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ASSESSMENT AND SELECTION OF CLOUD SERVICE PROVIDERS FOR HOSTING WEB APPLICATIONS BY APPLYING THE MADM APPROACH

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Abstract: The goal of the research is to propose the methodology for the effective assessment and selection of cloud service providers for hosting web applications by applying a multi-attribute decision-making approach. In the course of achieving the goal of the research, the methodology is divided into two parts. The first part involves setting attribute weights for evaluating potential cloud platforms as a group decision-making task. The BWM (Best-Worst Method) is applied at the individual decision-maker level to determine the weight vector, followed by aggregation using the quadratic mean operator, assuming equal importance of all decision-makers. The normalized attribute vector is obtained through linear normalization. The second part proposes an application of TODIM (an acronym in Portuguese for Interactive and Multicriteria Decision Making) MADM methods. The method is modified by employing an alternative normalization procedure compared to the conventional method. The weighted normalized decision matrices are constructed using the exponentiation principle instead of the traditional product principle. Finally, based on suggestions from relevant literature, the cloud platform priorities obtained are compared. The proposed model is illustrated with examples from a real supply chain in the information technology domain.

Keywords: Multi-attribute decision making, cloud service, assessment

1 INTRODUCTION

Multi-attribute decision-making (MADM) methods play a crucial role in evaluating and selecting the most suitable alternative in scenarios characterized by multiple, often conflicting, criteria. The selection of a cloud environment is a prime example where decision-makers (DMs) must balance various factors, such as cost, performance, security, and scalability. Given the complexity and the high stakes involved, employing

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a structured and systematic decision-making approach is essential. Numerous classifications of MADM methods exist in the literature, each reflecting different theoretical foundations and application contexts. One such classification [1] categorizes MADM methods into utility-based methods and ranking methods, such as the TODIM method. This classification provides a framework for understanding the diverse range of MADM techniques and their respective strengths and limitations in various decision-making scenarios [2, 3].

The primary goal of this research is to develop a comprehensive methodology for cloud platform selection, which incorporates both group decision-making and multi-attribute decision-making methods. The proposed methodology addresses the following research objectives:

- To determine the weights of the evaluation criteria using the Best-Worst Method (BWM) in a group decision-making context.
- To introduce modifications to the TODIM method by employing an alternative normalization procedure, enhancing the robustness and reliability of the decision-making process.

The first component of the methodology involves the group decision-making process for determining the attribute weights. The BWM, a relatively recent and efficient method, is employed to derive the weight vector at the individual DM level. The BWM has gained recognition for its ability to reduce the cognitive burden on DMs while providing consistent and reliable weight estimates [4, 5].

The second component focuses on the MADM process itself, where the TODIM method is employed. TODIM, as a ranking method, provides a comparative evaluation by considering the dominance of one alternative over others [6]. To enhance these methods, we modify the normalization procedure by using the exponentiation principle instead of the conventional product principle, aiming to improve the accuracy and reliability of the weighted normalized decision matrices [7].

Finally, the proposed methodology is validated through its application to real-world cases from a supply chain in the information technology domain. This research contributes to the existing body of knowledge by not only applying established MADM methods but also by proposing methodological enhancements that address current challenges in the field. The rest of the paper is organized as follows: Section 2 presents a relevant literature review. Section 3 presents the proposed model. An illustrative example is presented in Section 4 and a conclusion is presented in Section 5.

2 LITERATURE REVIEW

Determining the weight of attributes can be based on qualitative and/or quantitative methods. When utilizing qualitative methods, such as panel discussions or the Delphi method [8], the solutions obtained are significantly influenced by the subjective opinions of DMs.

The assessment of the relative importance of attributes in almost every problem depends on the judgment of the DMs. By applying subjective multi-attribute methods, such as the Analytic Hierarchy Process (AHP) [9] and Best-Worst Method (BWM) [4], a vector of attribute weights is obtained that is less burdened by the DMs' subjective assessments compared to the use of qualitative methods. In the literature, a large number of studies have employed the AHP method, which is well-grounded in theory [10]. In this method, a matrix of pairwise comparisons of the relative importance of attributes is constructed. Based on the calculated value of the consistency ratio, it is possible to determine whether the errors made by the DMs are acceptable or not. Although this method is straightforward for researchers to use, in practice, DMs often struggle to assess the relative importance of each pair of attributes.

In contrast to this approach, the BWM introduces the assumption that DMs can easily identify the most important and the least important attributes. Once these are identified, matrices are constructed comparing the best attribute against all others and the others against the worst attribute. It has been demonstrated that this approach is highly comprehensible for DMs operating in real organizational systems. This was the motivation for employing this method in the present study to evaluate the relative importance of attributes for assessing a set of cloud platforms. The literature contains numerous studies in which the BWM has been utilized to determine attribute weight vectors [11].

3 THE METHODOLOGY AND THE PROPOSED MODEL

In this section, the methodology used to solve the considered problem is briefly explained. The paper developed a two-phase model. In the first phase, attribute weights were determined based on which cloud platforms are evaluated. In the second phase, the ranking of alternatives is determined, which enables the selection of the best option. An analysis of the similarity of the rank obtained by applying two multi-attributive methods was also performed.

3.1 Defining a set of decision-makers

The evaluation of the relative importance of the attributes according to which the considered cloud platforms are evaluated, as well as the values of the qualitative attributes, was performed by several DMs. These DMs are formally represented by a set of indices $\{1,\ldots,e,..,E\}$. The total number of DMs is denoted as E. The DM index is denoted as e,e=1,…,E. In this research, the DMs are: the product owner (e=1), operations manager (e=2), and product development engineer (e=3).

3.2 Defining a set of alternatives

In general, DMs can use different platforms. In the general case, the set of platforms is denoted by the set of indices {1,…,,..,}. The total number of platforms is denoted as I. The platform index is denoted as i,=1,…,I.

The following platforms were considered in this paper: AWS (i=1), AZURE (i=2), Google Cloud (i=3), IBM (i=4), and Oracle (i=5).

3.3 Defining a set of attributes

Each alternative can be evaluated according to a number of attributes. A set of attributes is represented by a set of indices {1,…,,…,}. The total number of attributes is denoted as K. The attribute index is denoted as k,=1,…,K. In this problem, the platforms are rated according to the following attributes:

Unit price measured per gigabyte (eng. gigabyte) on a monthly basis (k=1), scalability (k=2), data processing method (k=3), storage security (k=4), management difficulty (k= 5) and the number of locations (k=6).

3.4 Determining attribute weights

At the level of each DM, the weights vector of attributes is given by using conventional BWM. As this method is well known, its algorithm is not presented here.

Step 1. The weights vector of the attribute at the level of each DM is presented:

$$[W_k^e]_{1xE} \tag{1}$$

Step 2. The aggregation of attributes weights is performed by applying the operator of mean square:

$$[W_k]_{1xK} \quad (2$$

where:

$$W_k = \sqrt{\frac{\sum_{e=1,..,E} W_k^2}{E}} \tag{3}$$

Step 3. The normalization aggregated weights vector is given by using the linear normalization procedure:

$$[\omega_k]_{1xK} \tag{4}$$

where:

$$\omega_k = \frac{W_k}{\sum_{k=1,..,K} W_k} \tag{5}$$

3.5 Determining the rank of the Cloud platform by applying modified TODIM method

The TODIM Method Algorithm is Executed Through the Following Steps:

*Step 1***:** Establish the decision matrix:

$$[\boldsymbol{x_{ik}}]_{\boldsymbol{IxK}} \tag{6}$$

Step 2. The normalized decision matrix is obtained by applying enhanced accuracy normalization [12]:

$$[r_{ik}]_{IxK} \tag{7}$$

a) benefit type

$$r_{ik} = 1 - \frac{x^{max} - x_{ik}}{\sum_{i=1}^{I}(x^{max} - x_{ik})} \tag{8}$$

b) cost type

$$r_{ik} = 1 - \frac{x_{ik} - x^{min}}{\sum_{i=1}^{I}(x_{ik} - x^{min})} \tag{9}$$

Step 3. Construct the weighted normalized decision matrix using the exponentiation procedure [13]:

$$[z_{ik}]_{IxK} \tag{10}$$

where

$$z_{ik} = (r_{ik})^{\omega_k} \tag{11}$$

Step 4. Determine the preference values of each alternative within each criterion:

$$d_{ii'}^{k} = \begin{cases} \sqrt{|z_{ik} - z_{i'k}|} & z_{ik} > z_{i'k} \\ 0 & z_{ik} = z_{i'k} \\ -\sqrt{|z_{ik} - z_{i'k}|} & z_{ik} < z_{i'k} \end{cases} \tag{12}$$

Step 5. Determine the dominance level of each alternative.

$$\delta_i = \sum_{k=1,..,K} d_{ii'}^{k} \tag{13}$$

Step 6. Determine the overall dominance level for each alternative.

$$\boldsymbol{\xi_i} = \frac{\boldsymbol{\delta_i - \delta^{min}}}{\boldsymbol{\delta^{max} - \delta^{min}}} \tag{14}$$

Step 7. Sort the values of the overall dominance level in non-decreasing order. The ranking of the alternatives is determined based on these values.

4 THE ILLUSTRATIVE EXAMPLE

The company that is chosen for the application of the proposed methodology operates with a flat organizational structure. It means that the highest level of management is hierarchically very close to the employees at the bottom of the organization. During the development of a web application, it goes through different stages: (1) Planning and design, (2) Development and testing, (3) Deployment on the cloud, and (4) Maintenance and improvement. Special attention should be paid to the selection of an adequate provider, to avoid later problems in the operation of the application. Some of the possible problems are unexpected and high costs, limited scalability, poor integration, or insufficient data protection.

The attribute values (k=1) and (k=6) were obtained from the official website of each cloud provider. Other attributes are of a qualitative nature, so DMs evaluate these attributes based on a standard scale of measures. A value of 1 indicates that the value of the attribute is the smallest, and a value of 9 indicates that the value of the attribute is the largest.

Criteria Number = 6	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6
Names of Criteria	к1	к2	к3	к4	к5	к6

Select the Best	к1

Select the Worst	к5

Best to Others	к1	к2	к3	к4	к5	к6
к1	1	1	4	1	9	5

Others to the Worst	к5
к1	9
к2	8
к3	5
к4	8
к5	1
к6	6

Weights	к1	к2	к3	к4	к5	к6
	0.28742515	0.26347305	0.08982036	0.26347305	0.0239521	0.07185629

Input-Based CR	0.29166667	The pairwise comparison consistency level is acceptable
Associated Threshold	0.3337	

Figure 1. *Fuzzy rating of the relative importance of the attributes at the level of the product owner*

The DMs evaluated the attributes' values based on their knowledge, experience, and data from the records. A panel discussion was organized that lasted about 30 minutes. At the panel discussion, DMs expressed their opinions on the value of attributes. Through a panel discussion, the decision on the value of qualitative attributes was made by consensus.The assessment of the relative importance of attributes is conducted at the level of each DM. The fuzzy rating of the product owner is illustrated in Figure 1. The vector of attribute weights is also presented in the same figure.

Similarly, the weight vectors for the other (DMs were obtained. By applying the quadratic mean operator and linear normalization procedure, the normalized weights vector of attributes was derived, such that:

$$[0{,}16 \quad 0{,}19 \quad 0{,}16 \quad 0{,}24 \quad 0{,}17 \quad 0{,}08]$$

The ranking of the evaluated cloud platforms was carried out using the modified TODIM method. The decision matrix is presented in Table 1.

Table 1. *The decision matrix*

	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=6$
$i=1$	0,023	8	7	7	3	126
$i=2$	0,018	9	8	8	1	116
$i=3$	0,020	2	4	8	2	200
$i=4$	0,020	7	5	8	4	20
$i=5$	0,025	4	6	9	5	43

By applying the proposed procedure (from Step 2 to Step 3), the weighted normalized decision matrix is constructed and presented in Table 2.

Table 2. *The weighted normalized decision matrix*

	$k = 1$	$k = 2$	$k = 3$	$k = 4$	$k = 5$	$k = 6$
$i = 1$	0,942	0,840	0,983	0,885	0,963	0,987
$i = 2$	1	1	1	0,948	1	0,985
$i = 3$	0,979	0,887	0,922	0,948	0,982	1
$i = 4$	0,979	0,973	0,945	0,948	0,941	0,964
$i = 5$	0,912	0,936	0,864	1	0,917	0,970

Determine the preference values of the cloud platforms and the overall dominance level (Step 4 and Step 5), as presented below in Table 3.

Table 3. *Preference Values of the First Cloud Platform Relative to Others*

	$k = 1$	$k = 2$	$k = 3$	$k = 4$	$k = 5$	$k = 6$
$i = 1; i = 2$	-0,241	-0,400	-0,130	-0,251	-0,192	0,045
$i = 1; i = 3$	-0,192	-0,217	0,247	-0,251	-0,138	-0,114
$i = 1; i = 4$	-0,192	-0,365	0,195	-0,251	0,148	0,152
$i = 1; i = 5$	0,173	0,309	0,345	-0,339	0,214	0,130

The procedure for calculating the dominance level of the first cloud platform is illustrated below:

$$\delta_1 = -0{,}241 - 0{,}192 + \cdots . + 0{,}130 = -1{,}315 \tag{15}$$

Similarly, the dominance levels for the other evaluated cloud platforms were calculated.

To calculate the overall dominance level (Step 6), determine:

$$\delta^{min} = \min_{i=1,..,5}(-1{,}315; 3{,}974; 0{,}318; 0{,}022; -2{,}999) = -2{,}999 \tag{16}$$

$$\delta^{max} = \max_{i=1,..,5}(-1{,}315; 3{,}974; 0{,}318; 0{,}022; -2{,}999) = 3{,}974 \tag{17}$$

The values of the overall dominance levels for all evaluated cloud platforms are shown in Figure 2.

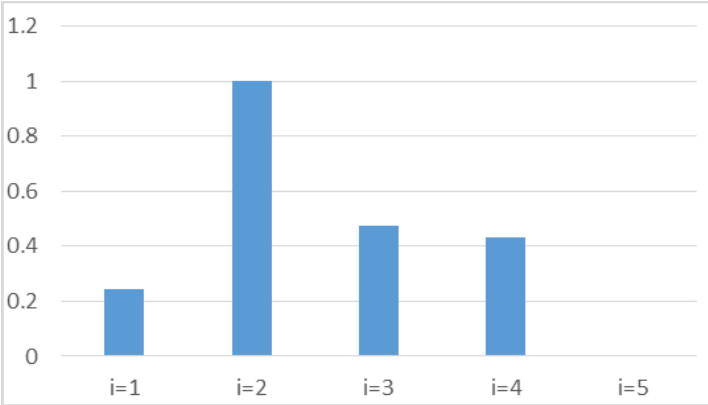

Figure 2. *Ranking of Cloud Platforms Using the Modified TODIM Method*

According to the recommendations from the literature, the cloud platforms with the best features are Azure ($\boldsymbol{i = 2}$) and Google Cloud ($\boldsymbol{i = 3}$). The cloud platform ranked lowest is AWS ($\boldsymbol{i = 1}$).

5 CONCLUSION

This study addresses the problem of evaluating and selecting cloud platforms, a critical operational management issue for companies in the information technology sector. Solving this problem aims to enhance customer satisfaction, which is a key business goal for the organization in question.

A two-stage multi-attribute decision-making model has been developed in this study. In the first stage, the weights of the attributes used to evaluate the identified cloud platforms were determined using the Best-Worst Method (BWM). In the second stage, the ranking of the identified cloud platforms was achieved using the modified TODIM method. Based on the obtained rankings, operational management can make an informed decision on which cloud platform to select, ultimately aiming to improve customer satisfaction.

The main contributions of this study are:

[1] The problem of determining attribute weights is framed as a group decision-making problem; the attribute weight vector was determined for each decision-maker using BWM.

[2] The normalized aggregated weights vector was obtained by applying the quadratic mean operator and the linear normalization procedure.

[3] The ranking of cloud platforms was determined using the modified TODIM method.

The developed methodology is flexible enough to quickly and easily incorporate changes in the number and values of attributes, as well as changes in their weights, into the proposed two-stage model. Future research should focus on developing software based on the proposed methodology.

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