3	7
C32	0.10	7	7	9	5	9
C33	0.052	7	7	7	5	7
C41	0.76	5	5	5	7	3
C42	0.153	3	3	3	5	3
C43	0.08	5	5	5	3	5
C51	0.77	5	5	5	4	3
C52	0.18	3	3	3	5	5
C53	0.04	5	5	5	7	7

Table 20 Weighted normlized matrix for PFAHP-TOPSIS tool

Criteria	Supplier1	Supplier2	Supplier3	Supplier4	Supplier5	P	A^+	A^-
C11	0.42	0.07	0.126	0.098	0.126	+	0.126	0.042
C12	0.014	0.023	0.023	0.023	0.032	+	0.032	0.014
C13	0.040	0.024	0.024	0.056	0.072	+	0.072	0.024
C21	0.022	0.022	0.022	0.022	0.013	-	0.013	0.022
C22	0.010	0.010	0.007	0.007	0.007	-	0.007	0.010
C23	0.002	0.002	0.002	0.001	0.001	-	0.001	0.002
C31	0.092	0.092	0.123	0.092	0.216	+	0.216	0.092
C32	0.014	0.014	0.018	0.010	0.018	-	0.010	0.018
C33	0.008	0.008	0.008	0.006	0.008	+	0.008	0.006
C41	0.028	0.028	0.028	0.039	0.016	-	0.016	0.039
C42	0.004	0.004	0.004	0.008	0.004	-	0.004	0.008
C43	0.002	0.002	0.002	0.001	0.002	-	0.001	0.002
C51	0.042	0.042	0.042	0.034	0.025	-	0.025	0.042
C52	0.006	0.006	0.006	0.011	0.011	+	0.011	0.006
C53	0.0015	0.0015	0.0015	0.002	0.002	+	0.002	0.0015

Table 21 Alternatives ranking using PFAHP-TOPSIS

	S_i^+	S_i^-	C_i	Rank
Supplier1	0.155	0.020	0.116	5
Supplier2	0.146	0.032	0.180	4
Supplier3	0.107	0.091	0.458	2
Supplier4	0.130	0.066	0.338	3
Supplier5	0.008	0.161	0.95	1

Table 22 Sensitivity analysis cases for AHP-TOPSIS

Cases	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43	C51	C52	C53
1(main case)	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
2	0.04	0.27	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
3	0.11	0.04	0.27	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
4	0.27	0.11	0.04	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
5	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
6	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
7	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
8	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
9	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
10	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
11	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
12	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
13	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
14	0.27	0.04	0.11	0.05	0.02	0.005	0.21	0.05	0.02	0.06	0.015	0.006	0.08	0.03	0.007
15(Equal)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015

Table 23 Results of sensitivity analysis for AHP-TOPSIS

Cases	Supplier1	Supplier2	Supplier3	Supplier4	Supplier5	Rank
case 1(main)	0.129	0.231	0.551	0.442	0.92	S5→S3→S4→ S2→S1
case 2	0.134	0.299	0.359	0.368	0.92	S5→S4→S3→ S2→S1
case 3	0.248	0.11	0.258	0.467	0.93	S5→S4→S3→ S1→S2
case 4	0.09	0.261	0.589	0.428	0.92	S5→S3→S4→ S2→S1
case 5	0.158	0.120	0.242	0.273	0.90	S5→S4→S3→ S1→S2
case 6	0.096	0.241	0.581	0.422	0.92	S5→S3→S4→ S2→S1
case 7	0.129	0.231	0.553	0.444	0.92	S5→S3→S4→ S2→S1
case 8	0.129	0.231	0.551	0.442	0.92	S5→S3→S4→ S2→S1
case 9	0.149	0.276	0.596	0.616	0.91	S5→S4→S3→ S2→S1
case 10	0.127	0.182	0.459	0.354	0.92	S5→S3→S4→ S2→S1
case 11	0.130	0.231	0.553	0.440	0.96	S5→S3→S4→ S2→S1
case 12	0.124	0.229	0.552	0.447	0.92	S5→S3→S4→ Sr2→S1
case 13	0.127	0.230	0.551	0.443	0.92	S5→S3→S4→ S2→S1
case 14	0.129	0.231	0.551	0.442	0.92	S5→S3→S4→ S2→S1
case 15(Equal)	0.299	0.321	0.414	0.470	0.77	S5→S4→S3→ S2→S1

Table 24 Sensitivity analysis cases for BWM-TOPSIS

Cases	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43	C51	C52	C53
1(main case)	0.35	0.09	0.034	0.39	0.007	0.003	0.165	0.029	0.012	0.07	0.021	0.007	0.079	0.031	0.008
2	0.09	0.35	0.034	0.39	0.007	0.003	0.165	0.029	0.012	0.07	0.021	0.007	0.079	0.031	0.008
3	0.034	0.09	0.35	0.39	0.007	0.003	0.165	0.029	0.012	0.07	0.021	0.007	0.079	0.031	0.008
4	0.35	0.034	0.09	0.39	0.007	0.003	0.165	0.029	0.012	0.07	0.021	0.007	0.079	0.031	0.008
5	0.39	0.09	0.034	0.35	0.007	0.003	0.165	0.029	0.012	0.07	0.021	0.007	0.079	0.031	0.008
6	0.35	0.09	0.39	0.034	0.007	0.003	0.165	0.029	0.012	0.07	0.021	0.007	0.079	0.031	0.008
7	0.35	0.09	0.034	0.007	0.39	0.003	0.165	0.029	0.012	0.07	0.021	0.007	0.079	0.031	0.008
8	0.35	0.09	0.034	0.39	0.003	0.007	0.165	0.029	0.012	0.07	0.021	0.007	0.079	0.031	0.008
9	0.35	0.09	0.034	0.39	0.007	0.165	0.003	0.029	0.012	0.07	0.021	0.007	0.079	0.031	0.008
10	0.35	0.09	0.034	0.39	0.007	0.003	0.029	0.165	0.012	0.07	0.021	0.007	0.079	0.031	0.008
11	0.35	0.09	0.034	0.39	0.007	0.003	0.165	0.012	0.029	0.07	0.021	0.007	0.079	0.031	0.008
12	0.35	0.09	0.034	0.39	0.007	0.003	0.165	0.029	0.07	0.012	0.021	0.007	0.079	0.031	0.008
13	0.35	0.09	0.034	0.39	0.007	0.003	0.165	0.029	0.012	0.07	0.0007	0.021	0.079	0.031	0.008
14	0.35	0.09	0.034	0.39	0.007	0.003	0.165	0.029	0.012	0.07	0.021	0.007	0.079	0.008	0.031
15(Equal)	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39

Table 25 Results of sensitivity analysis for BWM-TOPSIS

Cases	Supplier1	Supplier2	Supplier3	Supplier4	Supplier5	Rank
case 1(main)	0.078	0.26	0.58	0.44	0.96	S5→S3→S4→ S2→S1
case 2	0.082	0.33	0.39	0.35	0.95	S5→S3→S4→ S2→S1
case 3	0.26	0.10	0.13	0.477	0.96	S5→S4→S1→ S3→S2
case 4	0.10	0.24	0.57	0.45	0.96	S5→S3→S4→ S2→S1
case 5	0.07	0.27	0.62	0.47	0.96	S5→S3→S4→ S2→S1
case 6	0.18	0.23	0.42	0.58	0.97	S5→S4→S3→ S2→S1
case 7	0.08	0.27	0.71	0.55	0.96	S5→S3→S4→ S2→S1
case 8	0.07	0.26	0.58	0.44	0.96	S5→S3→S4→ S2→S1
case 9	0.08	0.28	0.60	0.49	0.95	S5→S3→S4→ S2→S1
case 10	0.13	0.30	0.60	0.51	0.80	S5→S3→S4→ S2→S1
case 11	0.079	0.26	0.58	0.44	0.98	S5→S3→S4→ S2→S1
case 12	0.06	0.26	0.58	0.44	0.96	S5→S3→S4→ S2→S1
case 13	0.074	0.26	0.58	0.44	0.95	S5→S3→S4→ S2→S1
case 14	0.078	0.26	0.58	0.44	0.96	S5→S3→S4→ S2→S1
case 15	0.29	0.32	0.41	0.47	0.77	S5→S4→S3→ S2→S1

Table 26 Sensitivity analysis cases for PFAHP-TOPSIS

Cases	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43	C51	C52	C53
1(main case)	0.22	0.054	0.106	0.046	0.019	0.004	0.296	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
2	0.054	0.22	0.106	0.046	0.019	0.004	0.296	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
3	0.106	0.054	0.22	0.046	0.019	0.004	0.296	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
4	0.22	0.106	0.054	0.046	0.019	0.004	0.296	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
5	0.046	0.054	0.106	0.22	0.019	0.004	0.296	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
6	0.22	0.054	0.046	0.106	0.019	0.004	0.296	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
7	0.22	0.054	0.106	0.019	0.046	0.004	0.296	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
8	0.22	0.054	0.106	0.046	0.004	0.019	0.296	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
9	0.22	0.054	0.106	0.046	0.019	0.296	0.004	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
10	0.296	0.054	0.106	0.046	0.019	0.004	0.22	0.035	0.018	0.065	0.013	0.006	0.085	0.02	0.004
11	0.22	0.054	0.106	0.046	0.019	0.004	0.296	0.018	0.035	0.065	0.013	0.006	0.085	0.02	0.004
12	0.22	0.054	0.106	0.046	0.019	0.004	0.296	0.035	0.065	0.018	0.013	0.006	0.085	0.02	0.004
13	0.22	0.054	0.106	0.046	0.019	0.004	0.296	0.035	0.018	0.065	0.006	0.013	0.085	0.02	0.004
14	0.22	0.054	0.106	0.046	0.019	0.004	0.296	0.035	0.018	0.065	0.013	0.006	0.085	0.004	0.02
15(Equal)	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013

Table 27 Results of sensitivity analysis for PFAHP-TOPSIS

Cases	Supplier1	Supplier2	Supplier3	Supplier4	Supplier5	Rank
case 1(main)	0.116	0.180	0.458	0.338	0.95	S5→S3→S4→ S2→S1
case 2	0.119	0.224	0.324	0.286	0.94	S5→S3→S4→ S2→S1
case 3	0.193	0.112	0.277	0.359	0.95	S5→S4→S3→ S1→S2
case 4	0.088	0.202	0.479	0.324	0.94	S5→S3→S4→ S2→S1
case 5	0.129	0.106	0.251	0.220	0.94	S5→S3→S4→ S1→S2
case 6	0.085	0.186	0.479	0.314	0.94	S5→S3→S4→ S1→S2
case 7	0.116	0.180	0.459	0.339	0.95	S5→S3→S4→ S2→S1
case 8	0.116	0.180	0.458	0.338	0.95	S5→S3→S4→ S2→S1
case 9	0.27	0.30	0.45	0.39	0.94	S5→S3→S4→ S2→S1
case 10	0.118	0.238	0.570	0.445	0.94	S5→S3→S4→ S2→S1
case 11	0.316	0.390	0.630	0.525	0.96	S5→S3→S4→ S2→S1
case 12	0.110	0.177	0.459	0.341	0.95	S5→S3→S4→ S2→S1
case 13	0.115	0.180	0.458	0.338	0.94	S5→S3→S4→ S2→S1
case 14	0.116	0.180	0.458	0.338	0.94	S5→S3→S4→ S2→S1
case 15	0.299	0.321	0.414	0.470	0.77	S5→S4→S3→ S2→S1