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Multi-Criteria Decision Making with Fuzzy TOPSIS - A Case Study in Bangladesh for Selection of Facility Location

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ABSTRACT

Multi-Criteria Decision Making with Fuzzy TOPSIS - A Case Study in Bangladesh for Selection of Facility Location

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The choice of an ideal facility location becomes essential as businesses work to streamline their processes and increase efficiency. In this study, the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is applied to choose the best facility location for Rokomari.com, a well-known Bangladeshi online book seller. The goal is to compare Fuzzy TOPSIS' effectiveness and efficiency to expert judgment when choosing a facility location. The research begins by examining the existing fulfillment center of Rokomari.com located in Motijheel, south Dhaka, and the company's desire to establish a new branch in north Dhaka for faster service expansion. Eleven potential alternatives are evaluated using the Fuzzy TOPSIS method, which incorporates fuzzy set theory to represent criteria values and preferences as fuzzy numbers. This approach enables the consideration of uncertainty and vagueness in decision-making, offering a more comprehensive evaluation of the facility location alternatives. The study incorporates the expert opinion of four managerial experts from Rokomari.com in addition to the Fuzzy TOPSIS analysis. To gain a thorough understanding of the decision-making process, their observations and viewpoints are contrasted with the Fuzzy TOPSIS findings. The study aims to compare the analyses produced by Fuzzy TOPSIS and expert judgment in order to assess the efficacy and efficiency of each method for choosing a facility location. The results of this study offer insightful information about the use of Fuzzy TOPSIS in the context of choosing a facility location. Additionally, it adds to the body of knowledge by contrasting the results of Fuzzy TOPSIS with professional judgment, highlighting the advantages and drawbacks of each method. The outcomes can help decision-makers at Rokomari.com and other comparable organizations choose a facility location in a knowledgeable and efficient manner.

Keywords: TOPSIS, MCDM, Fuzzy theory, Facility location

FOREWORD

This Master's thesis represents the culmination of my diligent efforts and intellectual pursuit, and I present it with great pleasure and a sense of accomplishment. My journey into this research has been a rewarding one that has allowed me to learn more about my field of study and to gain a deeper understanding of its nuances. This thesis is the result of months, if not years, of thorough investigation, data collection, analysis, and so on.

It is evidence of the countless hours invested in gathering, compiling, and enhancing ideas in order to produce a coherent body of work. I have been fortunate to have my supervisor and faculty members' advice, support, and encouragement throughout this process, and I sincerely appreciate it.

This thesis aims to add to the existing body of knowledge in the field by addressing certain research questions. It is my hope that the findings presented here will contribute to scholarly discussion as well as offer suggestions and insights for working professionals in the concerned field.

To ensure a thorough and rigorous analysis, I have used a variety of theoretical frameworks, methodologies, and empirical data in the course of this research. The research methodology used in this study adheres to the strictest guidelines for academic honesty, paying close attention to every last detail and upholding ethical research practices.

I would like to extend my heartfelt gratitude to all those who have supported me throughout this journey. I want to sincerely thank my supervisors for their advice, knowledge, and helpful criticism, all of which helped to shape this thesis. Their dedication to academic rigor and excellence has greatly motivated me to pursue the highest levels of academic success. I also want to express my gratitude to the participant organization for kindly providing their time and resources to support this study. It would not have been possible to conduct this study without their participation and cooperation.

I hope that this thesis will serve as a stepping stone for further exploration and inquiry in this field. May it inspire future research, and contribute to the ongoing pursuit of knowledge. With humility and gratitude, I present this thesis with humility and gratitude, aware that it is a culmination of not only my own academic development but also the efforts of everyone who has helped me along the way.

Oulu, 26.06.2023

Mostahasib Rashid
Author

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BSC	Balanced Scorecard
DEMATEL	DEcision-MAking Trial and Evaluation Laboratory
DMU	Decision-Making Unit
EAM	Extent Analysis Technique
ELECTRE	ELimination Et Choix Traduisant la REalité
ERP	Enterprise Resource Planning
FMEA	Failure Modes and Effects Analysis
MCDM	Multiple Criteria Decision-Making
RQ	Research Question
SWOT	Strength Weakness Opportunity Threat
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
A_i	i^{th} alternative
C_i	i^{th} criteria
M_i	de-fuzzified fuzzy numbers
N_i	normalized fuzzy numbers
P_i	performance score for A_i
$R_{i,j}$	Euclidean normalized values
$r_{i,j}$	fuzzy comparison value between C_i and C_j
S^-	Euclidean distance from the ideal worst
S^+	Euclidean distance from the ideal best
$V_{i,j}$	weighted fuzzy values
V_j^-	ideal worst for C_j
V_j^+	ideal best for C_j
W_i	fuzzy triangular value for C_i
$W_i^{\sim}$	fuzzy triangular value for C_i multiplied by increasing order of W_i
$X_{i,j}$	value of C_j for A_i

1 INTRODUCTION

As businesses expand their operations and establish new facilities, there is a rising need for them to optimize the location of these facilities in order to save costs and maximize on efficiency. This need for an optimum choice was at the core of developing mathematical models and methodologies for examining the costs and benefits of various facility sites. The choice of a facility location is critical for every organization since it can have a substantial impact on the overall performance and profitability of the company. The decision process behind selecting a facility location involves the identification, analysis, evaluation and selection among various alternatives (Yang and Lee 1997). The purpose of the facility location selection process is to reduce expenses while increasing overall efficiency and effectiveness.

The process of selecting a facility location involves several key steps, including identification, analysis, evaluation, and selection among various alternatives. Multiple criteria decision-making (MCDM) techniques are often employed to aid in selecting the best option when multiple criteria or objectives need to be considered. These techniques provide decision-makers with a systematic approach to evaluate competing alternatives and make informed decisions. Some popular MCDM methods include the Analytic Hierarchy Process (AHP) (Wind and Saaty 1980), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang et al. 1981), Analytic Network Process (ANP) (Saaty 1996), and ELimination et Choix Traduisant la REalité (ELECTRE) (Figueira et al. 2016).

Among the MCDM methods, TOPSIS (Hwang et al. 1981) stands out as an attractive choice for facility location decision-making ((Chu 2002, Yong 2006)) due to its ability to consider multiple criteria, provide a relative ranking of alternatives, and handle imprecise and uncertain information. The TOPSIS approach compares each alternative's performance to an ideal solution and a negative ideal solution to determine their relative similarity. To further enhance the decision-making process, fuzzy TOPSIS extends the traditional TOPSIS method by utilizing fuzzy set theory to represent criteria values and preferences as fuzzy numbers (Zadeh 1965). This allows decision-makers to handle the vagueness and imprecision often encountered in real-world scenarios.

The primary objective of this thesis is to investigate the application of the fuzzy TOPSIS method in selecting the best facility location among 11 alternatives for Rokomari.com. Rokomari.com is a prominent online bookstore based in Bangladesh, and with an existing fulfillment center in Motijheel, south Dhaka, they aim to open a branch in north Dhaka to expand their services more efficiently. Additionally, the study aims to compare the results obtained through fuzzy TOPSIS with expert judgment from four managerial experts within the company. By examining the facility location selection process in this specific case, the research seeks to highlight the comparative effectiveness and efficiency of fuzzy TOPSIS and expert judgment.

To achieve this goal, the following research questions are addressed:

RQ1. How can Fuzzy TOPSIS be used to evaluate the alternatives for a facility location?

RQ2. How does the use of Fuzzy TOPSIS compare to expert judgment in terms of effectiveness and efficiency for facility location selection?

The thesis is structured into five chapters. The first chapter serves as an introduction, providing an overview of the thesis topic and elaborating on various areas of interest related to the subject. It also outlines the main goals that the research aims to achieve. The second chapter, the literature review, delves into previous studies and literature related to MCDM, fuzzy theory, TOPSIS, and other relevant topics, providing a comprehensive understanding of the subject matter.

The third chapter focuses on the materials and methods employed in the research, particularly the application of the fuzzy TOPSIS method. It describes the research method while introducing the case company under investigation. This section also addresses the first research question RQ1, namely, how fuzzy TOPSIS can be used to evaluate facility location alternatives.

In the fourth chapter, the results are obtained from the research and presented sequentially. Finally, the fifth and last chapter of the thesis is the discussion section. This section includes a comparative analysis to address the second research question RQ2, comparing the effectiveness and efficiency of fuzzy TOPSIS with expert judgment in the context of facility location selection. In this section, the entire work is summarized, and the research challenges encountered throughout the study are also identified. Additionally, this chapter provides insights into potential areas for future research and the continuation of this line of work.

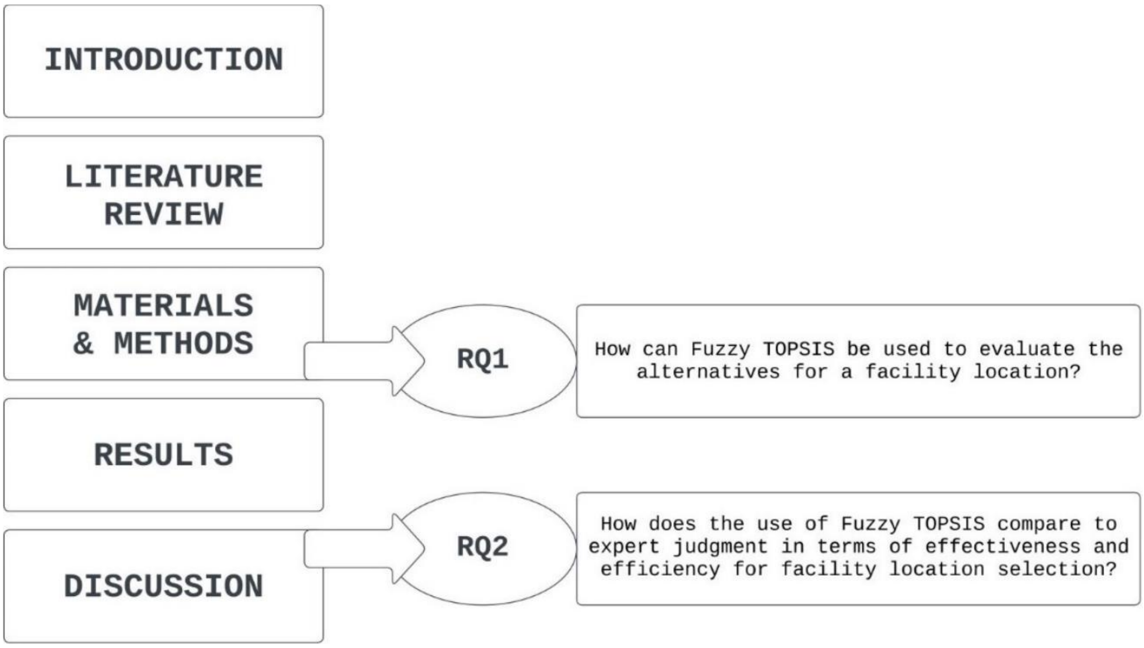

Figure 1. The structure of the thesis Sections and the addressed research questions.

Figure 1 represents the sections and the research questions addressed in those sections. By structuring the thesis in this manner, the research aims to comprehensively explore the application of fuzzy TOPSIS in facility location selection and shed light on the comparative effectiveness and efficiency of fuzzy TOPSIS and expert judgment.

2 LITERATURE REVIEW

Use of mathematical models in decision making for facility location selection has been in practice for a long while. These applications span over a multitude of industries and financial sectors. Early studies on facility location selection were mostly focused on transportation costs as well as access to raw supplies and customers. However, later on, researchers began to integrate other variables into their models, such as availability of skilled labor, environmental and zoning rules, political and economic conditions etc. Over the past few decades, the studies on facility location selection have continued to improve and expand, with new approaches and techniques being developed to accommodate changing business needs and the rising complexity of the global economy (Yang and Lee 1997, Kahraman et al. 2003, Chu 2002). Nowadays, facility location selection methods are used not only by businesses, but also by government and non-government organizations to assess the feasibility and impact of constructing new infrastructure and facilities such as hospitals, schools, and transportation hubs. In recent years, advanced analytical tools such as GIS, remote sensing (Mussa and Suryabhagavan 2021, Mahmood et al. 2020), and optimization techniques have grown more widespread.

2.1 Multiple Criteria Decision Making

There is a large body of literature and research on the problem of facility location selection and particularly the use of Multi-Criteria Decision Making methods (Current and Schilling 1990, Liang and Wang 1991, Tzeng and Huang 2011). MCDM (Multiple Criteria Decision Making) is an interdisciplinary topic of research that deals with multiple-criteria decision-making problems. The goal of MCDM is to assist decision-makers in evaluating and selecting alternatives based on numerous, competing objectives. Early research on MCDM concentrated on establishing methods for weighting and aggregating criteria, as well as ranking and selecting alternatives (Zionts and Wallenius 1976, Dyer et al. 1992). To evaluate alternatives based on multiple criteria, MCDM methods such as Analytic Hierarchy Process (AHP) (Wind and Saaty 1980), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang et al. 1981), Analytic Network Process (ANP) (Saaty 1996), ELimination et Choix Traduisant la REalité (ELECTRE) (Figueira et al. 2016) etc. have been in practice for a long while.

While some studies compare and contrast between these existing decision making methods (Opricovic and Tzeng 2004, Farahani et al. 2010, Aruldoss et al. 2013, Zavadskas et al. 2014, Kumar et al. 2017), others have proposed novel ones to address the issues prevalent in earlier works. Some MCDM methods are presented in Figure 2.

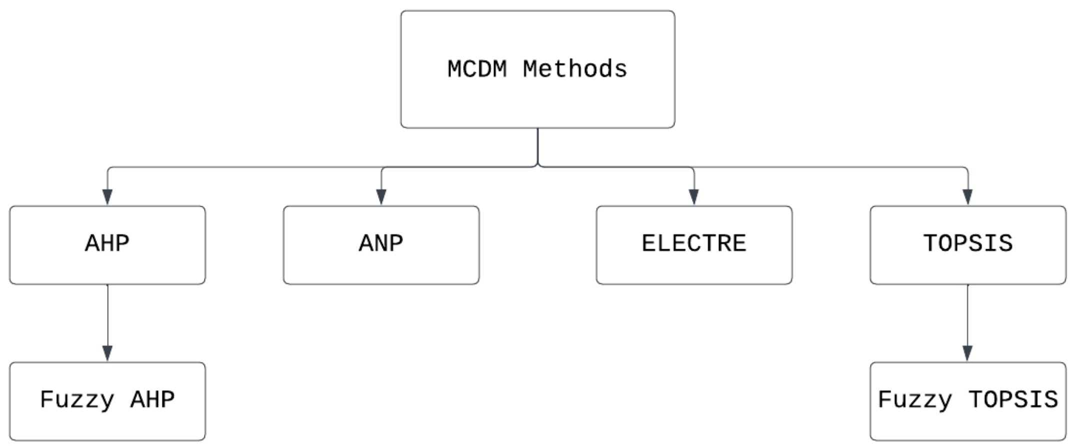

Figure 2. Different MCDM methods.

2.2 Fuzzy Theory

Fuzzy theory, also referred to as fuzzy logic or fuzzy sets, addresses uncertainty and imprecision in decision-making and problem-solving. It was developed by Lotfi Zadeh in the 1960s, the mathematical foundations of fuzzy set theory was presented and its applications in modeling imprecise and uncertain information were discussed (Zadeh 1965), and since then, it has been used in a variety of fields, including economics, engineering, computer science, and artificial intelligence. Fuzzy sets are extensions of classical sets that allow elements to have degrees of membership ranging between 0 and 1. This fundamental concept forms the basis of fuzzy theory. Afterwards, fuzzy set theory was expanded and the concept of fuzzy logic was introduced by (Zadeh 1973) and how fuzzy logic can be used to handle the imprecision and uncertainty inherent in complex systems and decision-making processes was discussed. Fuzzy logic expands on traditional binary logic by allowing truth values to be represented as degrees of truth. It makes it possible to reason and make decisions even in the face of ambiguity and imprecision. Figure 3 shows the comparison between boolean logic and fuzzy logic.

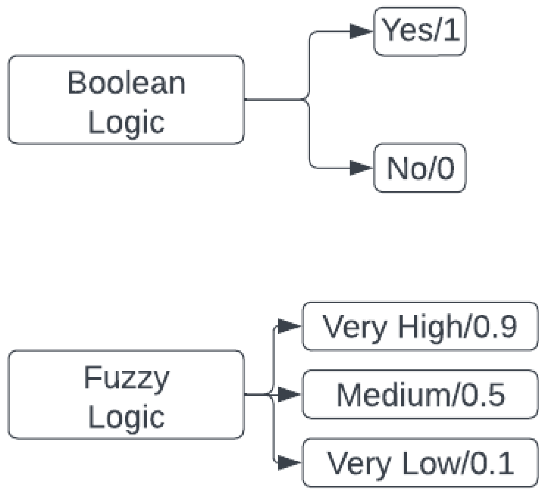

Figure 3. Comparison between Boolean logic and Fuzzy logic.

(Zadeh 1979) further presented a comprehensive theory of approximate reasoning and discussed how fuzzy sets and fuzzy logic can be applied to reasoning tasks, such as inference, decision-making, and expert systems.

2.3 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP), first introduced by (Wind and Saaty 1980), is by far the most frequently used MCDM method which provides a technique for deriving scales covering the full range of the comparison, from 1/9 for 'least valued than', to 1 for 'equal', and to 9 for 'definitely more important than', to measure both qualitative and quantitative performance (Vaidya and Kumar 2006). Wei et al. (2005) proposed a comprehensive ERP system selection framework utilizing the Analytic Hierarchy Process (AHP) method. For facility location selection, (Yang and Lee 1997) presented an Analytic Hierarchy Process decision model to match location site attributes with decision makers' choices. Current et al. (1990) also investigated facility site considerations using Fuzzy Analytic Hierarchy Process. Later on, the Analytic Hierarchy Process method was extended to incorporate fuzzy logic and fuzzy set theory (Zadeh 1965) and has been widely used ever since. Fuzzy Analytic Hierarchy Process is able to deal with the uncertainty that comes with any decision making process.

Zhu et al. (1999) discussed the extent analysis technique (EAM) and its combination with Fuzzy Analytic Hierarchy Process in order to resolve complex decision-making problems with various criteria. Lee et al. (2008) proposed a hybrid approach combining Fuzzy Analytic Hierarchy Process and Balanced Scorecard (BSC) to evaluate the performance of the IT department in the manufacturing industry in Taiwan. For supplier selection in a gearmotor company, (Ayhan 2013) utilized a Fuzzy Analytic Hierarchy Process approach. Fuzzy AHP was also incorporated in evaluating machine tool alternatives (Ayağ and Özdemir 2006), selecting the suitable bridge construction method (Pan 2008), assessment of water management plans (Srdjevic and Medeiros 2008), supplier selection (Cengiz et al. 2003, Kahraman et al. 2003, Chan et al. 2008), personnel selection (Güngör et al. 2009), hospital site selection (Vahidnia 2009), analysis of assessment factors (Heo et al. 2010), analysis of healthcare service quality (Büyüközkan et al. 2011), evaluating teaching performance (Chen et al. 2015) etc. Fuzzy Analytic Hierarchy Process was used by Kahraman et al. (2004) to evaluate and compare catering service providers in Turkey. (Leung and Cao 2000) examined the importance of consistency in Analytic Hierarchy Process decision-making and the difficulties that arise when dealing with imprecise or fuzzy preferences. Wang et al. (2008) looked into the mathematical foundation and methods involved in the Fuzzy AHP extent analysis approach, such as determining fuzzy synthetic extent values and calculating fuzzy weights for criteria and alternatives. Figure 4 illustrates the basic steps in AHP.

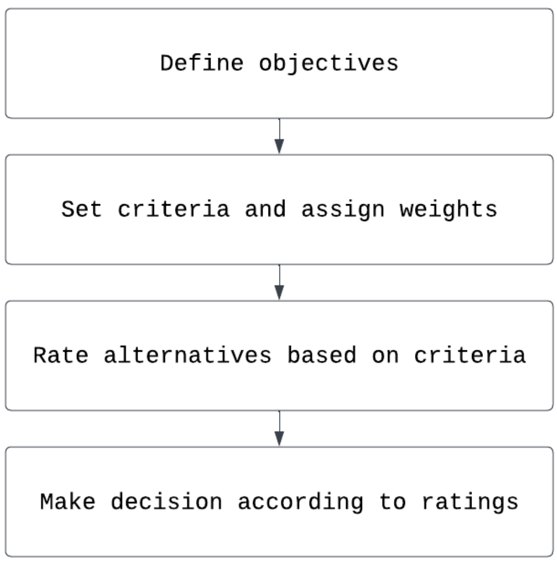

Figure 4. Basic steps of AHP.

2.4 Analytic Network Process

The Analytic Network Process (ANP), first introduces by (Saaty 1996), is an extension of the Analytic Hierarchy Process (AHP) and offers a systematic method for handling decision problems involving interdependencies between criteria and alternatives. ANP is suitable for a variety of applications because it enables decision-makers to model complex decision structures by including feedback loops and dependence relationships. (Saaty 1996) explained that the ANP process first identifies the decision hierarchy, constructs a network that represents the interrelationships among the criteria and alternatives and then pair-wise comparisons are conducted to derive relative weights and priorities, which are used to calculate the overall ranking of alternatives. Chung et al. (2005) presented the application of the Analytic Network Process (ANP) methodology for product mix planning in a semiconductor fabricator. Applying ANP to model the metrics of lean, agile and leagile supply chain was proposed by Agarwal et al. (2006). (Jharkharia and Shankar 2007) applied the Analytic Network Process (ANP) methodology to the selection of logistics service providers as well as demonstrated the effectiveness of ANP in evaluating and prioritizing potential logistics service providers based on multiple criteria. (Yüksel and Dagdeviren 2007) presented a case study demonstrating the application of ANP in conducting a SWOT analysis for a textile firm. Ervural et al. (2018) also applied the Analytic Network Process (ANP) along with Fuzzy TOPSIS in conducting a SWOT analysis for energy planning in Turkey. Many other studies have applied ANP in a variety of decision-making problems such as shopping mall location selection (Cheng et al. 2005), selection of photovoltaic solar power plant investment projects (Aragonés-Beltrán et al. 2010), selecting key performance indicators (Carlucci 2010) etc.

Yang et al. (2008) introduced a novel decision-making model that combines the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method and the Analytic Network Process (ANP). Similarly, (Yang and Tzeng 2011) combined DEMATEL for a novel cluster-weighted with ANP. A large number of other works have been done on such applications of ANP in combination with the Decision-Making Trial and Evaluation Laboratory (DEMATEL) for example, in choosing knowledge management strategies

(Wu 2008), selecting management systems for sustainable development (Tsai and Chou 2009), evaluating green suppliers (Büyüközkan and Çifçi 2012) etc. The ANP technique is presented in a simplified way in Figure 5.

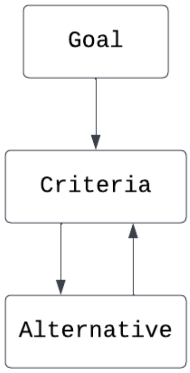

Figure 5. Steps in ANP simplified.

2.5 TOPSIS

Hwang et al. (1981) first introduced the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) as an extension of the concept of distance-based approaches. In TOPSIS, a set of alternatives is compared to a predetermined set of criteria, and each alternative is given a score based on how closely it resembles the ideal and not ideal solutions. To determine how close or similar each alternative is to these two reference points, their distance from each is calculated. Fuzzy TOPSIS is a method that combines fuzzy logic (Zadeh 1965) and the TOPSIS method for multiple criteria decision making. The TOPSIS method is founded on the concept of comparing each alternative's performance to an ideal solution and a negative ideal solution, and then finding the relative similarity of each alternative to the ideal solution. Fuzzy TOPSIS is an extension of the TOPSIS method in which the criteria values and preferences of the decision maker are represented as fuzzy numbers, and the similarity between the alternatives and the ideal answer is computed using fuzzy set theory (Chen 2000).

(Chu 2002, Yong 2006) incorporated Fuzzy TOPSIS for plant location selection. Similarly, (Chu and Lin 2003) utilized the Fuzzy TOPSIS method for selecting robots based on multiple criteria. (Wang and Elhag 2006) proposed a new approach for Fuzzy TOPSIS method using alpha level sets and applies it to bridge risk assessment. (Chen and Tsao 2008) conducted experimental analysis on a case study to illustrate the usefulness of the proposed interval-valued Fuzzy TOPSIS strategy. (Wang and Lee 2009) developed a fuzzy TOPSIS approach based on subjective weights and objective weights whereas Ashtiani et al. (2009) extended the Fuzzy TOPSIS method based on interval-valued fuzzy sets. (Singh and Benyoucef 2011) proposed a methodology for selecting the best supplier in an e-sourcing scenario using the Fuzzy TOPSIS approach. A new approach to generalize the Fuzzy TOPSIS method was introduced by Dymova et al. (2013) with a new weighting scheme that takes into account the interactions between the criteria. (Kutlu Gündoğdu and Kahraman 2019) compared the results achieved using the spherical Fuzzy TOPSIS approach to those obtained using other decision-making methods to demonstrate the usefulness of the proposed method.

2.6 Fuzzy AHP and Fuzzy TOPSIS

Many studies combine Fuzzy Analytical Hierarchical Process (AHP) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) in different sectors. (Sun 2010) proposed a model that integrates Fuzzy AHP and Fuzzy TOPSIS methods to evaluate the performance of decision-making units (DMUs). A new approach to Failure Modes and Effects Analysis (FMEA) using Fuzzy TOPSIS-based Fuzzy AHP was proposed by (Kutlu and Ekmekçioğlu 2012). Taylan et al. (2014) proposed a framework that integrates both the Fuzzy AHP and Fuzzy TOPSIS methods to evaluate and rank the construction projects based on multiple criteria and assess their risk. (Abdullah and Zulkifli 2015) proposed a new approach for Fuzzy Failure Modes and Effects Analysis (F-FMEA) using the Fuzzy TOPSIS and Fuzzy AHP methods in human resource management. While many studies work with both these techniques, many also compare and contrast between Fuzzy AHP and Fuzzy TOPSIS (Ertuğrul and Karakaşoğlu 2008, Junior et al. 2014).

3 MATERIALS & METHODS

Rokomari.com, one of the newest businesses in the portfolio of regional conglomerate OnnoRokom Group, a renowned retail E-commerce company in Bangladesh, is actively seeking a suitable location for a distribution center in North Dhaka to enhance its customer service capabilities. On January 19, 2012, Rokomari.com was launched with a small team, roughly 10,000 books, and a modest number of distributors. In recent years, the organization has become one of the major players in online trade, particularly for books. Today, it works with many distributors and boasts a staggering 200,000+ books on its foundation. The new distribution center aims to provide faster and more efficient deliveries to customers in that region. By establishing a distribution center in North Dhaka, Rokomari.com aims to reduce delivery times and costs, ensuring a seamless shopping experience for its customers. This strategic decision will enable the company to expand its reach, cater to a larger customer base, and further solidify its position as a leading E-commerce platform in Bangladesh. Ultimately, the chosen location will serve as a critical hub for Rokomari.com's distribution operations, enabling the company to enhance its service and meet the growing demands of customers in North Dhaka.

The study will follow the steps of the Fuzzy TOPSIS methodology to analyze the data collected from the interviews and make informed decisions. The specific steps of the methodology will be elaborated in the subsequent subsections of the research. These steps involve mathematical calculations and computations to determine the ranking and preference of the alternatives. To provide a visual representation of the Fuzzy TOPSIS technique, a flow chart is presented in Figure 6. This flow chart summarizes the steps involved in the methodology, providing a clear overview of the process that will be followed. The following subsections also elaborates on the decision alternatives in consideration for Rokomari.com and the set of criteria that the alternatives will be evaluated based on.

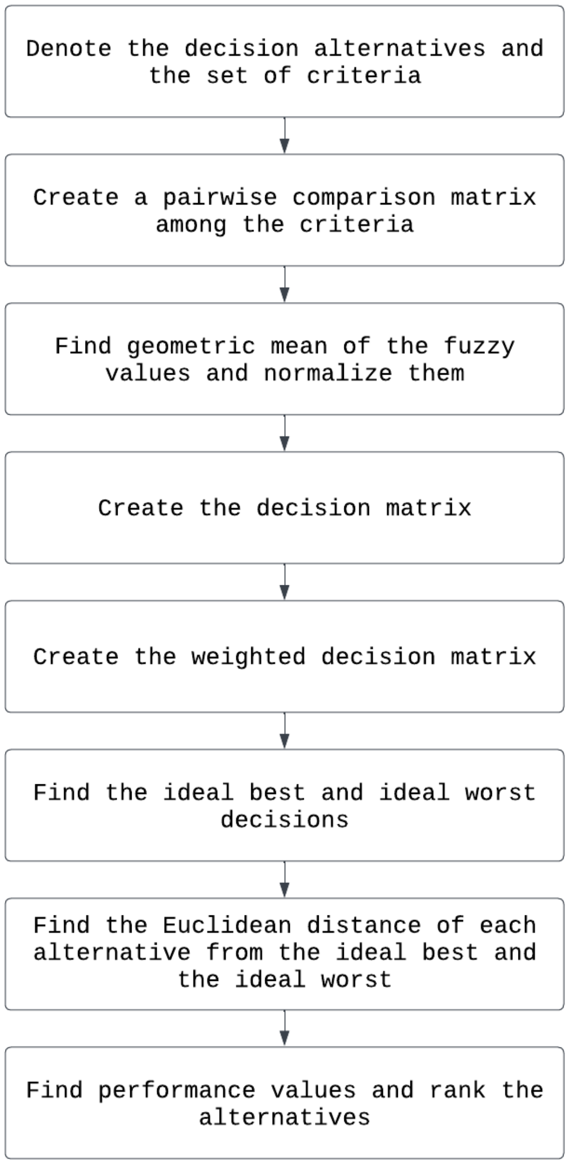

Figure 6. Steps of the Fuzzy TOPSIS technique.

3.1 Decision Alternatives

11 alternative (A_1-A_{11}) locations has been chosen by Rokomari.com, the case company, as potential facility locations. The alternatives which will be evaluated in this study are illustrated in Table 1.

Table 1. 11 alternatives for the selection of facility location.

Alternative No	Area
A1	Agargaon
A2	Mirpur
A3	Pallabi
A4	Uttara
A5	Dakkhin Khan
A6	Bashundhara
A7	Badda
A8	Gulshan
A9	Mohakhali
A10	Banani
A11	Cantonment

These alternatives will be evaluated based on 7 criteria (C_1- C_7), which are presented in Table 2. By considering these seven criteria, a comprehensive evaluation can be conducted to determine the strengths and weaknesses of each alternative. This will help in making an informed decision based on the specific needs and priorities of the evaluation process. The alternatives and the evaluation criteria are set by Rokomari.com based on their requirements.

Table 2. 7 criteria to evaluate the alternatives for the selection of facility location.

Serial No	Criteria
C_1	Rent
C_2	Cost of labor
C_3	Distance from suppliers
C_4	Closeness of markets
C_5	Availability of labor
C_6	Business climate
C_7	Distance from Motijheel center

Table 3 provides the order volumes associated with the different alternative locations under consideration. This information allows Rokomari.com to evaluate the potential business opportunities and assess the feasibility of operating in each location which in turn affects the comparative rankings for the alternatives provided by the managerial board. By analyzing the order volumes, Rokomari.com estimates the potential customer base and market demand in each area.

Table 3. The average percentages of order volume for each alternative location.

Alternative No	Area	Order volume percentages
A_1	Agargaon	3.21%
A_2	Mirpur	19.25%
A_3	Pallabi	5.25%
A_4	Uttara	21.56%
A_5	Dakkhin Khan	2.21%
A_6	Bashundhara	10.06%
A_7	Badda	5.65%
A_8	Gulshan	12.94%
A_9	Mohakhali	7.34%
A_{10}	Banani	7.10%
A_{11}	Cantonment	5.44%

The process of managerial decision-making involves evaluating various criteria on a comparative basis. Traditionally, this evaluation has been done using the Saaty scale (Wind and Saaty 1980), which assigns ratings on a scale of 1 to 9. However, in order to incorporate the concept of fuzzy numbers into the decision-making process, the ratings from the Saaty scale are converted to the Fuzzy Triangular scale. To accomplish this conversion, a set of relationships outlined in Table 4 are utilized. These relationships provide guidelines for replacing the original ratings, which range from 1 to 9, with fuzzy numbers (Zadeh 1965).

Table 4. Relationship between the Saaty scale and the Fuzzy Triangular scale.

Saaty scale	Definition	Fuzzy Triangular Scale
1	Equally important	(1, 1, 1)
3	Weakly important	(2, 3, 4)
5	Fairly important	(4, 5, 6)
7	Strongly important	(6, 7, 8)
9	Absolutely important	(9, 9, 9)
2	The intermittent values between two adjacent scales	(1, 2, 3)
4		(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

3.2 Fuzzy TOPSIS Evaluation Steps

In order to evaluate the alternatives by the Fuzzy TOPSIS method for Rokomari.com, the following steps are performed:

Step 1

The managers provide the comparative ratings for the set of 7 criteria. The ratings on 1 to 9 are then converted to the equivalent fuzzy triangles using Table 4. The resulting pairwise comparison matrix is used to perform calculations for getting the fuzzy weights.

Step 2

For each of the 7 criteria C_i the comparative fuzzy triangular values are used to get the 3 final geometric mean of the fuzzy comparison values $r_{i,j}$ for each criteria. So, each of the 3 fuzzy numbers for the 7 criteria in comparison to each other are multiplied and the *n*th root is taken where n is 7 to finally get 3 fuzzy numbers for each criterion.

$$W_i = (r_{i,1} \times r_{i,2} \times r_{i,3} \times r_{i,4} \times r_{i,5} \times r_{i,6} \times r_{i,7})^{\frac{1}{7}}$$

Here W_i represents the fuzzy triangular values that can be denoted as lW_i, mW_i, and nW_i each calculated from the corresponding $r_{i,j}$ values.

Step 3

The sum of the total for all the criteria are calculated as three fuzzy values and the multiplicative inverses of the values are calculated. The increasing order I is then found.

Step 4

Each of the 3 fuzzy numbers for each criterion is then multiplied by the increasing order of values.

$$W_i^{\sim} = W_i \times I$$

Here $W_i^{\sim}$ represents 3 fuzzy values that can be denoted as l$W_i^{\sim}$, m$W_i^{\sim}$, and n$W_i^{\sim}$ each calculated from the corresponding W_i values.

Step 5

The fuzzy numbers are de-fuzzified by finding the center of the area.

$$M_i = \frac{lW_i^{\sim} + mW_i^{\sim} + nW_i^{\sim}}{3}$$

Step 6

The de-fuzzified values are normalized to a scale of 0 to 1.

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i}$$

Step 7

TOPSIS is now performed on the table for the alternatives with respect to each criterion. First vector or Euclidean normalization is done for each cell on the table.

$$R_{i,j} = \frac{X_{i,j}}{\sum_{j=1}^{n} X_{i,j}^2}$$

Here $X_{i,j}$ denotes the value assigned to a criterion C_j for an alternative A_i.

Step 8

The fuzzy weights are then multiplied to the corresponding criteria values for each alternative.

$$V_{i,j} = N_j \times R_{i,j}$$

Step 9

According to the values of criteria for each alternative, the ideal best and the ideal worst values for each criteria is found. The ideal best is the lowest value for criteria such as Rent, Cost of Labor, Distance from Suppliers and Distance from Motijheel Center whereas the ideal best is the highest value for Closeness of Markets, Availability of Labor and Business Climate. Intuitively, the ideal worsts would be the opposites for each criteria.

Step 10

For ranking the alternatives, the euclidean distance for each alternative is calculated from the ideal best and the ideal worst values.

Euclidean distance from the ideal best values:

$$S^{+} = \sqrt{\sum_{j=1}^{m} (V_{i,j} - V_j^{+})^2}$$

Euclidean distance from the ideal worst values:

$$S^{-} = \sqrt{\sum_{j=1}^{m} (V_{i,j} - V_j^{-})^2}$$

Here V_j^+ denotes the ideal best for the criteria C_j whereas V_j^- denotes the ideal worst for the criteria C_j.

Step 11

The performance score for each alternative is calculated based on the distance values S^+ and S^-.

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

Step 12

Based on the values P_i for each alternative A_i, the alternatives are ranked. The highest performance value results in the highest ranked alternative and vice versa.

4 RESULTS

This section illustrates the data and the results obtained after performing each step of the Fuzzy TOPSIS elaborated in the previous section. The collected data and the detailed intermediate results of each step are presented in different tables throughout the following subsections.

4.1 Data Collection

To get the necessary data to proceed with the Fuzzy TOPSIS methodology, four managerial experts were interviewed. These interviews aimed to gather the necessary data for the study. During the interviews, the experts were asked to provide pairwise comparisons among different criteria, criteria values for various alternatives, and their expert ranking based on their intuition and knowledge. The interviews took place in March 2023. The collected data from these interviews are crucial for the subsequent steps of the study and are presented in the Results section. These data will be used to evaluate decision alternatives for Rokomari.com.

The appointed managers were required to rate each of the criteria by comparison among all of them. The comparative values collected are on a scale of 1 to 9 where a higher value indicates that the row criterion is ranked as more important than the column criterion. The initial comparison matrix is shown in table 5.

Table 5. Pairwise comparison matrix between the criteria with ratings from 1 to 9.

Criteria	Rent	Cost of Labor	Distance from Suppliers	Closeness of Markets	Availability of Labor	Business Climate	Distance from Motijheel Center
Rent	1	3	5	3	5	9	5
Labor Cost	$\frac{1}{3}$	1	3	1	5	5	3
Distance From Suppliers	$\frac{1}{5}$	$\frac{1}{3}$	1	$\frac{1}{3}$	$\frac{1}{3}$	5	3
Closeness of Markets	$\frac{1}{3}$	1	3	1	3	5	5
Availability of labor	$\frac{1}{5}$	$\frac{1}{5}$	3	$\frac{1}{3}$	1	5	1
Business Climate	$\frac{1}{9}$	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{1}{5}$	$\frac{1}{5}$	1	$\frac{1}{3}$
Distance From Motijheel Center	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{5}$	1	3	1

From Rokomari.com the values of each criteria for each alternative are also collected. The corresponding values are represented in Table 6. The rent and cost of labor are given per month. The distances are in the KM unit.

Table 6. Criteria values with respect to each alternative.

Alternative No	Area	Rent	Cost of Labor	Distance from Suppliers	Closeness of Markets	Availability of Labor	Business Climate	Distance From Motijheel Center
A_1	Agargaon	30000	10000	10.71	3.21	3	4	9.748
A_2	Mirpur	25000	9000	15.984	19.258	5	5	15.022
A_3	Pallabi	27000	9500	18.314	5.25	4	4	17.352
A_4	Uttara	40000	12000	22.574	21.56	3	3	21.612
A_5	Dakkhin Khan	20000	8000	18.428	2.21	5	4	17.466
A_6	Bashundhara	35000	10000	18.415	10.06	3	2	17.453
A_7	Badda	32000	9000	7.85	5.65	3	3	6.48
A_8	Gulshan	50000	13000	10.009	12.94	2	2	9.047
A_9	Mohakhali	35000	9000	8.56	7.34	3	3	7.598
A_{10}	Banani	50000	13000	9.972	7.1	2	1	9.01
A_{11}	Cantonment	25000	8000	14.903	5.44	4	3	13.941

Additionally, each of four managers provides a comparative ranking for each location based on the set of criteria. Table 7 shows the rankings using the expert judgment. The rankings are averaged to get the combined ranking for each alternative.

Table 7. Rankings for the alternatives by human judgment.

Alternative No	Area	Manager 1	Manager 2	Manager 3	Manager 4	Sum	Combined Ranking
A_1	Agargaon	5	5	4	5	19	5
A_2	Mirpur	1	2	2	2	7	1
A_3	Pallabi	2	1	3	3	9	2
A_4	Uttara	4	3	5	1	13	4
A_5	Dakkhin Khan	6	6	8	7	27	6
A_6	Bashundhara	9	10	9	9	37	9
A_7	Badda	8	7	7	8	30	8
A_8	Gulshan	11	11	10	10	42	11
A_9	Mohakhali	7	8	6	6	27	7
A_{10}	Banani	10	9	11	11	41	10
A_{11}	Cantonment	3	4	1	4	12	3

4.2 Data Analysis

The comparative ratings for the set of 7 criteria provided are on 1 to 9. These ratings are converted to the equivalent fuzzy triangles using Table 4. For example, if criteria 1 (C_1) is slightly more important than criteria 2 (C_2) then the value $r_{1,2}$ will be (2, 3, 4) for C_1 to C_2 and in the comparison for C_2 to C_1, the value $r_{2,1}$ will be $(\frac{1}{4}, \frac{1}{3}, \frac{1}{2})$. The comparative value with a criterion itself $r_{i,i}$ will always be (1, 1, 1). The resulting pairwise comparison matrix is shown in Table 8.

Table 8. Pairwise comparison matrix between the criteria represented by fuzzy numbers.

Criteria	Rent	Cost of Labor	Distance from Suppliers	Closeness of Markets	Availability of labor	Business Climate	Distance from Motijheel Center
Rent	(1,1,1)	(2,3,4)	(4,5,6)	(2,3,4)	(4,5,6)	(9,9,9)	(4,5,6)
Labor Cost	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(1,1,1)	(2,3,4)	(1,1,1)	(4,5,6)	(4,5,6)	(2,3,4)
Distance From Suppliers	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(1,1,1)	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(4,5,6)	(2,3,4)
Closeness of Markets	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(1,1,1)	(2,3,4)	(1,1,1)	(2,3,4)	(4,5,6)	(4,5,6)
Availability of labor	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	(2,3,4)	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	(1,1,1)	(4,5,6)	(1,1,1)
Business Climate	$(\frac{1}{9},\frac{1}{9},\frac{1}{9})$	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	(1,1,1)	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$
Distance From Motijheel Center	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	(1,1,1)	(2,3,4)	(1,1,1)

The three final geometric means of the fuzzy comparison values $r_{i,j}$ for each of the seven criteria C_i are obtained using the comparative fuzzy triangular values (Shown in Table 8) for each of the criteria. Each of the 3 fuzzy numbers for the 7 criteria in comparison to each other are multiplied and the nth root is taken where n is 7 to finally get 3 fuzzy numbers lW_i, mW_i, and nW_i for each criteria. Table 9 containes the 3 lW_i, mW_i, and nW_i values for each of the 7 criteria.

Table 9. Geometric mean of the fuzzy comparison values for each criterion.

Criteria	lW_i	mW_i	nW_i
Rent	3.022	3.734	4.383
Labor Cost	1.486	1.853	2.246
Distance From Suppliers	0.575	0.73	0.96
Closeness of Markets	1.486	1.853	2.246
Availability of labor	0.662	0.794	0.96
Business Climate	0.215	0.249	0.3
Distance From Motijheel Center	0.445	0.54	0.673
Total	7.891	9.753	11.768

The lW_i, mW_i, and nW_i values for all the criteria are summed to get three final values. These values are then reversed by performing inverse power of 1. The increasing order of the three values are then found. These steps are presented through intermediate values in Table 10.

Table 10. Increasing order of the reverse values of total mean over all criteria.

Total	7.891	9.753	11.768
Reverse (power of -1)	0.127	0.102	0.085
Increasing Order, I	0.085	0.102	0.127

The increasing order of fuzzy values presented in table 10 are then used to multiply with the 3 fuzzy numbers for each criterion shown in Table 9. The weighted fuzzy values l$W_i^{\sim}$, m$W_i^{\sim}$, and n$W_i^{\sim}$ for each of the 7 criteria are shown in Table 11.

Table 11. Mean fuzzy comparison values of criteria multiplied with the increasing order of total mean values.

Criteria	l$W_i^{\sim}$	m$W_i^{\sim}$	n$W_i^{\sim}$
Rent	0.257	0.381	0.557
Labor Cost	0.126	0.189	0.285
Distance From Suppliers	0.045	0.074	0.122
Closeness of Markets	0.126	0.189	0.285
Availability of labor	0.056	0.081	0.122
Business Climate	0.018	0.025	0.038
Distance From Motijheel Center	0.038	0.055	0.085

The weighted fuzzy values for the 7 criteria are then required to be de-fuzzified. De-fuzzifying means converting the fuzzy triangle into one value for each criterion. To achieve that, the fuzzy triangular values for each criterion presented in Table 11 are summed and the center of area M_i is found for each criterion. These de-fuzzified values are then normalized to a scale of 0 to 1. The de-fuzzified and normalized values are illustrated in Table 12 below.

Table 12. De-fuzzified criteria values normalized to 0 to 1.

Criteria	M_i	N_i
Rent	0.398	0.38
Labor Cost	0.2	0.19
Distance From Suppliers	0.08	0.076
Closeness of Markets	0.2	0.19
Availability of labor	0.086	0.082
Business Climate	0.027	0.026
Distance From Motijheel Center	0.059	0.056
Total	1.05	1

Table 13 represents the values of each criteria with respect to all the alternatives. These are, as explained before, collected from the case company and are used in the calculations ahead.

Table 13. Criteria values with respect to each alternative.

Alternative No	Area	Rent	Cost of Labor	Distance from Suppliers	Closeness of Markets	Availability of Labor	Business Climate	Distance From Motijheel Center
A_1	Agargaon	30000	10000	10.71	3.21	3	4	9.748
A_2	Mirpur	25000	9000	15.984	19.258	5	5	15.022
A_3	Pallabi	27000	9500	18.314	5.25	4	4	17.352
A_4	Uttara	40000	12000	22.574	21.56	3	3	21.612
A_5	Dakkhin Khan	20000	8000	18.428	2.21	5	4	17.466
A_6	Bashundhara	35000	10000	18.415	10.06	3	2	17.453
A_7	Badda	32000	9000	7.85	5.65	3	3	6.48
A_8	Gulshan	50000	13000	10.009	12.94	2	2	9.047
A_9	Mohakhali	35000	9000	8.56	7.34	3	3	7.598
A_{10}	Banani	50000	13000	9.972	7.1	2	1	9.01
A_{11}	Cantonment	25000	8000	14.903	5.44	4	3	13.941

Next the Euclidean normalization is needed to be done on each cell of Table 13. To do that, first the summation of the squared values of all the cells in that table are found as presented in Table 14 below.

Table 14. Summation of squared values of the alternatives for each criterion.

	Rent	Cost of Labor	Distance from Suppliers	Closeness of Markets	Availability of Labor	Business Climate	Distance From Motijheel Center
$\sum_{j=1}^{n} X_{i,j}^2$	115555.18	33811.98	49.5	36.23	11.62	10.86	46.43

The summations of squared criteria values with respect to each alternative are then used to divide each cell $X_{i,j}$ of Table 13 by. This results into the required Euclidean normalized values $R_{i,j}$ for each criterion with respect to each alternative and are shown in Table 15.

Table 15. Criteria values for each alternative divided by the summation of squared values of the alternatives for each criterion.

Alternative No	Area	Rent	Cost of Labor	Distance from Suppliers	Closeness of Markets	Availability of Labor	Business Climate	Distance From Motijheel Center
A_1	Agargaon	0.26	0.296	0.216	0.089	0.258	0.368	0.21
A_2	Mirpur	0.216	0.266	0.323	0.531	0.43	0.46	0.324
A_3	Pallabi	0.234	0.281	0.37	0.145	0.344	0.368	0.374
A_4	Uttara	0.346	0.355	0.456	0.595	0.258	0.276	0.465
A_5	Dakkhin Khan	0.173	0.237	0.372	0.061	0.43	0.368	0.376
A_6	Bashundhara	0.303	0.296	0.372	0.278	0.258	0.184	0.376
A_7	Badda	0.277	0.266	0.159	0.156	0.258	0.276	0.14
A_8	Gulshan	0.433	0.384	0.202	0.357	0.172	0.184	0.195
A_9	Mohakhali	0.303	0.266	0.173	0.203	0.258	0.276	0.164
A_{10}	Banani	0.433	0.384	0.201	0.196	0.172	0.092	0.194
A_{11}	Cantonment	0.216	0.237	0.301	0.15	0.344	0.276	0.3

The Euclidean normalized values $R_{i,j}$ from table 15 are then multiplied with corresponding normalized fuzzy weights N_i of each criterion from Table 12. The resulting values $V_{i,j}$ for each alternative with respect to each criterion are shown inTable 16.

Table 16. Criteria values for each alternative multiplied with corresponding fuzzy weights.

Fuzzy weights		0.38	0.19	0.076	0.19	0.082	0.026	0.056
Alternative No	Area	Rent	Cost of Labor	Distance from Suppliers	Closeness of Markets	Availability of Labor	Business Climate	Distance From Motijheel Center
A_1	Agargaon	0.099	0.056	0.016	0.017	0.021	0.009	0.012
A_2	Mirpur	0.082	0.05	0.024	0.101	0.035	0.012	0.018
A_3	Pallabi	0.089	0.053	0.028	0.027	0.028	0.009	0.021
A_4	Uttara	0.131	0.067	0.035	0.113	0.021	0.007	0.026
A_5	Dakkhin Khan	0.066	0.045	0.028	0.011	0.035	0.009	0.021
A_6	Bashundhara	0.115	0.056	0.028	0.053	0.021	0.005	0.021
A_7	Badda	0.105	0.05	0.012	0.03	0.021	0.007	0.008
A_8	Gulshan	0.164	0.072	0.015	0.068	0.014	0.005	0.011
A_9	Mohakhali	0.115	0.05	0.013	0.038	0.021	0.007	0.009
A_{10}	Banani	0.164	0.073	0.015	0.037	0.014	0.002	0.011
A_{11}	Cantonment	0.082	0.045	0.023	0.028	0.028	0.007	0.017

Now, the ideal best and ideal worst values for each criterion are found. The ideal best is the lowest value for criteria such as Rent, Cost of Labor, Distance from Suppliers and Distance from Motijheel Center whereas the ideal best is the highest value for Closeness of Markets, Availability of Labor and Business Climate. Intuitively, the ideal worsts would be the opposites for each criteria. So, the ideal best and the ideal worst values for each criteria are picked from Table 16 and are presented in Table 17.

Table 17. Ideal best and ideal worst values for each criterion.

Criteria	Rent	Cost of Labor	Distance from Suppliers	Closeness of Markets	Availability of Labor	Business Climate	Distance From Motijheel Center
Desired Ideal	low	low	low	high	high	high	low
Ideal Best, V_j^+	0.066	0.045	0.012	0.113	0.035	0.012	0.008
Ideal Worst, V_j^-	0.164	0.073	0.035	0.011	0.014	0.002	0.026

Table 18 shows the Euclidean distance of each alternative from the ideal best and the ideal worst values. The necessary calculations are done on the values from table 16 and Table 17 by using the following formulas:

Euclidean distance from the ideal best values:

$$S^+ = \sqrt{\sum_{j=1}^{m} (V_{i,j} - V_j^+)^2}$$

Euclidean distance from the ideal worst values:

$$S^- = \sqrt{\sum_{j=1}^{m} (V_{i,j} - V_j^-)^2}$$

Table 18. Euclidean distance of each alternative from the ideal best and the ideal worst.

Alternative No	Area	S_i^+	S_i^-
A_1	Agargaon	0.103	0.072
A_2	Mirpur	0.026	0.127
A_3	Pallabi	0.092	0.081
A_4	Uttara	0.076	0.108
A_5	Dakkhin Khan	0.104	0.105
A_6	Bashundhara	0.082	0.068
A_7	Badda	0.093	0.073
A_8	Gulshan	0.113	0.062
A_9	Mohakhali	0.091	0.067
A_{10}	Banani	0.129	0.036
A_{11}	Cantonment	0.088	0.091

Now that we have the Euclidean distances of each alternative from the ideal best and the ideal worst, the performance score for each alternative is calculated based on the distance values S^+ and S^- from Table 18 by using the formula below:

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

The performance values P_i of each of the alternatives is shown in Table 19.

Table 19. Performance values of each alternative.

Alternative No	Area	$S_i^+ + S_i^-$	P_i
A_1	Agargaon	0.175	0.411
A_2	Mirpur	0.153	0.83
A_3	Pallabi	0.173	0.468
A_4	Uttara	0.184	0.587
A_5	Dakkhin Khan	0.209	0.502
A_6	Bashundhara	0.15	0.453
A_7	Badda	0.166	0.44
A_8	Gulshan	0.175	0.354
A_9	Mohakhali	0.158	0.424
A_{10}	Banani	0.165	0.218
A_{11}	Cantonment	0.179	0.508

These performance scores presented in Table 19 are now used to rank the alternatives based on the increasing order of said values. These comparative rankings are shown in Table 20 along with their corresponding performance values.

Table 20. The alternatives ranked based on the increasing order of performance values.

Alternative No	Area	P_i	Rank
A_2	Mirpur	0.83	1
A_4	Uttara	0.587	2
A_{11}	Cantonment	0.508	3
A_5	Dakkhin Khan	0.502	4
A_3	Pallabi	0.468	5
A_6	Bashundhara	0.453	6
A_7	Badda	0.44	7
A_9	Mohakhali	0.424	8
A_1	Agargaon	0.411	9
A_8	Gulshan	0.354	10
A_{10}	Banani	0.218	11

Table 21 represents a side by side comparison of the rankings from both ways of calculations which are the combined ranking from the Managers (Shown in Table 7) and the rankings from the Fuzzy TOPSIS method. The combined expert rankings are provided by the case company to be compared with the rankings from Fuzzy TOPSIS performed in this study.

Table 21. Comparison of the rankings by expert judgment and Fuzzy TOPSIS.

Alternative No	Area	Combined Ranking from the Managers	Ranking from Fuzzy TOPSIS
A1	Agargaon	5	9
A2	Mirpur	1	1
A3	Pallabi	2	5
A4	Uttara	4	2
A5	Dakkhin Khan	6	4
A6	Bashundhara	9	6
A7	Badda	8	7
A8	Gulshan	11	10
A9	Mohakhali	7	8
A10	Banani	10	11
A11	Cantonment	3	3

5 DISCUSSION

The objective of this study was to employ Fuzzy TOPSIS as a Multi-Criteria Decision Making (MCDM) technique to choose a facility location for the case company Rokomari.com in Bangladesh. To evaluate the efficacy and dependability of the methodology, the rankings produced by Fuzzy TOPSIS are contrasted with the rankings offered by case company managers. Table 21 in the previous section shows the rankings derived from the two approaches.

This section provides both qualitative and quantitave comparison between the expert judgment and the Fuzzy TOPSIS technique as well as provides recommendation for the case company while also outlining possible future directions in research. The Fuzzy TOPSIS method is also evaluated in this section.

5.1 Quantitative Comparison

Figure 7 illustrates a graphical comparison between the rankings by the Fuzzy TOPSIS performed in this study and the combined expert rankings from the four managers of the case company, Rokomari.com. Figure 8 shows the same comparison sorted in ascending order of the Fuzzy TOPSIS rankings.

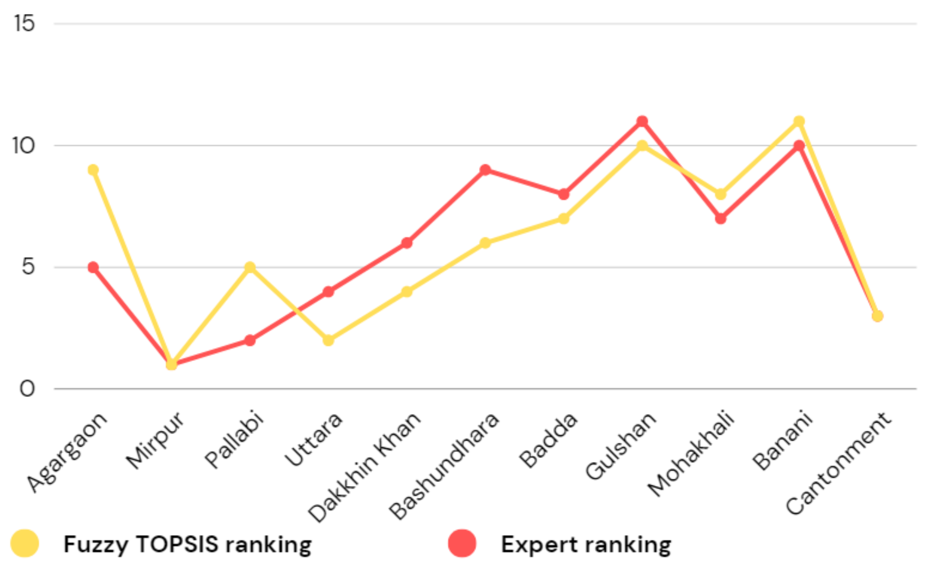

Figure 7. Graphical representation of the comparison between rankings by Fuzzy TOPSIS and Expert Judgment.

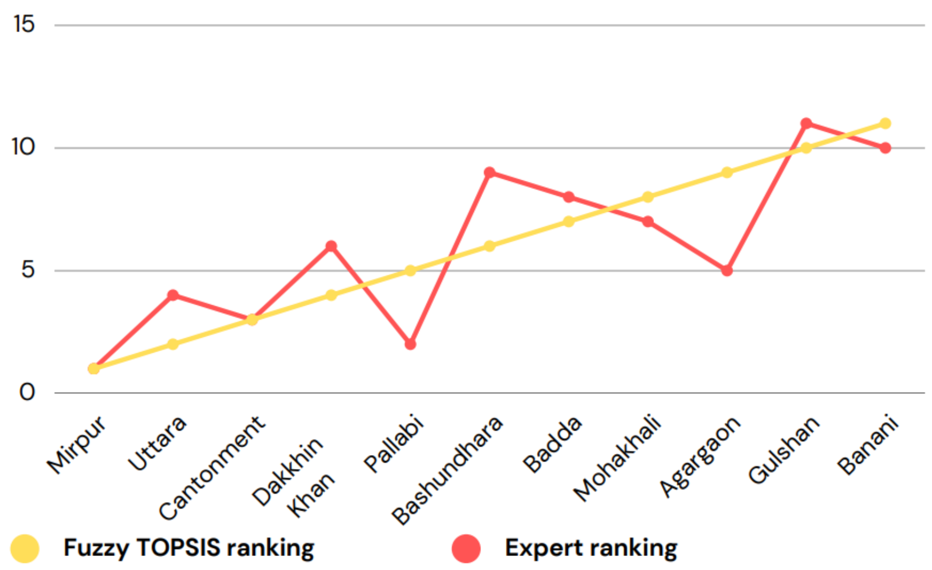

Figure 8. Graphical representation of the comparison between rankings sorted in ascending order of Fuzzy TOPSIS rankings.

These rankings make it clear that the rankings provided by the case company managers and the rankings obtained from Fuzzy TOPSIS differ to some extent. These discrepancies may occur as a result of the expert rankings' subjectivity, which can include the experts' biases and personal preferences as well as their ignorance of certain alternative decisions.

However, in most cases, the rankings from both methods are not too far off from each other including some alternatives having the same ranking by both methods. The optimum choice, which is settled by having the highest ranking among all alternatives, is the location of Mirpur according to both expert judgment and the Fuzzy TOPSIS technique which indicates that the case company can rely on having this alternative as the facility location.

Another factor to be noted here is the averaged ranking from four managers. The combined rankings by the experts are calculated from four different sets of rankings by four different managers and averaging them to the final ranking. This can also lead to the rankings being different from the rankings by Fuzzy TOPSIS.

5.2 Qualitative Comparison

Fuzzy TOPSIS is a quantitative decision-making technique that incorporates fuzzy set theory to handle uncertainties and imprecise data (Zadeh 1965, Hwang et al. 1981). It adopts a methodical and organized approach, taking into account various factors and their relative weights to produce rankings for the alternatives. Fuzzy TOPSIS offers a thorough framework that enables decision-makers to impartially assess and contrast various alternatives in light of the specified criteria (Chen 2000). The methodology can produce consistent and reproducible outcomes while handling complex decision-making issues.

Expert judgment, on the other hand, is based on the expertise and subjective opinions of people who have experience and knowledge in the area. Expert judgment can be useful in identifying tacit knowledge and insights that may be difficult to quantify or identify using formal criteria. It enables decision-makers to take into account intangible factors and incorporate their past experiences and current perspectives. Expert judgment can be adaptable and flexible, taking into account contextual factors that quantitative models might not explicitly capture.

It is clear that there are differences between the two approaches when comparing the rankings obtained from Fuzzy TOPSIS and expert judgment in this study. Numerous factors, such as individual perspective differences, prejudices, and the inherent uncertainties present in both approaches, may contribute to these discrepancies. When compared to expert judgment, fuzzy TOPSIS offers a more methodical and structured approach.

In case of Fuzzy TOPSIS, the method weighs in all the different criteria values and tries to decide on the optimum choice based on all the criteria on a somewhat equal level. On the other hand, expert judgment can be prone to biases and might lead to putting greater emphasis on some criteria compared to other ones. For example, if we look at the rankings given by the managers for the alternative location of Uttara, which ar as follows: 4, 3, 5 and 1, we can see that every manager has ranked the alternative differently and some are really far off from each other. These discrepancies might result in a slightly different rankings by experts in coparison with the rankings from Fuzzy TOPSIS. The difference in rankings by different managers for the same alternatives also raises the question of whether expert judgment can be trusted after all.

Junior et al. (2014) exclaimed that Fuzzy TOPSIS may be better suited for issues with less criteria. However, as apparent from the results, expert judgment becomes even less reliable as the number of criteria grows. Similar to the results indicated through the proposed methodology by Singh and Benyoucef (2011), Fuzzy TOPSIS is a more effective way of supplier selection in e-sourcing scenarios.

5.3 Recommendations

The case organization should carefully assess the implications of each ranking approach in light of the variations in rankings. In general, it is advised that the organization conduct a thorough evaluation of the criteria and weights used in the decision-making process as these elements can have a significant impact on the final rankings. The case organization should also take the knowledge and experience of the decision-makers into account and look for ways to better incorporate their expertise into the decision-making process.

As mentioned in the previous subsections, the managerial decisions can be prone to biases and very different from each other. So, it is recommended that the case company Rokomari.com relies on the rankings attained by the Fuzzy TOPSIS technique rather than the expert judgment. However, we have already seen that both the methods yield the same alternative as the top ranked choice for the facility location, the case company can easily decide on said location as the optimum choice which is Mirpur.

The results of this study also have a number of managerial implications. First of all, when choosing a facility location, decision-makers in the case organization should exercise caution when relying solely on expert opinions. The disparities between the Fuzzy TOPSIS rankings and the expert rankings emphasize the need for a structured and systematic approach to decision-making. Second, to improve the reliability and accuracy of the decision-making process, the case organization can look into using a hybrid strategy that combines expert judgment with quantitative decision-making techniques, such as Fuzzy TOPSIS.

In general, Fuzzy TOPSIS can be used in any organization to aid decision-making on a managerial level, handle resource optimization, assess risks and sustainability, perform strategic planning etc. However, the effectiveness of Fuzzy TOPSIS depends on the quality of the data and the accurate representation of uncertainties and dependencies in the issue at hand. Proper training and understanding of the method are crucial for successful implementation and reaping its managerial benefits.

5.4 Evaluation

The application of fuzzy TOPSIS in the context of facility location selection can be better understood by this study as it offers insights into how uncertainties and erroneous data can be incorporated into the decision-making process by using Fuzzy TOPSIS. The results of this study show that Fuzzy TOPSIS has the potential to be a reliable and adaptable MCDM technique for complex decision-making issues.

Several measures were taken to guarantee the study's validity and reliability. First, a thorough literature review was done in conjunction with the case company's suggestions to determine the pertinent set of criteria for facility location selection. This made it easier to make sure the chosen criteria were appropriate and consistent with the body of existing knowledge in the field. Second, a thorough data collection procedure was used to compile precise and trustworthy data for the study. Using Fuzzy TOPSIS, which is already established as a popular MCDM method, a thorough analysis of the data gathered from the case organization and the expert rankings was performed.

If the expert rankings are to be considered as ground truths in terms of potential facility locations, even though prone to biases, the Fuzzy TOPSIS technique producing rankings that are not that different from the expert judgment is also an indication to the reliability of Fuzzy TOPSIS in facility location selection. Additionally, there are existing literature on the use of Fuzzy TOPSIS for facility location selection that look into the same and are mentioned in the Literature Review section.

5.5 Future Research

The contrast between fuzzy TOPSIS and expert judgment highlights the unique features and benefits of each strategy. Making decisions that are more solid and well-informed can result from a hybrid strategy that combines the advantages of both approaches. Along with the managerial and scientific ramifications, the recommendations for the case organization add to the body of knowledge that exists in the area. However, it is important to acknowledge and address each approach's drawbacks and potential biases.

Future studies can investigate how these approaches can be combined and create more thorough decision-making frameworks for facility location selection. Furthermore, other MCDM techniques such as AHP, ELECTRE, and PROMETHEE etc. can also be incorporated to add other metrics to the comparison. The criteria values can also be played with, assigning different weights to them and varying the values to further assess the reliability of the techniques. In conclusion, even though a large body of work already exists in the field, explorations can still be done to compare and contrast in future.

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