

## **An Intelligent Multi-Criteria Decision-Making Model for selecting an optimal location for a data center: Case Study in Egypt**

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### **Abstract**

For businesses that depend on reliable and secure IT systems, choosing the best location for a data center is of paramount importance. Data center accessibility, operational efficiency, cost, and security are all affected by their physical location. The procedure entails considering a wide range of elements to guarantee that the final site meets the needs of the business. This paper investigated the multi-criteria decision-making (MCDM) model to select the best data center location based on a set of criteria. The MCDM method is integrated with the single-valued neutrosophic set (SVNS) to deal with vague and inaccurate information. A neutrosophic set with truth, indeterminacy, and falsity membership functions all in the range [0, 1] is called a SVNS. This paper used SVNS with three MCDM methods such as entropy, TOPSIS, and MABAC techniques. The entropy technique is used to compute the weights of criteria, then the TOPSIS and MABAC methods are used to rank the locations. The case study is investigated in Egypt. This paper used ten criteria and eight alternatives.

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### **1. Introduction**

Today's businesses have a greater need for data centers than ever before due to the proliferation of digital technologies and their rising dependence on data-driven operations. When it comes to storing, analyzing, and disseminating massive volumes of data, data centers are an organization's lifeblood. A company's IT operations' efficacy, dependability, and cost-effectiveness may all be greatly influenced by the location of its data center. The aim of this study is to examine the elements that should be taken into account when choosing a data center's physical location, with the hopes of illuminating the decision-making process and providing useful advice to businesses that are setting up or relocating their data storage facilities[1], [2].

The rise of digital technologies and the popularity of cloud storage have made data centers an indispensable part of today's businesses. Data centers are crucial to the operations of businesses across all sectors because of their capacity to host important applications, provide continuous uptime, and store and protect sensitive data. A data center's performance, resilience, and operational efficiency are all heavily influenced by its location[3], [4]. Organizations that are serious about optimizing their IT infrastructure, minimizing risks, and keeping up with the demands of a data-driven business environment must make an educated selection when choosing a site for their data center[5], [6].

The major objective of this study is to provide researchers with a thorough grasp of how to choose the best site for a data center. The study intends to uncover the crucial components that impact the decision-making process by evaluating the major dimensions, such as geography, power and energy concerns, connectivity, climatic and environmental issues, security and stability, cost considerations, and scalability[7], [8]. As an added benefit, this study intends to provide organizations with actionable advice and guidelines for assessing and selecting the best possible site for their data center facilities[9], [10].

Zadeh's proposal of a fuzzy set was a significant step forward in the study of fuzziness and uncertainty. As a result of the theory's popularity, numerous variants of fuzzy sets have been established, including the intuitionistic fuzzy set (IFS), the interval-valued (IV-FS), the hazy set, and the hesitant FS. The IFS model is the most popular, and it has produced a number of offshoots including the IV-IFS and the bipolar IFS. Smarandache then expanded on IFS theory with a concept he named neutrosophic set (NS)[11], where neutros means "nothing" in Greek. The primary distinction between the theory of FS, IFSs, and NS is the focus on the examination of the neutrality element of knowledge[12], [13].

Assuming standards in the non-standard interval  $[0, 1+]$ , the conventional NS is categorized by 3 membership functions that explain the truth (T), indeterminacy (I), and falsity (F). In an NS, the truth and falsity membership functions express the level to which elements belong to the set or do not, respectively, while the function of membership of indeterminacy indicates the degree to which the data is neutral. The neutrality elements of the information may be handled by NSs thanks to the extra indeterminacy membership function, which is beyond the capabilities of FS and their extensions. All 3 membership functions in an NS are completely independent of each other, which is in contrast to the membership and non-membership functions in an IFS or other FS-based theories, where the standards of these functions are contingent on one another[14], [15].

Specifically, this equips NSs to deal with information that is ambiguous, imprecise, inconsistent, or indeterminate when the variables influencing these characteristics are disentangled from one another. Matched to IFSs and other fuzzy or IF-based models in the works, this expands the NS's applicability[16], [17].

There has been a lot of interest in the SVNNS model ever since it was first introduced, and it has been actively applied to many other kinds of multi-attribute decision-making (MADM) issues. certain aspects of the SVNNS model were investigated by Wang et al, who also developed certain set-theoretic operators for SVNNSs[18]. Ye presented a decision-making technique that uses SVNNS correlation coefficients and used it to address various MADM issues. This paper integrated the SVNNS with the entropy, TOPSIS, and MABAC methods. The entropy method is used to compute the weights of standards. Then the SVN TOPSIS and MABAC methods are applied to order the alternatives[19], [20].

In this article, we'll examine what goes into finding the best spot to house your data center, and why. Geographical factors, power and energy needs, connectivity and network infrastructure, climate and environmental considerations, security and stability, cost considerations, and scalability for future growth are just some of the many dimensions that will be explored[21], [22]. In this article, we'll lay out a method for systematically assessing and ranking these considerations so that businesses may tailor their strategies to meet their unique requirements[23], [24].

A company's operational efficacy, cost-effectiveness, and competitiveness may all be affected by the location of its data center. Risks may be reduced, data center performance improved, and essential IT infrastructure maintained with minimal interruptions if only businesses took the time to do their homework. The purpose of this study is to aid businesses in making informed decisions about where to locate data centers by providing insights and concrete suggestions. Organizations may better ensure operational resilience, cost savings, and long-term growth by using research results and gaining insight into the most important factors[25], [26].

## **2. Problem Definition**

The process of selecting an optimal location for a data center is a multifaceted endeavor that necessitates a thorough evaluation of various factors. In the context of Egypt, a country experiencing rapid technological development and urban expansion, the decision regarding data center placement holds significant implications for both operational efficiency and sustainable growth. To ensure the success of such a strategic undertaking, it becomes imperative to consider a comprehensive set of criteria that encompasses not only technical and financial aspects but also societal, environmental, and regulatory dimensions.

The following criteria have been meticulously chosen to guide the selection of the best data center location within Egypt:

1. Proximity to resident area [27]: refers to how close the data center is to a populated area. Being close to a residential area can provide benefits such as easier access to a skilled workforce and better connectivity to transportation and communication infrastructure. However, it can also increase the risk of disruptions from events such as protests or natural disasters.
2. Climate [28], [29]: The climate of the location can affect the operation of a data center. For example, a cooler climate can reduce the cost of cooling the data center, while a location with high humidity may require additional measures to control moisture levels.
3. Transport & logistics operations[30]: This refers to the availability and efficiency of transportation and logistics infrastructure in the area. Good transport and logistics operations can make it easier to transport equipment and supplies to and from the data center, reducing costs and improving efficiency.
4. Operation costs[28]: This refers to the ongoing costs of operating the data center, such as electricity, cooling, maintenance, and staffing. These costs can vary depending on factors such as local labor costs, energy prices, and taxes.
5. Energy availability & cost[27]: This refers to the availability and cost of energy in the area. Data centers consume large amounts of electricity, so it is important to ensure that there is a reliable and cost-effective supply of energy available.
6. Disaster risks[30], [31]: This refers to the risk of natural or man-made disasters that could disrupt the operation of the data center. For example, a location that is prone to earthquakes or floods may require additional measures to protect against these risks.
7. Installing & operating costs[28], [31]: This refers to the costs associated with installing and setting up the data center, as well as ongoing operating costs. These costs can vary depending on factors such as local labor costs, energy prices, taxes, and regulations.
8. Development rate[30]: This refers to the rate at which the area is developing in terms of infrastructure, population growth, and economic activity. A rapidly developing area may provide opportunities for growth and expansion but may also increase competition for resources such as land and labor.
9. Governmental policies and regulations[32]: This refers to the policies and regulations set by local, state, or national governments that affect the operation of data centers. These can include regulations on energy use, emissions, data privacy, and building codes.
10. Construction costs[30]: This refers to the cost of constructing the data center building and installing the necessary infrastructure such as power, cooling, and networking systems. These costs can vary depending on factors such as local labor costs, material prices, and building codes.

Table 1: The selected criteria.

| <b>Code</b> | <b>Criteria</b>                       |
|-------------|---------------------------------------|
| C1          | Proximity to resident area            |
| C2          | Climate                               |
| C3          | Transport & logistics operations      |
| C4          | Operation costs                       |
| C5          | Energy availability & cost            |
| C6          | Disaster risks                        |
| C7          | Installing & operating costs          |
| C8          | Development rate                      |
| C9          | governmental policies and regulations |
| C10         | Governmental policies and regulations |

### 3. Methodology

This section outlines the research methodology adopted to evaluate and rank the potential cities for locating data centers using a combination of Entropy-based criteria weighting, MABAC, and TOPSIS techniques. The main impartial of this research is to identify the optimal city for data center location among a set of ten potential candidate cities. The selection will be based on a comprehensive evaluation of multiple criteria in Table 1 that are vital for data center suitability. To ensure the accuracy and dependability of the decision-making procedure, a comprehensive dataset was collected from five Experts. Then the Entropy technique was used to determine the relative importance of each criterion. The technique is widely recognized for its capability to handle imprecise and vague information while avoiding biases introduced by subjective judgment.

Then TOPSIS, a widely used MCDM method, was employed to compare the candidate cities against selected criteria. TOPSIS seeks to determine the substitute that is neighboring to the optimistic perfect solution and farthest from the bad ideal answer. Then multi-attributive border approximation area comparison (MABAC), another robust MCDM procedure, was chosen to compare the candidate cities against multiple criteria and to verify the consequences attained from the TOPSIS method. The technique provides a comprehensive view of each alternative's performance and incorporates both positive and negative preferences. The suggested methodology is in detail in Fig. 1.

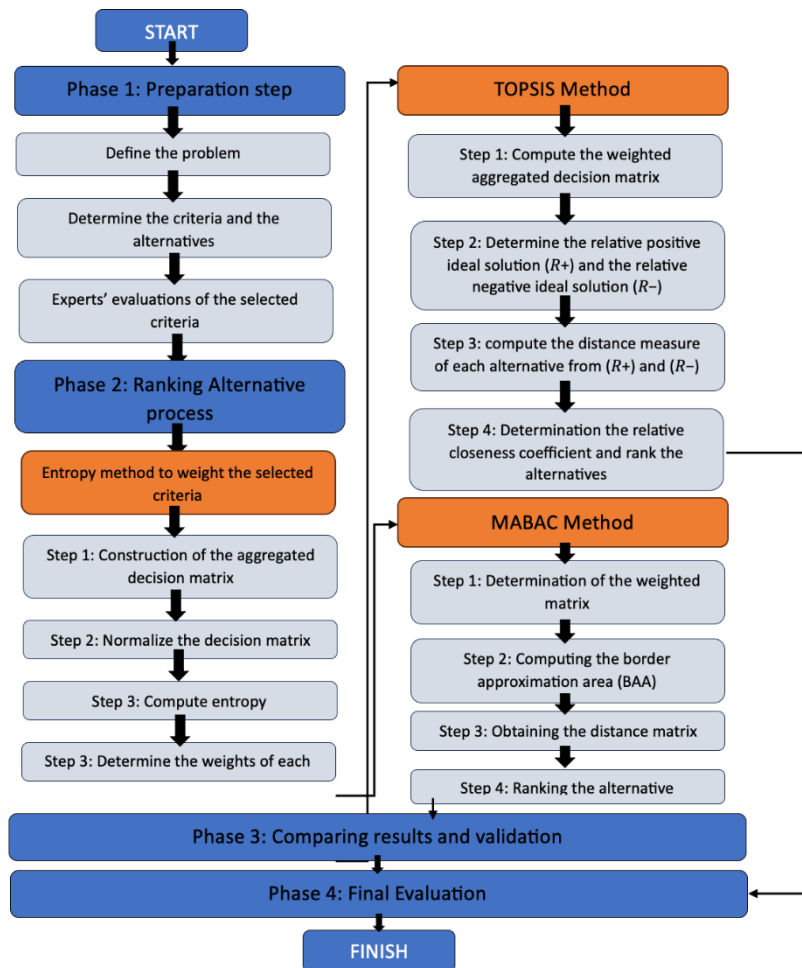


Figure 1: The proposed methodology and its steps

### 3.1 Neutrosophic Entropy

In MCDM, managers take into account a number of factors simultaneously and use a number of established methods of support[33]. In MCDM situations, the Entropy technique provides a neutral means of assigning relative importance to individual criteria[34]. Different approaches to making decisions allow us to categorize the relative importance of various criteria. Various criteria, including the decision-maker's knowledge, experience, and competence, are assigned subjective weights. One of the goal approaches to weighing variables is the Entropy method[35]. Based on the selected criteria, the five decision-makers matrixes  $L^k = (l_{ij}^{(k)})_{m \times n}$ :  $m = 8, n = 10$ , and according to the weight of each expert ( $\alpha = .2$ ), the Entropy method is used to calculate the weight of each criterion as the following[36]:

**1. Step 1: Construction of the aggregated neutrosophic decision matrix based on the assessments of decision makers.**

The single-valued neutrosophic weighted averaging (SVNWA) aggregation operator, proposed by YE[37], can be used to obtain the aggregated matrix for SVNSs as in Eq1. And the weighted vector of decision makers is  $\alpha = (.2, .2, .2, .2)$ .

$$L = (l_{ij}^{(k)})_{m \times n}$$

$$l_{ij} = \text{SVNSWA } \alpha (l_{ij}^1, l_{ij}^2, l_{ij}^3, l_{ij}^4, l_{ij}^5) \quad (1)$$

To obtain a group decision, we combine all the individual decision matrices and create a single aggregated decision matrix that has a single value for each cell. This matrix is called the aggregated single-valued neutrosophic decision matrix and is denoted by  $L$ .

**2. Step 2: Normalize the decision matrix using Eq (2) to obtain the Normalized decision matrix.**

$$s_{ij} = \frac{l_{ij}}{\sum_{i=1}^m l_{ij}}, i = 1, 2, \dots, m \quad (2)$$

**3. Step 3: Eq (3) is used to Compute entropy.**

$$e_j = -k \sum_{i=1}^m s_{ij} \ln s_{ij}, j = 1, 2, \dots, n \quad (3)$$

where  $k = \frac{1}{\ln m}, m = 8$

**4. Step 4: Calculate the weights of each criterion using Eq (4).**

$$w_j = \frac{1-e_j}{\sum_{i=1}^n (1-e_j)}, j = 1, 2, 3, \dots, n \quad (4)$$

### 3.2 Neutrosophic TOPSIS

Using a normalized score for every factor and a calculation of the geometric distance between every option and the ideal alternative (which has the best score for every criterion), the TOPSIS provides an integrated evaluation technique for ranking preferences. The findings of the Entropy approach are used to determine how much emphasis should be placed on each criterion in the TOPSIS procedure. Using the Entropy and TOPSIS techniques, we can assign relative importance to each criterion and determine where each option falls on the list.

Step 1: Use Eq (5) to determine the weighted aggregated decision matrix.

$$L^h = (l_{ij}^{hj})_{m \times n} \quad (5)$$

Step 2: Determine the relative positive ideal solution ( $R^+$ ) and the relative negative ideal solution ( $R^-$ ) USING Eq (6) and Eq(7).

$$R^+ = [l_1^{h+}, l_2^{h+}, l_3^{h+}, \dots, l_n^{h+}] \quad (6)$$

$$R^- = [l_1^{h-}, l_2^{h-}, l_3^{h-}, \dots, l_n^{h-}] \quad (7)$$

Step 3: Determination of the distance measure of each alternative from  $(R^+)$  and  $(R^-)$  using the normalized Euclidean distance measure of each alternative Eq (8) and Eq (9).

$$E_{Eu}^{i+}(l_{ij}^{hj}, l_{ij}^{h+}) = \sqrt{\frac{1}{3n} \sum_{j=1}^n \left( T_{ij}^{hj}(x_i) - T_{ij}^{h+}(x_i) \right)^2 + \left( I_{ij}^{hj}(x_i) - I_{ij}^{h+}(x_i) \right)^2 + \left( F_{ij}^{hj}(x_i) - F_{ij}^{h+}(x_i) \right)^2} \quad (8)$$

$$E_{Eu}^{i-}(l_{ij}^{hj}, l_{ij}^{h-}) = \sqrt{\frac{1}{3n} \sum_{j=1}^n \left( T_{ij}^{hj}(x_i) - T_{ij}^{h-}(x_i) \right)^2 + \left( I_{ij}^{hj}(x_i) - I_{ij}^{h-}(x_i) \right)^2 + \left( F_{ij}^{hj}(x_i) - F_{ij}^{h-}(x_i) \right)^2} \quad (9)$$

Step 4: Determination of the relative closeness coefficient to the neutrosophic ideal solution of each alternative using Eq (10)

$$CC_i = \frac{E^{i-}}{E^{i+} + E^{i-}} \quad (10)$$

Step 5: The order of alternatives can be determined by ranking them according to their closeness index, and the optimal alternative can be selected based on this ranking.  $CC_i \in [0,1]$ .

### 3.3 Neutrosophic MABAC

The MABAC method is a multi-criteria decision-making (MCDM) method that is used to solve problems where there are multiple criteria that need to be considered. It is used here to compare its result with TOPSIS method to be sure that the two methods give the same alternative. MABAC is based on the multi-attributive border approximation area comparison (MABAC) method which is used to compare alternatives based on their performance on multiple criteria. The MABAC method can express complex decisions systematically and is known for its ease of use and reliable results[38]. The basic assumption in this method is to define the distance of the alternatives from the border approximation area. In fact, each alternative is evaluated and ranked by specifying the difference between the distances. This method is mostly used in the same area of this paper[39].

Using the weights resulting from the Entropy method and MABAC method to rank the alternatives based on their performance on multiple criteria by specifying the difference between the distances as the following steps[39]:

Step 1: Determination of the weighted matrix  $B = (b_{ij})_{m \times n}$  using Eq (11) and the Normalized decision matrix  $s_{ij}$ .

$$b_{ij} = \bar{h}_j \bar{s}_{ij} \quad (11)$$

Step 2: Computing the border approximation area (BAA) matrix  $A = (a_j)_{1 \times n}$ . Using Eq (12) The BAA for each Alternative is obtained.

$$a_j = \prod_{i=1}^m (b_{ij})^{\frac{1}{m}} \quad (12)$$

Step 3: Obtaining the distance matrix  $C = (c_{ij})_{m \times n}$  using the weighted parameter from the Hamming and Hausdorff single-valued distance [12]with different values of  $v$  (.1, .3, .5, .7, .9) and Eq (13).

$$c_{ij} = \begin{cases} d_{wHH}(b_{ij}, a_j) & \text{if } b_{ij} > g_i \\ 0 & \text{if } b_{ij} = g_i \\ -d_{wHH}(b_{ij}, a_j) & \text{if } b_{ij} < g_i \end{cases} \quad (13)$$

Step 4: Ranking the alternative using Eq (14) and the most desired alternative is the one with the maximum value of  $z_i$ .

$$z_i = \sum_{j=1}^n c_{ij}, \quad i = 1, 2, \dots, m; j = 1, 2, 3, \dots, n \quad (14)$$

#### 4. Case study

In this section, we present a case study illustrating the application of the previously defined criteria and methodologies to evaluate and select the optimal data center location within Egypt. The case study offers a practical demonstration of how the multi-criteria decision-making process informed the final decision and sheds light on the insights gained from the analysis.

To ensure the accuracy and reliability of the decision-making process, a comprehensive dataset was collected from five Experts. Then the Entropy method was employed to determine the relative importance of each criterion as follows:

##### 1. Step 1: Construction of the aggregated neutrosophic decision matrix based on the assessments of decision makers.

The single-valued neutrosophic weighted averaging (SVNWA) aggregation operator, proposed by YE can be used to obtain the aggregated matrix for SVNSs as in Eq1. The weighted vector of decision makers is  $\kappa = (.2, .2, .2, .2)$ . To obtain a group decision, we combine all the individual decision matrices and create a single aggregated decision matrix that has a single value for each cell. This matrix is called the aggregated single valued neutrosophic decision matrix as in Table 2 and denoted by  $L$ .

Table 2: Aggregated neutrosophic decision matrix

|   | C1         | C2        | C3       | C4       | C5       | C6       | C7       | C8       | C9       | C10      |
|---|------------|-----------|----------|----------|----------|----------|----------|----------|----------|----------|
| A | 0.67,0.2   | 0.67,0.28 | 0.78,0.2 | 0.6,0.35 | 0.89,0.1 | 0.62,0.3 | 0.38,0.6 | 0.72,0.2 | 0.49,0.4 | 0.58,0.4 |
| 1 | 9,0.33     | ,0.33     | 2,0.22   | ,0.4     | 1,0.11   | 3,0.38   | 2,0.62   | 3,0.28   | 7,0.51   | ,0.42    |
| A | 0.72,0.2   | 0.47,0.49 | 0.74,0.2 | 0.43,0.5 | 0.6,0.35 | 0.44,0.5 | 0.41,0.5 | 0.38,0.5 | 0.23,0.7 | 0.72,0.2 |
| 2 | 3,0.28     | ,0.53     | ,0.26    | 2,0.57   | ,0.4     | 1,0.56   | 6,0.59   | 8,0.62   | 5,0.77   | 3,0.28   |
| A | 0.38,0.6   | 0.65,0.3, | 0.38,0.6 | 0.49,0.4 | 0.42,0.5 | 0.58,0.3 | 0.78,0.2 | 0.6,0.35 | 0.35,0.6 | 0.6,0.4, |
| 3 | 2,0.62     | 0.35      | 2,0.62   | 9,0.51   | 8,0.58   | 9,0.42   | 2,0.22   | ,0.4     | 5,0.65   | 0.4      |
| A | 0.63,0.3   | 0.61,0.35 | 0.69,0.2 | 0.51,0.4 | 0.61,0.3 | 0.45,0.5 | 0.17,0.8 | 0.39,0.5 | 0.58,0.3 | 0.52,0.4 |
| 4 | 3,0.37     | ,0.39     | 6,0.31   | 4,0.49   | 5,0.39   | 2,0.55   | 4,0.83   | 9,0.61   | 9,0.42   | 3,0.48   |
| A | 0.6,0.35   | 0.68,0.29 | 0.18,0.8 | 0.5,0.45 | 0.2,0.8, | 0.4,0.55 | 0.78,0.2 | 0.72,0.2 | 0.12,0.9 | 0.31,0.6 |
| 5 | ,0.4       | ,0.32     | 4,0.82   | ,0.5     | 0.8      | ,0.6     | 2,0.22   | 3,0.28   | ,0.88    | 6,0.69   |
| A | 0.73,0.2   | 0.6,0.35, | 0.42,0.5 | 0.51,0.4 | 0.5,0.47 | 0.58,0.3 | 0.36,0.6 | 0.25,0.7 | 0.48,0.5 | 0.83,0.1 |
| 6 | 6,0.27     | 0.4       | 8,0.58   | 4,0.49   | ,0.5     | 9,0.42   | 1,0.64   | 8,0.75   | 4,0.52   | 6,0.17   |
| A | 0.33,0.6   | 0.45,0.52 | 0.52,0.4 | 0.5,0.5, | 0.42,0.5 | 0.58,0.3 | 0.89,0.1 | 0.43,0.5 | 0.6,0.35 | 0.28,0.7 |
| 7 | 3,0.67     | ,0.55     | 8,0.48   | 0.5      | 8,0.58   | 9,0.42   | 1,0.11   | 9,0.57   | ,0.4     | ,0.72    |
| A | 0.73,0.26, | 0.57,0.   | 0.48,0.4 | 0.31,0.6 | 0.59,0.3 | 0.44,0.5 | 0.5,0.47 | 0.68,0.2 | 0.72,0.2 | 0.38,0.6 |
| 8 | 0.27       | 41,0.4    | 8,0.52   | 6,0.69   | 9,0.41   | 1,0.56   | ,0.5     | 9,0.32   | 3,0.28   | 2,0.62   |
|   |            | 3         |          |          |          |          |          |          |          |          |

##### 2. Step 2: Normalize the decision matrix using Eq (2) to obtain the Normalized decision matrix in Table 3.

Table 3: Normalized decision matrix

|   | C1       | C2        | C3       | C4       | C5       | C6       | C7       | C8       | C9       | C10      |
|---|----------|-----------|----------|----------|----------|----------|----------|----------|----------|----------|
| A | 0.14,0.2 | 0.14,0.28 | 0.19,0.2 | 0.16,0.3 | 0.21,0.1 | 0.15,0.3 | 0.09,0.6 | 0.17,0.2 | 0.14,0.4 | 0.14,0.4 |
| 1 | 9,0.33   | ,0.33     | 2,0.22   | 5,0.4    | 1,0.11   | 3,0.38   | 2,0.62   | 3,0.28   | 7,0.51   | ,0.42    |
| A | 0.15,0.2 | 0.1,0.49, | 0.18,0.2 | 0.11,0.5 | 0.14,0.3 | 0.11,0.5 | 0.1,0.56 | 0.09,0.5 | 0.07,0.7 | 0.17,0.2 |
| 2 | 3,0.28   | 0.53      | ,0.25    | 2,0.56   | 5,0.4    | 1,0.56   | ,0.59    | 8,0.62   | 4,0.76   | 3,0.28   |
| A | 0.08,0.6 | 0.14,0.3, | 0.09,0.6 | 0.13,0.4 | 0.1,0.58 | 0.14,0.3 | 0.18,0.2 | 0.14,0.3 | 0.1,0.65 | 0.14,0.4 |
| 3 | 2,0.62   | 0.35      | 2,0.62   | 9,0.51   | ,0.58    | 9,0.41   | 2,0.22   | 5,0.4    | ,0.65    | ,0.4     |

|   |            |           |          |          |          |          |          |          |          |          |
|---|------------|-----------|----------|----------|----------|----------|----------|----------|----------|----------|
| A | 0.13,0.3   | 0.13,0.35 | 0.16,0.2 | 0.13,0.4 | 0.14,0.3 | 0.11,0.5 | 0.04,0.8 | 0.09,0.5 | 0.16,0.3 | 0.12,0.4 |
| 4 | 3,0.37     | ,0.39     | 6,0.31   | 4,0.49   | 5,0.39   | 2,0.55   | 4,0.83   | 9,0.61   | 9,0.41   | 3,0.48   |
| A | 0.13,0.3   | 0.14,0.29 | 0.04,0.8 | 0.13,0.4 | 0.05,0.8 | 0.1,0.55 | 0.18,0.2 | 0.17,0.2 | 0.03,0.9 | 0.07,0.6 |
| 5 | 5,0.4      | ,0.32     | 4,0.81   | 5,0.5    | ,0.8     | ,0.6     | 2,0.22   | 3,0.28   | ,0.88    | 6,0.69   |
| A | 0.15,0.2   | 0.13,0.35 | 0.1,0.58 | 0.13,0.4 | 0.12,0.4 | 0.14,0.3 | 0.08,0.6 | 0.06,0.7 | 0.13,0.5 | 0.2,0.16 |
| 6 | 6,0.27     | ,0.4      | ,0.58    | 4,0.49   | 7,0.5    | 9,0.42   | 1,0.64   | 8,0.75   | 4,0.52   | ,0.17    |
| A | 0.07,0.6   | 0.1,0.52, | 0.12,0.4 | 0.13,0.5 | 0.1,0.58 | 0.14,0.3 | 0.21,0.1 | 0.1,0.59 | 0.17,0.3 | 0.07,0.7 |
| 7 | 3,0.67     | 0.55      | 8,0.48   | ,0.5     | ,0.58    | 9,0.41   | 1,0.11   | ,0.57    | 5,0.4    | ,0.72    |
| A | 0.15,0.25, | 0.12,0.   | 0.11,0.4 | 0.08,0.6 | 0.14,0.3 | 0.11,0.5 | 0.12,0.4 | 0.16,0.2 | 0.2,0.22 | 0.09,0.6 |
| 8 | 0.27       | 41,0.4    | 8,0.52   | 6,0.69   | 9,0.41   | 1,0.56   | 7,0.5    | 9,0.32   | ,0.27    | 2,0.62   |
|   |            | 3         |          |          |          |          |          |          |          |          |

3. Step 3: Eq (3) is used to Compute entropy.

4. Step 4: Estimate the weights of each criterion ( $h$ ) using Eq (4)

Table 4: The weight ( $h$ ) of each criterion is as follows:

| Criteria | Weight ( $h_j$ ) |
|----------|------------------|
| C1       | 0.10572          |
| C2       | 0.11169          |
| C3       | 0.09602          |
| C4       | 0.10606          |
| C5       | 0.09662          |
| C6       | 0.10861          |
| C7       | 0.08853          |
| C8       | 0.09856          |
| C9       | 0.09021          |
| C10      | 0.09798          |

Then TOPSIS is used to compare the candidate cities against selected criteria as follows:

1. Step 1: Use Eq (5) and Table 4 to determine the weighted aggregated decision matrix.

2. Step 2: Determine the relative positive ideal solution ( $R^+$ ) and the relative negative ideal solution ( $R^-$ ) USING Eq (6) and Eq(7).

3. Step 3: Determination of the distance measure of each alternative from ( $R^+$ ) and ( $R^-$ ) using the normalized Euclidean distance measure of each alternative Eq (8) and Eq (9) as in Table 5.

Table 5: The distance degree of each option from RPIS and the RNIS.

| Alternatives | E+       | E-       |
|--------------|----------|----------|
| A1           | 0.201112 | 0.298746 |
| A2           | 0.257266 | 0.221075 |
| A3           | 0.260189 | 0.196425 |
| A4           | 0.262307 | 0.200739 |
| A5           | 0.32441  | 0.198047 |
| A6           | 0.269346 | 0.208932 |
| A7           | 0.273086 | 0.221276 |
| A8           | 0.238331 | 0.224676 |

4. **Step 4: Determination of the relative closeness coefficient to the neutrosophic ideal solution of each alternative using Eq. (10).**

5. **The order of options can be computed by ranking them based on their closeness index, and the optimal alternative can be selected based on this ranking.  $CC_i \in [0, 1]$  and the final ranking is shown in Table 6.**

Table 6: Ordering of the options using TOSIS method.

|    | CC          | rank |
|----|-------------|------|
| A1 | 0.597660979 | 1    |
| A2 | 0.462169976 | 3    |
| A3 | 0.430177017 | 7    |
| A4 | 0.433518765 | 6    |
| A5 | 0.379068874 | 8    |
| A6 | 0.436842275 | 5    |
| A7 | 0.447598915 | 4    |
| A8 | 0.485254172 | 2    |

Then MABAC was chosen to compare the candidate cities against multiple criteria and to verify the results obtained from the TOPSIS method.

1. **Step 1: Determination of the weighted matrix  $B = (b_{ij})_{m \times n}$  using Eq (11) and the Normalized decision matrix  $S_{ij}$ .**

2. **Step 2: Computing the BAA matrix  $A = (a_j)_{1 \times n}$ . Using Eq (12) The BAA for each Alternative is obtained in Table 7.**

Table 7: the BAA matrix for each Alternative.

| Alternatives | BBA ( $a_j$ )    |
|--------------|------------------|
| A1           | <0.8,0.11,0.1>   |
| A2           | <0.79,0.11,0.1>  |
| A3           | <0.81,0.08,0.08> |
| A4           | <0.8,0.08,0.07>  |
| A5           | <0.81,0.08,0.08> |
| A6           | <0.8,0.08,0.08>  |
| A7           | <0.82,0.08,0.08> |
| A8           | <0.81,0.08,0.08> |

3. **Obtaining the distance matrix  $C = (c_{ij})_{m \times n}$  using the weighted parameter from the Hamming and Hausdorff single-valued distance with different values of  $v$  (. 1, . 3, . 5, . 7, . 9) and Eq (13).**

4. **Step 4: Ranking the alternative using Eq (14) and the most wanted option is the one with the maximum value of  $z_i$  as in Table 8.**

Table 8: The ordering of alternatives using the MABAC method with different values of  $v$  (.1, .3, .5, .7, .9)

| $v$ |     |     |     |     |     |
|-----|-----|-----|-----|-----|-----|
|     | 0.1 | 0.3 | 0.5 | 0.7 | 0.9 |

|              |           |   |   |   |   |   |
|--------------|-----------|---|---|---|---|---|
| Alternatives | <b>A1</b> | 1 | 1 | 1 | 1 | 1 |
|              | <b>A2</b> | 4 | 4 | 4 | 4 | 4 |
|              | <b>A3</b> | 5 | 5 | 5 | 5 | 5 |
|              | <b>A4</b> | 6 | 6 | 6 | 6 | 6 |
|              | <b>A5</b> | 8 | 8 | 8 | 8 | 8 |
|              | <b>A6</b> | 2 | 3 | 3 | 3 | 3 |
|              | <b>A7</b> | 7 | 7 | 7 | 7 | 7 |
|              | <b>A8</b> | 3 | 2 | 2 | 2 | 2 |

## 5. Outcomes and Discussion

In this section, we show the consequences got from the request of the Entropy-based criteria weighting, MABAC, and TOPSIS techniques for selecting the optimal city for data center location among the ten cities. The Entropy technique was employed to define the criteria weights, reflecting their relative importance in the decision-making procedure.

The MABAC and TOPSIS methods were subsequently applied to order the candidate cities based on their performance against the selected criteria. The rankings obtained from both methods are abridged in Table 9.

Table 9: The final order of the substitutes with the selected procedure

| Alternatives | MABAC Rank with different values of $v$ |          |          |          |          | TOPSIS Rank |
|--------------|---|----------|----------|----------|----------|-------------|
|              | $v = .1$                                | $v = .3$ | $v = .5$ | $v = .7$ | $v = .9$ |             |
| <b>A1</b>    | 1                                       | 1        | 1        | 1        | 1        | 1           |
| <b>A2</b>    | 4                                       | 4        | 4        | 4        | 4        | 3           |
| <b>A3</b>    | 5                                       | 5        | 5        | 5        | 5        | 7           |
| <b>A4</b>    | 6                                       | 6        | 6        | 6        | 6        | 6           |
| <b>A5</b>    | 8                                       | 8        | 8        | 8        | 8        | 8           |
| <b>A6</b>    | 2                                       | 3        | 3        | 3        | 3        | 5           |
| <b>A7</b>    | 7                                       | 7        | 7        | 7        | 7        | 4           |
| <b>A8</b>    | 3                                       | 2        | 2        | 2        | 2        | 2           |

The judgment of the rankings obtained from the MABAC and TOPSIS approaches reveals a high degree of consistency in the selection of the top-performing cities. This convergence lends credibility to the final city rankings and suggests a robust decision-making process. However, subtle differences in rankings highlight the importance of considering multiple methods to capture nuanced variations in city performance.

Based on the combined analysis of MABAC and TOPSIS, Alternative 1 which is the new capital city emerges as the most suitable location for establishing data centers. This selection aligns with the criteria weights assigned through the Entropy method, where proximity to the resident area, Climate, Transport & logistics operations, Operation costs, Energy availability & cost, Disaster risks, Installing & operating costs, Development rate, governmental policies and regulations, and Governmental policies and regulations play pivotal roles in the decision-making procedure.

## 6. Conclusion

The present study effectively aided in decision-making for choosing the best site for data centers in Egypt. Data centers are a vital component of the global economy, whether you are an individual, a business, a city, or a country. By selecting the best location for the data center based on the selected criteria, we can drive growth, generate employment, and boost the digital economy. By using the entropy method to prioritize the weightage of the selected standards, and the TOPSIS and MABAC methods to rank 10 different cities, and from the judgment of consequences of the two

approaches, the selection of the new capital has been achieved in this study. It is believed that the selected methodology, the methodology when comparing the selected criteria determines a valid result.

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