ISSN 2085-4552

Application of Fuzzy AHP-TOPSİS Hybrid Method in Facility Location Selection for Software Systems

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Accepted 07 May 2024
Approved 08 January 2025

***Abstract*— Facility location is an integral part of the strategic planning process of almost every organization. Selecting the right location for software systems facilities involves considering various factors to ensure optimal performance, reliability, and cost-effectiveness. For business success, and competitive advantage there are some critical factors that very highly affect facility location. They are proximity to customers, infrastructure, labor quality, total cost, suppliers, etc. The criteria for selecting a facility location may be vaguely defined or open to interpretation. External factors such as economic conditions, political stability, and environmental risks may introduce vagueness and unpredictability into facility location decisions. In this paper we apply fuzzy AHP-TOPSIS hybrid method for facility location in software systems. Fuzzy AHP (Analytic Hierarchy Process) and fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) are both decision-making methods commonly used in facility location selection. Fuzzy AHP is particularly useful in situations where decision criteria are subjective and uncertain, providing a more robust framework for making well-informed decisions. Fuzzy TOPSIS is useful in complex decision-making where uncertainty and subjectivity play a significant role, offering a flexible and comprehensive approach to evaluating and ranking alternatives. In the first part of the facility location selection process, we use fuzzy AHP method for determining weights of criteria that are important in selection process. Then by using fuzzy TOPSIS we rank alternatives and select appropriate location for facility. Selection of the best location for software systems provided according to three attributes and three alternatives (A, B, C). Relative closeness of each alternative to the ideal solution represents that alternative C is the best alternative.**

Index Terms*— Fuzzy numbers, facility location selection, software systems, ideal solution, fuzzy AHP-TOPSIS.

I. INTRODUCTION

Facility location typically refers to the problem of selecting the location of facilities (for example, warehouses, factories, offices, production centers, stores) based on various criteria, such as minimizing transportation costs or maximizing customer service [1]. Facility location in the context of software systems often refers to the strategic placement of data centers, servers, or other infrastructure to optimize performance, reliability, and cost-effectiveness. Key considerations for facility location in software systems are proximity to users, redundancy and disaster recovery, cost optimization, regulatory compliance, network connectivity, scalability, security, environmental considerations etc. Placing facilities closer to many users can reduce latency and improve response times. This is particularly important for real-time applications like online gaming or video streaming. Distributing facilities across different geographic locations helps ensure redundancy and disaster recovery. In the event of a natural disaster or network outage in one location, services can be quickly restored from another location. Considerations such as the cost of real estate, electricity, cooling, and labor vary by location. Choosing locations with lower operational costs can result in significant savings over time. Compliance with data protection regulations may require storing data in specific geographic regions. It's essential to choose locations that comply with relevant laws and regulations. Facilities should be in areas with robust network connectivity to ensure high-speed and reliable connections to the internet backbone and other networks. Choose locations that can accommodate future growth and scalability needs. This includes factors such as available space for expansion and access to skilled labor. Security considerations, including physical security and access controls, are crucial for protecting data and infrastructure. Facilities should be in areas with low crime rates and have appropriate security measures in place. Choosing locations with access to renewable energy sources or implementing energy-efficient technologies can help reduce environmental impact. Facility location decisions for software systems require careful consideration of technical, regulatory, financial, and environmental factors to ensure optimal performance, reliability, and compliance. Some attributes are so important in selection of location that they control all decision process. These are capacity, successful labor climate, distances, accessibility, service, proximity to suppliers and resources. Capacity considerations are an important consideration in facility location decisions that directly impact operational efficiency and customer satisfaction. Successful labor climate plays a critical role in facility location decisions by influencing workforce availability, costs, stability, productivity, regulatory compliance, and community relations. Businesses that prioritize a favorable labor climate are better positioned to establish sustainable and successful operations in their chosen locations. Labor climate is a criterion of wages, training needs, regards to work, labor performance, and union strength. Proximity to customers or locating near customers is important when customers' needs technical support, products are voluminous and shipping rates are high [2]. Proximity to suppliers and resources is a critical consideration in facility location decisions, impacting transportation costs, supply chain efficiency, quality control, collaboration, risk mitigation, and access to specialized skills. By strategically locating facilities close to suppliers and key resources, businesses can gain competitive advantages, improve operational performance, and enhance overall business resilience. These need permanent coordination and negotiation, which can become heavier as distance increases [3]. In selection process is especially important availability resources and minimal costs. Different facility location factors are determined in place choosing, including investment cost, availability of high-quality labors, shipping, infrastructure. and facility location thus obviously involves multiple criteria.

Uncertainty is a significant factor in facility location decisions due to several reasons. Market dynamics, economic conditions, consumer preferences, and market demand can fluctuate, leading to uncertainty in forecasting future sales volumes and distribution patterns. This uncertainty makes it challenging to determine the optimal location for facilities to meet evolving market demands effectively. It offers a way to model and reason about uncertain or ambiguous situations by capturing the inherent fuzziness in human reasoning and natural language [4]. Changes in regulations, zoning laws, and government policies can impact facility location decisions. Uncertainty regarding future regulatory requirements or restrictions may influence the suitability of certain locations and affect long-term investment decisions. The conditional method of approaching facility location problems like cost volume analysis that is s a managerial accounting technique used to examine the relationship between costs, volume, and profit within a business, factor rating method that is a decision-making tool utilized in place choosing or facility location analysis, and center of gravity method that is a quantitative methodology used in facility location analysis to define the optimal place for a facility, such as a warehouse, distribution center, or manufacturing plant are generally less effective at combating imprecision or vagueness in linguistic judgments [5]. In real life, data for assessing the accessibility of object locations for various subjective factors and factor weights are represented in linguistic terms [6]. For effectively resolve the vagueness that often arises in accessible information and eliminate the essential vagueness of human thinking and preferences, fuzzy set theory has been employed to identify uncertain multi-attribute decision-making problems [7]. Thus, fuzzy AHP -TOPSIS hybrid method offered in this article for facility location selection problem in software system, where the ratings of various alternative locations under different subjective attributes and the weights of all attributes are introduced by fuzzy numbers [8]. The basis for decision-making is that the main decisions are made based on the results of AHP [9]. The decision-makers require to estimate alternatives always comprise vagueness. For modeling such vagueness in the facility location selection, fuzzy sets can be integrated with binary comparisons, for example using the AHP extension [10]. The fuzzy AHP technology permits a more precise specification of the decision-making process [11]. The fuzzy TOPSIS technology is a highly employed technique in decision-making for prioritization alternatives [12].

In this article, the fuzzy AHP-TOPSIS hybrid technique used for defining weights of importance of attributes, ranking alternatives, and determining best location for software system [13-15]. Basic goal in facility location for software systems is to create a strategic infrastructure footprint that optimizes performance, reliability, and cost-effectiveness while ensuring compliance with regulations and minimizing environmental impact. This article is structured as follows. Section 2 represents the main steps of the fuzzy AHP-TOPSIS hybrid technique that is employed in facility location problem. Section 3 offered hybrid methodology with fuzzy numbers for the facility location problem. Section 4 represents discussion and Section 5 presents conclusions of this research.

II. THEORY

Fuzzy AHP-TOPSIS methodology is one of the largely used techniuqes of multi-attribute decision making and this hybrid decision-making method combines the Analytic Hierarchy Process methodology with the Technique for Order of Preference by Similarity to Ideal Solution method, while also incorporating fuzzy set theory. This method is especially useful when dealing with decision problems involving multiple criteria or attributes that are subjective, imprecise, or uncertain in nature. Basic functions of fuzzy AHP-TOPSIS hybrid methodology are hierarchy formation, fuzzy pairwise comparison, aggregation of weights, fuzzy normalization, determining fuzzy similarity to ideal solution. Hierarchy formation is identifying the decision hierarchy, which consists of the main objective, attributes, and alternatives. Break down the main objective into multiple criteria and further decompose each criterion into sub-criteria if necessary. Fuzzy AHP use fuzzy pairwise comparison matrices to assess the comparative significancy or weights of attributes and sub-attributes. Decision-makers assign linguistic terms such as "weak", "strong", "very strong", "extremly" or fuzzy numbers to express the pairwise comparisons between criteria based on their perceived importance or preference. Aggregation of weights function is aggregating the fuzzy pairwise comparison matrices to calculate the overall weights of attributes and sub-attributes. Various aggregation methods, such as fuzzy geometric mean, fuzzy arithmetic mean, or fuzzy weighted average, can be used to compute the aggregated weights. Fuzzy normalization normalize the decision matrix for each criterion to convert linguistic assessments or fuzzy numbers into crisp values. Fuzzy normalization techniques, such as triangular or trapezoidal fuzzy numbers, can be employed to handle vagueness and imprecision in the data. Fuzzy TOPSIS technique determine fuzzy positive ideal solution and fuzzy negative ideal solution is determined [13]. Then, computed the fuzzy closeness coefficient or similarity score for each alternative relative to the fuzzy positive ideal solution and fuzzy negative ideal solution using fuzzy TOPSIS. Alternatives with higher similarity scores to the fuzzy positive ideal solution and lower similarity scores to the fuzzy negative ideal solution are considered more preferable. Ranking and sensitivity analysis is oderig the alternatives on base of their fuzzy closeness coefficients to identify the most preferred alternative(s). Performance sensitivity analysis to assess the robustness of the rankings to changes in the criteria weights or input data and evaluate the stability of the decision. Fuzzy AHP-TOPSIS provides a structured and systematic approach to decision-making in complex and uncertain environments, allowing decision-makers to incorporate subjective judgments, imprecise data, and uncertainty into the decision process. By integrating fuzzy set theory with AHP and TOPSIS, this method enables more comprehensive and nuanced decision analysis, leading to more informed and robust decisions. Some of the superiorities of this hybrid technique are determining weights of criterias by calculating consistency ratio, rationality, comprehensibility, well computational efficiency and the ability to measure the relative performance of each alternative in a simple mathematical form.

The basic steps in multi-attribute decision-making technique fuzzy AHP-TOPSIS are the following:

Step 1. Creating a fuzzy comparison matrix. The scale of linguistic terms is determined. The scale used is the triangular fuzzy numbers scale from one to nine and determined by the membership function that represented in Table I

TABLE I. SCALE OF INTEREST

Scale of interest	Linguistic term	Member function
1	Equally important	(1,1,1)
3	Weakly important	(1,3,5)
5	Strongly more important	(3,5,7)
7	Very strongly important	(5,7,9)
9	Extremely important	(7,9,9)

Then, using the triangular fuzzy numbers to make pair-wise comparison matrix for the basic attribute and sub-attribute. The form of fuzzy pairwise comparison matrix represented in formula (1) [14].

$$\tilde{A} = \begin{bmatrix} 1 & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{1n} & \cdots & 1 \end{bmatrix} \tag{1}$$

Step 2. Determining fuzzy geometric mean. The fuzzy geometric mean calculated by using formula (2) [14]:

$$\tilde{r}_i = \left(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in}\right)^{1/n} \tag{2}$$

where $\tilde{a}_{in}$ is estimation of fuzzy comparison matrix from attributes i to n. The outcome of the fuzzy geometric mean will be later to called local fuzzy number.

Step 3. Determining the fuzzy weight for each attribute. Calculate the global fuzzy number for each evaluated attribute with formula (3).

$$\tilde{w}_i = \tilde{r}_1 \otimes \left(\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \tilde{r}_n\right)^{-1} = \left(lw_i, mw_i, uw_i\right) \tag{3}$$

Step 4. Determining the best non fuzzy performance. The global fuzzy number transformed to crisp weight value using the sentry of area method to find the value of best non fuzzy performance (BNP) from the fuzzy weight in each attribute, determined using formula (4).

Step 5. Normalization decision matrix provided by using formula (4) [14].

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \tag{4}$$

Step 6. Formulated weighted normalized decision matrix by using equation (5) [14].

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix} \tag{5}$$

Step 7. Determine fuzzy positive ideal solution A^* and fuzzy negative ideal solution A^-. The positive ideal solution technique represents that each evaluated factor has a monotonically increasing or decreasing characteristic. For determination of the fuzzy positive ideal solution set used equation (6) [15]:

$$A^* = \left\{\max v_{ij} \mid j \in J\right\}, \left\{\min v_{ij} \mid j \in J'\right\}$$
$$A^* = \left\{v_1^*, v_2^*, \cdots, v_n^*\right\} \tag{6}$$

Fuzzy negative ideal solutions set selects the smallest of the column values in the matrix. For determination of the fuzzy negative ideal solution set used equation (7) [15]:

$$A^{-} = \left\{ \min v_{ij} \mid j \in J \right\}, \left\{ \max v_{ij} \mid j \in J' \right\}$$
$$A^{-} = \left\{ v_1^{-}, v_2^{-}, \cdots, v_n^{-} \right\} \tag{7}$$

Step 8. Calculation positive ideal and negative ideal the seperation measures.

Positive ideal separation measure is calculated by using formula (8).

$$S_i^{*} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{*} \right)^2} \tag{8}$$

Negative ideal separation measure is calculated by using formula (9) [16].

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-} \right)^2} \tag{9}$$

Step 9. Calculation the relative closeness to the positive ideal solution [16].

$$C_i^{*} = \frac{S_i^{-}}{S_i^{-} + S_i^{*}} \tag{10}$$

Step 10. Ranking alternatives.

III. METHOD

Selecting the appropriate facility for software systems involves choosing the infrastructure or platform where the software will be developed, deployed, and maintained. There are different functions for facility selection process in the context of software systems [17].

- Defining requirements. Clearly defining the requirements and objectives of the software system. Consider factors such as scalability, performance, security, reliability, compliance, and integration needs. Determine any specific infrastructure or platform requirements based on the nature of the software and its intended use.
- Evaluating hosting options. Assess different hosting options for the software system, such as on-premises, cloud, or hybrid solutions. Evaluate the advantages and disadvantages of each option in terms of cost, scalability, flexibility, reliability, security, and maintenance requirements.
- Considering cloud providers. If opting for a cloud-based solution, evaluate various cloud service providers based on factors such as pricing, services offered, performance, availability, security, compliance certifications, and geographical coverage.
- Assessing infrastructure requirements. Determine the infrastructure requirements for the software system, including computing resources, networking, databases, development tools, and middleware. Consider whether specialized hardware or software components are needed to support specific functionalities or performance requirements.
- Evaluating data storage and management. Assess requirements for data storage, management, and backup. Consider factors such as data volumes, access patterns, data consistency, latency, replication, disaster recovery, and compliance with data protection regulations.
- Considering development environment. Evaluate options for the development environment, including programming languages, frameworks, extension tools, control systems, continuous integration/continuous deployment pipelines, and collaboration platforms. Choose tools and technologies that align with the skills and preferences of the development team and support efficient software development practices.
- Assessing security and compliance. Ensure that the selected facility meets security and compliance requirements for the software system. Consider factors such as data encryption, access controls, identity management, audit logging, vulnerability management, and regulatory compliance.
- Evaluating support and maintenance. Consider support and maintenance requirements for the software system, including monitoring, troubleshooting, patch management, upgrades, backups, and technical support. Evaluate the availability of support services from vendors or service providers and assess their responsiveness and expertise.
- Cost analysis. Conduct a comprehensive cost analysis of different facility options, taking into account upfront costs, ongoing operational expenses, licensing fees, subscription costs, and potential cost savings or cost avoidance associated with each option.
- Risk assessment. Identify and assess potential risks associated with each facility option, such as vendor lock-in, service outages, security breaches, data loss, regulatory non-compliance, and changes in business requirements or market conditions. Develop mitigation strategies to address identified risks.
- Finalizing decision. Based on the evaluation criteria, prioritize the facility options and make a final decision on the most suitable facility for the software system. Document the rationale behind the decision and communicate it to stakeholders involved in the software development and deployment process. By following this systematic approach, organizations can make informed decisions when selecting facilities for software systems, ensuring that the chosen facility meets the requirements of the software system and supports its successful development, deployment, and maintenance. There may be a lack of comprehensive data or uncertainty surrounding key factors such as demand patterns, infrastructure availability, regulatory requirements, making it challenging to make well-informed decisions. Stakeholders may have different preferences, priorities, and risk tolerances when it comes to facility location selection. Vague or conflicting preferences can lead to uncertainty and disagreement in decision-making. The business and technological landscape is constantly evolving, introducing uncertainty and vagueness into facility location decisions. Factors such as market trends,

technological advancements, and regulatory changes can impact the suitability of a chosen location over time.

Assume that a multi criteria decision making problem of facility location selection for software systems involves three criteria - C_1, C_2, C_3, (C_1 - Labor climate, C_2 - Proximity to customers, C_3 -Proximity to suppliers and resources) and 3 alternatives - A, B, C. For determining best location of software systems integrated fuzzy AHP-TOPSIS approach is used. Graphical structure of this methodology given in fig 1.

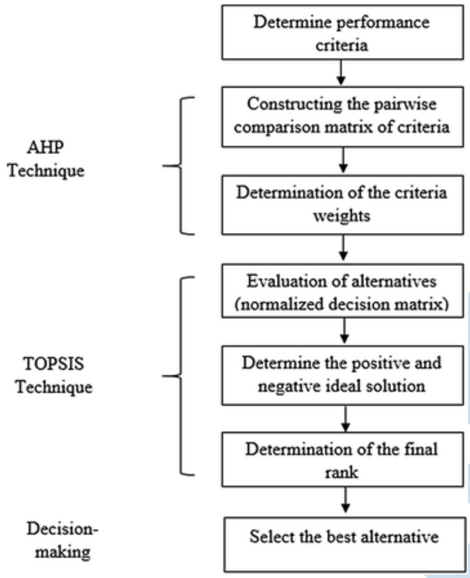

Fig 1. Graphical structure of fuzzy AHP-TOPSIS hybrid methodology

Step 1. Determining labor climate, proximity to customers and proximity to suppliers and resources as criteria for facility location selection [18]. Labor climate criteria in software systems refer to the conditions, environment, and factors that affect the morale, productivity, and satisfaction of software development teams. By considering and actively managing these labor climate criteria, organizations can create an environment that supports the well-being and productivity of their software development teams, ultimately leading to better outcomes for projects and the organization as a whole. These criteria play a crucial role in determining the overall success of software projects. Proximity to customers in software systems refers to the degree to which software development teams interact, understand, and collaborate with end-users or customers throughout the development process. This criterion is essential for building successful software products that meet the needs and expectations of customers effectively. By prioritizing proximity to customers in software systems, organizations can build products that are not only technically robust but also resonate with users, drive adoption, and ultimately contribute to the success of the business. Proximity to suppliers and resources in software systems refers to the accessibility and availability of necessary resources, tools, and external partners that support the software development process. By effectively managing proximity to suppliers and resources in software systems, organizations can enhance their agility, scalability, and competitiveness in delivering high-quality software solutions that meet customer needs and expectations.

Step 2. Constructing the pairwise comparison matrix of criteria. For determining weights of criteria we use fuzzy triangle numbers. Using scale of interest that represented in Table I we construct pairwise comparison matrix that represented in Table II.

TABLE II. PAİRWİSE COMPARİSON MATRİX OF CRİTERİA

	C_1	C_2	C_3
C_1	(1,1,1)	(1,3,5)	(1/7,1/5,1/3)
C_2	(1/5,1/3,1)	(1,1,1)	(1/9,1/7,1/5)
C_3	(3,5,7)	(5,7,9)	(1,1,1)

Step 3. Determining weights of each criteria. The geometric mean of fuzzy comparison values of each attribute is determined by using formula (2). $\tilde{r}_i$ - geometric mean of fuzzy comparison values of "Labor climate" criterion calculated as down.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n} = \left[\left(1*1*{}^{1}\!/_{7}\right)^{\frac{1}{3}};\left(1*{}^{1}\!/_{3}*{}^{1}\!/_{5}\right)^{\frac{1}{3}};\left(1*5*{}^{1}\!/_{3}\right)^{\frac{1}{3}}\right] =$$

$$= \left[0.53, 0.41, 1.18\right]$$

r_i -geometric mean of fuzzy comparison values of "Proximity to customers" criterion calculated as down.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n} = \left[\left({}^{1}\!/_{5}*1*{}^{1}\!/_{9}\right)^{\frac{1}{3}};\left({}^{1}\!/_{3}*1*{}^{1}\!/_{7}\right)^{\frac{1}{3}};\left(1*1*{}^{1}\!/_{5}\right)^{\frac{1}{3}}\right] =$$

$$= \left[0.29, 0.36, 0.59\right]$$

r_1 -geometric mean of fuzzy comparison values of "Proximity to suppliers and resources" criterion is calculated as down.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n} = \left[(3*5*1)^{\frac{1}{3}};(5*7*1)^{\frac{1}{3}};(7*9*1)^{\frac{1}{3}}\right] =$$

$$= \left[2.44, 3.23, 3.92\right]$$

The geometric means of fuzzy comparison values for different attributes shown in Table III.
In addition, the total values and the reverse values are also present.

TABLE III. THE GEOMETRIC MEANS OF FUZZY COMPARISON VALUES

Criteria	$\tilde{r}_i$		
Labor climate	0.53	0.41	1.18

Proximity to customers	0.29	0.36	0.59
Proximity to suppliers and resources	2.44	3.23	3.92
Total	3.26	4	5.69
Reverse (power of -1)	0.31	0.25	0.17
Increasing Order	0.17	0.25	0.31

The fuzzy weight of „Labor climate" criteria $\tilde{w}_1$ found by using of equation (3).

$$\tilde{w}_1 = \left[(0.53 * 0.17);(0.41 * 0.25);(1.18 * 0.31)\right] =$$
$$= [0.09, 0.1, 0.36]$$

The fuzzy weight of „Proximity to customers" criterion $\tilde{w}_2$ calculated as down.

$$\tilde{w}_2 = \left[(0.29 * 0.17);(0.36 * 0.25);(0.59 * 0.31)\right] =$$
$$= [0.05, 0.09, 0.18]$$

The fuzzy weight of „Proximity to suppliers and resources" criterion calculated as down.

$$\tilde{w}_3 = \left[(2.44 * 0.17);(3.23 * 0.25);(3.92 * 0.31)\right] =$$
$$= [0.41, 0.8, 0.9]$$

The weight of each criterion represented by fuzzy numbers, such as,

$$\tilde{w}_1 = (0.09,\ 0.1,\ 0.36)$$
$$\tilde{w}_2 = (0.04, 0.09, 0.2)$$
$$\tilde{w}_3 = (0.41, 0.8, 0.9)$$

A performance evaluation matrix, also known as performance assessment matrix, is an organized tool that used to estimate and evaluate the performance of individuals, teams, projects, or processes against predefined criteria or objectives. It provides a systematic framework for measuring performance, identifying strengths, drawbacks, and facilitating decision-making related to performance improvement, recognition, rewards, corrective actions. Performance rating decision matrix presented in Table IV.

TABLE IV. DECISION MATRIX OF PERFORMANCE RATING

	C_1	C_2	C_3
	w_1	w_2	w_3
	0.09, 0.1, 0.36	0.04,0.09,0.2	0.41,0.8,0.9
A	0.06, 0.2, 0.8	0.3, 0.8, 0.9	0.4, 0.65, 0.9
B	0.21, 0.6, 0.9	0.15, 0.5, 0.75	0.05, 0.07, 0.09
C	0.23,0.5,0.8	0.15,0.25,0.65	0.65, 0.74, 0.85

By implementing a performance evaluation matrix, organizations can effectively assess and manage performance, foster accountability, transparency, and drive continuous improvement and excellence across individuals, teams, and organizational units.

For solution of this problem and selection better location for facility used TOPSIS steps [19].

Step 4. Constructing the weighted decision matrix (Table V).

TABLE V. WEIGHTED DECISION MATRIX

	C_1	C_2	C_3
A	0.005, 0.02, 0.3	0.01, 0.07, 0.18	0.16, 0.52, 0.81
B	0.02, 0.06, 0.32	0.006, 0.04, 0.15	0.02, 0.06, 0.08
C	0.02, 0.05, 0.29	0.006, 0.02, 0.13	0.27, 0.6, 0.76

Step 5. Calculating the fuzzy positive ideal solution and fuzzy negative-ideal solution:

$$A^* = \{(0.02,\ 0.06,\ 0.32), (0.01,\ 0.07,\ 0.18), (0.27, 0.6, 0.76)\}$$
$$A^- = \{(0.005,\ 0.02,\ 0.29), (0.006, 0.02, 0.13), (0.02,\ 0.06,\ 0.08)\}$$

Determining separation measure for each alternative. For example, separation measure for first alternative can be determined as

$$S_A^* = \Big\{\left[(0.005,\ 0.02,\ 0.29) - (0.005,\ 0.02,\ 0.29)\right]^2 +$$
$$+\left[(0.01,\ 0.07,\ 0.18) - (0.005,\ 0.02,\ 0.29)\right]^2 +$$
$$+\left[(0.16,\ 0.52,\ 0.81) - (0.005,\ 0.02,\ 0.29)\right]^2\Big\}^{1/2} =$$
$$= (0.091, 0.34, 1.45)$$

$$S_A^* = (0.091, 0.34, 1.45), \qquad S_A^- = (0.08, 0.3, 1.05)$$

Similarly, for other alternatives separation measures are determined.

$$S_B^* = (0.19, 0.65, 1.98), \qquad S_B^- = (0.04, 0.19, 0.76)$$
$$S_C^* = (0.18, 0.60, 1.96), \qquad S_C^- = (0.035, 0.185, 0.73)$$

Step 6. Determination of the final rank by defining relative closeness to the ideal solutions for each alternative:

$$C_A^* = \frac{S_A^-}{S_A + S_A^-} = \frac{(0.091, 0.34, 1.45)}{(0.091, 0.34, 1.45) + (0.08, 0.31, 1.05)} =$$
$$= (0.05, 0.3, 5.6)$$

$$C_B^* = \frac{S_B^-}{S_B^* + S_B^-} = (0.02, 0.3, 3.4)$$

$$C_C^* = \frac{S_C^-}{S_C^* + S_C^-} = (0.07, 0.9, 9.1)$$

Step 7. Selecting best alternative. Relative closeness of each alternative to the ideal solution represents that alternative C is best alternative - $C > A > B$

IV. RESULT

Facility location for software systems in uncertain conditions involves determining optimal locations for data centers, servers, or other computing facilities considering potential uncertainties such as fluctuations in demand, network latency, power outages, and natural disasters. There are some basic strategies for addressing uncertainty in facility location for software systems. They are conducting a comprehensive risk analysis to identifying potential sources of uncertainty, including environmental factors, market dynamics, and technical issues, assessing the probability and potential impact of each risk to inform decision-making, designing facilities with flexibility in mind to adapt to changing conditions [20]. This could involve modular designs that allow for easy expansion or relocation of computing resources based on demand fluctuations or unexpected events. Implementing redundancy and backup mechanisms to mitigate the impact of failures or disruptions is important in facility location [21]. This may include duplicating critical infrastructure components across multiple locations to ensure continuous operation in the event of failures [22]. Game-theoretic models can be used to address uncertainties in competitive environments where the actions of other agents (e.g., competitors, regulators) are uncertain [23]. This approach helps in making strategic decisions regarding facility locations. These methods, such as genetic algorithms and simulated annealing, are used to find near-optimal solutions for complex facility location problems under uncertainty. They are particularly useful when exact solutions are computationally infeasible [24]. Distributing computing facilities across geographically diverse locations for minimization the risk of localized disruptions such as natural calamity or regional infrastructure failures, considering factors such as proximity to target markets, regulatory requirements, and network connectivity when selecting locations also important issues in facility location of software systems. Implementation real-time monitoring systems to track key performance indicators and environmental conditions and using this data to dynamically adjust resource allocation, routing decisions, and failover strategies to optimize performance and resilience in uncertain conditions are significant of facility location for software systems in uncertainty conditions. Cloud services, leverage cloud computing services are offered built-in redundancy, scalability, and geographic diversity. Cloud providers typically operate data centers in multiple regions, providing inherent resilience to failures and disruptions. Foster collaboration and communication between stakeholders, including IT teams, facility managers, and business units, ensure alignment of goals and priorities in addressing uncertainty. Regularly review and update facility location strategies based on evolving risks and opportunities. By incorporating these strategies into facility location decisions, software systems can better withstand uncertainty and maintain optimal performance and reliability in dynamic environments.

V. CONCLUSIONS

The selection of a facility location is a multifaceted decision that affects various operational, financial, and strategic aspects of a business. A thorough analysis considering these practical implications can lead to a more informed and effective location decision, ultimately contributing to the business's success. The application of the fuzzy AHP-TOPSIS hybrid method in facility location selection for software systems is not only theoretically sound but also practically applicable. It provides decision-makers with a systematic and structured approach to evaluate and select the most suitable location based on their specific requirements and constraints. To make decision on facility location selection for software systems, the methodology of fuzzy AHP-TOPSİS with fuzzy numbers is applied in this paper to take high vagueness that appropriates to the considered problem. Selection of the best location for software systems provided according to three attributes and three alternatives- A, B, C . The first attribute for selection is labor climate, the second attribute is proximity to customers, and third attribute is proximity to suppliers and resources. Results defined from the relative closeness to the positive ideal solutions used for ranking the preference order and determined that alternative C is best alternative for facility location.

In concluding the application of the Fuzzy Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) hybrid method in facility location selection for software systems, several key points can be highlighted. The hybrid method provides a robust framework for decision-making by incorporating both fuzzy AHP and TOPSIS. This integration allows for handling the inherent uncertainties and complexities involved in facility location selection for software systems. Facility location selection involves multiple criteria such as labor climate, proximity to customers, proximity to suppliers and resources proximity. The fuzzy AHP-TOPSIS hybrid method enables the consideration of these diverse criteria and their relative importance in decision-making. Fuzzy logic is effective in capturing the subjectivity and imprecision in expert judgments during pairwise comparisons of criteria and alternatives. This ensures a more accurate representation of decision-makers' preferences and enhances the reliability of the decision-making process. Sensitivity analysis allows for assessing the robustness of the selected facility location against changes in criteria weights and alternative rankings. This helps decision-makers understand the stability of their decisions and identify potential risks associated with the chosen location. Validation of the selected facility location through simulation or real-world experimentation validates the effectiveness of the hybrid method. Moreover, the method can be adapted and customized to suit different contexts and decision-making scenarios, making it a versatile tool for facility location selection in various industries.

In summary, the Fuzzy AHP-TOPSIS hybrid method offers a comprehensive and effective approach to facility location selection for software systems, integrating fuzzy logic, AHP, and TOPSIS to address the complexities and uncertainties inherent in decision-making processes. Its systematic framework, coupled with sensitivity analysis and validation, empowers decision-makers to make informed and reliable decisions regarding facility location selection

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