A combined fuzzy AHP with fuzzy TOPSIS to locate industrial supporting bonded logistics centers

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ABSTRACT

Raw material availability is critical for the sustainability of industrial activity. A bonded logistics centre is required as a multipurpose warehouse for the storage of raw commodities, particularly those imported from other countries. The operationalization of bonded logistics centers in terms of supplying raw materials effectively and efficiently is largely location dependent. Proper facility placement is critical for resolving the storage issue and boosting the efficiency of the transportation system. The purpose of this article is to suggest a technique for locating a bonded logistics centre. In an unpredictable context, decision making requires a range of criteria generated from knowledge and stakeholder experience. As a result, this work proposes the combination of the fuzzy analytic hierarchy process (FAHP) with the fuzzy technique for ordering preferences by similarity to ideal solution (FTOPSIS). By disclosing linguistic characteristics, fuzzy numbers contribute to the resolution of ambiguity and imprecision. Obtaining the weighted value of the criteria and sub-criteria using fuzzy AHP. Using fuzzy TOPSIS, determining alternate preferences based on weighting factors. Its use lies in being able to distinguish between criteria that provide advantages and those that generate expenses. The findings indicate that the selected option is the one that is most closely related to the positive ideal.

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1. INTRODUCTION

The worldwide market and the process of procuring commodities have evolved and altered at a breakneck pace [1]. Accelerating the flow of products is a critical success element in global logistics operations [2], as it enables the network of prospective suppliers to be expanded at the lowest possible cost [3]. In today's environment, supply chain networks that ensure timely and efficient product delivery are becoming more vital [4]. Logistics activities as well as warehousing, distribution, and transportation have faced certain changes in the history of world trade [5]. Logistics centres have grown in importance and strategic importance at both the downstream and upstream phases of various companies' supply chain processes [6]. The logistics centre is a location that houses all logistics and transportation operations on a national and worldwide scale and is managed by a company that specializes in different business activities [7]. A well-functioning logistics centre delivers enormous advantages [8], adding value to the value chain and hence increasing competitiveness [9].

International commerce is strongly reliant on the operation of logistics and transportation [10]. Numerous gauges exist for evaluating a country's logistical performance [11]. Measurement and comparison of logistics performance indicators on a macro basis uses the logistics performance index (LPI). LPI compiles data on logistics costs, customs processes, and land and marine transportation infrastructure for comparison across nations [10]. Industrialization is critical to a country's economic growth. A bonded logistics centre is one of the customs facilities that helps with industrial products delivery. A bonded logistics centre is a multipurpose warehouse that is primarily used for the storage of imported products. Prior to being employed by industry, raw materials imported from other countries would enter the bonded logistics centre after obtaining a duty suspension.

The effectiveness and efficiency of the logistics center operation is highly dependent on the location selection [12]. Location selection is a strategic choice that affects the long-term success of an enterprise [13]. Selecting the optimal site may help alleviate traffic congestion [8], [12] hence lowering operating costs and increasing income [6]. On the other hand, an inconvenient site might result in a variety of extra expenses [8]. Recently, establishing the site of the logistics centre has remained a contentious topic [14]. Bonded logistic is a method implemented to manage various cross-border trade flows that used some tools and methods of customs, tax regulations, the Internet of Things (IoT), and blockchain, to ensure the well ordered exchange of goods in transit, export, and import [15]. The installation of a bonded logistics hub near an industerial area may alleviate the country's raw material storage issue. The placement of the bonded logistics centre is critical in ensuring the rapid and cost-effective availability of raw materials.

In the actual world, decision-making has both quantitative and qualitative components, but the qualitative components are fraught with ambiguity and inconsistent consistency [16]–[18]. Fuzzy logic is defined in terms of resolving uncertainty and imprecision to address this [17]. Fuzzy findings may be more easily interpreted when converted to the correct amount [19]. By combining fuzzy sets with analytic hierarchy process (AHP), a more exact link between criteria and options is established [20], resulting in a more effective decision-making process than the classic analytical hierarchy approach [21].

Recently, location issues have been extensively solved using a mix of multi-criteria decision making approaches and fuzzy logic [22]. Numerous studies have investigated a decision-making model based on fuzzy multi-criteria decision making (FMCDM) for the site of logistics centres [8]. Calculates the weights using fuzzy AHP and uses the artificial neural network (ANN) phase to obtain the most suitable freight logistics location [7]. Presented the fuzzy technique for ordering preferences by similarity to ideal solution (FTOPSIS) along with criteria for geographic, physical, socioeconomic, and cost considerations [23]. Assessed the sites of three logistics centres using the fuzzy additive ratio assessment (FARAS) technique [24]. Using the combination of AHP and FTOPSIS to tackle the issue of global logistics hub placement. The decision matrix components and weighting index are represented as fuzzy integers in this manner.

Furthermore, this research proposes combination of fuzzy expansions from AHP technique and TOPSIS fuzzy technique to select the bonded logistics centre location. The fuzzy extension of the AHP approach is utilized to establish the relative weight from every criteria and sub-criteria in the activity of selected the site of the bonded logistics centre. In this research, fuzzy AHP overcomes the AHP method's drawback in terms of input, which comes in the form of an imprecise impression of a bonded logistics centre expert. The fuzzy TOPSIS approach is then used to rank options for industrial support bonded logistics centre site selection. Alternative sites for bonded logistics hubs are ranked by transforming expert responses into a triangular fuzzy number.

2. METHOD

Assessment of alternative locations for bonded logistics centers supporting large industries using expert questionnaires. This study uses expert opinion to compare the criteria, so the linguistic values must be converted to fuzzy numbers. Meanwhile, these fuzzy results cannot be easily interpreted, so they must be converted to the correct quantity through a defuzzification process.

This section details the three major phases involved in the process of identifying a site for an industrial support bonded logistics centre. First, establish the criteria and sub-dependent criteria factors. This study uses a sampling technique based on certain considerations. Respondents are based on their expertise, have influence and have an interest in bonded logistics center.

The second phase is compiling a hierarchical model contains objectives, criteria, sub-criteria and alternatives. The value obtained for each criterion will be used as the criterion value by averaging it. Then weight the criteria that have been obtained along with the sub-criteria following the fuzzy AHP.

The third phase, assessment of alternatives by determining the preference value for every alternative using fuzzy TOPSIS. The weight of the evaluated criteria and the assessment of alternatives is expressed in linguistic form to assess risk in a fuzzy circumstance. Linguistic variables represent the degree of compatibility and the weight of criteria from the alternative with the predetermined criteria.

Filling out the alternative assessment questionnaires using a linguistic scale from very high, high, medium, low, and very low. The final step is to choose the decision alternatives with the highest priority as the optimal alternative. To arrive at an effective choice, fuzzy number based processes are used. Figure 1 represents a flowchart of the proposed procedure to choose the site of the bonded logistics center.

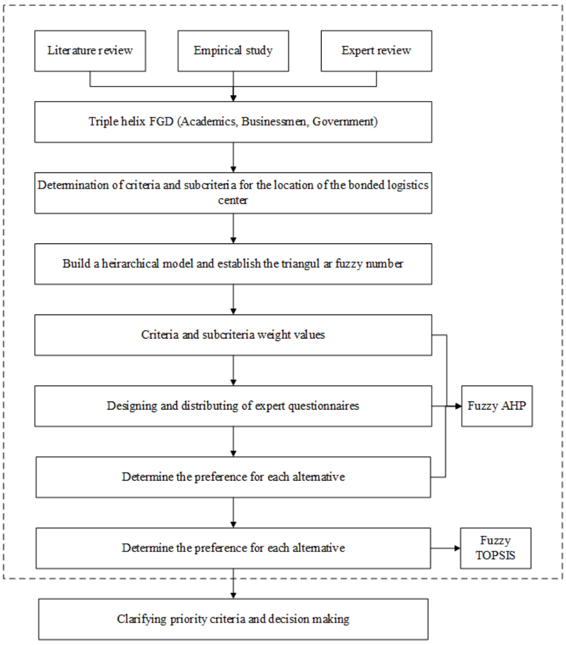

Figure 1. Flowchart of the proposed method

2.1. Fuzzy analytical hierarchy process

The method of fuzzy AHP enables a more precise description of complicated decision-making processes [25]. A fuzzy AHP solution organizes and systematizes a difficult multi-criteria issue [26]. This research makes advantage of Chang's fuzzy analytic hierarchy process (FAHP) development [27].

– Triangular fuzzy number (TFN) weighting
  Create a hierarchical model of the issue and compare it to the Triangular FN scale using the criteria.

$$M_2 \otimes M_1 = (l_1 . l_2, m_1 . m_2, u_1 . u_2) \quad (1)$$

– Fuzzy synthetic extent
  The synthetic fuzzy extent value is used to establish the expansion of an object [28], with the indicator's $M_{gi}^{1}, M_{gi}^{2}, ..., M_{gi}^{m}$, $i = 1 \dots \dots \dots n$, where ($j = 1 \dots \dots \dots m$) are triangular fuzzy numbers. The i object's synthetic fuzzy extent value is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}} \quad (2)$$

– Vector values and defuzzification ordinates
  In this process, comparison of two fuzzy numbers $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, with the probability level ($M_2 \geq M_1$), measured by (3).

$$V(M_2 \geq M_1 = \sup_{y \geq x} \left[min\left(\mu M_1(x), \mu M_2(y)\right)\right] \quad (3)$$

– Normalization of the weights of fuzzy vectors
  The weight of a normalized vector is

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \quad (4)$$

Where W is a non-fuzzy number.

2.2. Fuzzy technique for order of preference by similarity to ideal solution

TOPSIS is a multi-criteria decision-making strategy which take basis of alternative comparison [28]. Fuzzy TOPSIS is a useful approach because it allows for the consideration of an infinite number of options and criteria, which may be done with both positive (+) and negative (–) criteria [29]. The weighting of evaluation criteria and alternative judgments is stated in language terms in this stage. The use of the fuzzy TOPSIS technique relies on the closest distance obtained. Steps to solve the problem using the TOPSIS expansion with triangular fuzzy numbers by Chen [30].

- Construct a matrix of fuzzy decisions
  Utilize linguistic characteristics to create a comparison matrix R with m choices and n criteria. The use of a linear scale to convert the used criteria scale to a comparative scale. $R = [r_{ij}]_{mxn}$ where $i = 1 \dots \dots \dots m$ and $j = 1 \dots \dots \dots n$
- Determining the fuzzy decision matrix's normalized weights
- The weight of a normalized matrix V with m options and n criteria is equal to the product of the weights of the criteria in the fuzzy r_{ij} decision matrix and the weights of the criteria in the normalized matrix. The weight of normalization to fuzzy decisions is measured using (5) $V = [v_{ij}]_{mxn}$ where $i = 1 \dots \dots \dots m$ and $j = 1 \dots \dots \dots n$

$$v_{ij} = k_{ij} \otimes w_j \tag{5}$$

- Calculating the distance between every alternative
  Calculating the distance between values of every option using fuzzy positive ideal and fuzzy negative ideal (6).

$$d_i^* = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_{ij}^{+}\right)^2\right\}^{1/2}, i = 1 \dots \dots \dots m \tag{6}$$

$$d_i^- = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_{ij}^{-}\right)^2\right\}^{1/2}, i = 1 \dots \dots \dots m \tag{7}$$

- Calculating the coefficient of similarity

The proximity of the ideal solution is used to establish the value assigned to each option. The closeness coefficient (CC_i) may be computed as (8). The last step is to order the alternative priorities as stated by their CC_i values, starting with the candidate that have the greatest CC_i value and ending with the candidate that have the lowest CC_i value.

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} i = 1 \dots \dots \dots, m \tag{8}$$

3. RESULTS AND DISCUSSION

3.1. Decision making criteria and sub-criteria

Criteria are factors that have to be met to select or evaluate the location of the industrial supporting bonded logistics centre. The initial criteria and sub-criteria for selecting the location of the bonded logistics center were identified through an intensive literature review. Furthermore, it is offered and is a stimulus for focus group discussion participants involving elements of academia, business, and government. From the triple helix focus group discussion, six criteria and eighteen sub-criteria were obtained. These criteria and sub-criteria will be used as input in the pairwise comparison questionnaire for selecting the location of the industrial supporting bonded logistics center which proceeds are represented in Table 1.

The site of a bonded logistics centre is critical to its effectiveness and efficiency. Concentration of industry in a single location fosters the growth of other sectors. Four sites were evaluated, MM2100 (MM), Jababeka (JB), Greenland International Industrial Center (GI), and Marunda Center (RC), since they have a prominent impact on the effectiveness of a bonded logistics centre in supplying raw materials to industries.

3.2. Value assigned to each criterion

All comparison matrices of criterion and sub-criteria are subjected to consistency testing. The pairwise comparison matrix was certified consistent in this investigation with a consistency ratio of 10%. Then change the respondent's answer into triangular fuzzy numbers (TFNs). Table 2 indicates average value of the conversion results of TFNs. The fuzzy synthetic extent (S_i) value for criteria linked to hierarchical goal is represented in Table 3.

Table 1. Primary and secondary criteria

Kode	Main criteria	Kode	Sub criteria
C_1	Accessibility	Pc_1	Close to the motorway
		Pc_2	Close to the port
		Pc_3	Close to the highway
		Pc_4	Close to customers
C_2	Cost	Pc_5	Land and buildings
		Pc_6	Transportation
		Pc_7	Storage
		Pc_8	Labor
C_3	Property condition	Pc_9	Surface area
		Pc_{10}	Clear layout and boundaries
		Pc_{11}	Ownership
C_4	Regulation	Pc_{12}	Bonded stockpile
		Pc_{13}	Space utilization
C_5	Infrastructure	Pc_{14}	Road infrastructure
		Pc_{15}	Information and communication technology
		Pc_{16}	Electrical infrastructure
C_6	Environmental management	Pc_{17}	Security and safety
		Pc_{18}	Environmentally friendly

Table 2. Average value of TFNs

Main criteria	Symbol	C_1	C_2	C_3	C_4	C_5	C_6
	l	1.000	0.249	0.206	2.500	0.182	0.184
C_1	m	1.000	0.695	0.410	4.048	0.352	0.295
	u	1.000	0.905	0.905	5.571	0.619	0.810
	l	1.286	1.000	0.349	2.429	0.176	0.304
C_2	m	2.143	1.000	0.981	4.429	0.276	0.752
	u	4.143	1.000	1.476	6.429	0.714	1.286
	l	1.286	1.171	1.000	3.286	0.457	0.257
C_3	m	3.000	2.048	1.000	5.286	1.286	0.714
	u	5.000	3.857	1.000	7.286	2.143	1.000
	l	0.677	0.163	0.149	1.000	0.150	0.149
C_4	m	1.011	0.249	0.224	1.000	0.222	0.224
	u	0.771	0.600	0.543	1.000	0.486	0.543
	l	2.143	2.029	0.771	3.286	1.000	0.571
C_5	m	3.857	4.143	1.952	5.286	1.000	1.667
	u	5.857	6.143	3.571	7.286	1.000	2.714
	l	1.571	1.743	1.000	3.286	0.657	1.000
C_6	m	3.571	3.190	1.857	5.286	1.286	1.000
	u	5.571	5.000	3.857	7.286	2.714	1.000

Table 3. Fuzzy synthetic extent value

Main criteria	Lower (l)	Medium (m)	Upper (u)
C_1	0.077	0.217	0.616
C_2	0.060	0.166	0.467
C_3	0.036	0.099	0.304
C_4	0.141	0.368	0.910
C_5	0.025	0.066	0.203
C_6	0.027	0.083	0.229

Table 4. Final weight

Main criteria	Main criteria weight	Sub-criteria	Sub-criteria weight	Final weight
C_1	0.250	Pc_1	0.199	0.050
		Pc_2	0.321	0.080
		Pc_3	0.288	0.072
		Pc_4	0.191	0.048
C_2	0.202	Pc_5	0.295	0.060
		Pc_6	0.366	0.074
		Pc_7	0.199	0.040
		Pc_8	0.140	0.028
C_3	0.113	Pc_9	0.381	0.043
		Pc_{10}	0.249	0.028
		Pc_{11}	0.369	0.042
C_4	0.346	Pc_{12}	0.720	0.249
		Pc_{13}	0.280	0.097
C_5	0.055	Pc_{14}	0.420	0.023
		Pc_{15}	0.385	0.021
		Pc_{16}	0.195	0.011
C_6	0.034	Pc_{17}	0.653	0.022
		Pc_{18}	0.347	0.012

Fuzzy numbers are represented by three digits, namely (l, m, u). These factors reflect the smallest conceivable value, promised value, and fuzzy problem's maximum value. Additionally, the weight vector computation results are normalized to obtain the weights for every criteria and sub-criteria. Table 4 summarizes the final weights.

A weighted value of 0.346 is assigned to the regulatory criterion. When compared to other criterion, this value is substantial. A bonded logistics centre may be operated with the collaboration of numerous organizations. Institutional strengthening and regulatory compliance are required for effective coordination [31]. The next criterion is accessibility with a weight value of 0.250. The most often utilized criterion for selecting the site of a logistics centre is accessibility.

Cost comes in second place in this survey. Bonded logistics facilities expedite supplies to industry and ensure that orders are filled on schedule. A bonded logistics facility located near industry and with convenient access to transportation infrastructure enables faster delivery of products. Cost is ranked third, with a weight of 0.202. Bonded logistics hubs benefit from expedited clearance, entrance, and release of products.

Construction expenditures may be substituted for land rent costs to make the cost criterion more appropriate for underdeveloped nations. The standards for property and infrastructure conditions are strongly tied to the functioning of a bonded logistics centre after the commodities arrive at the port and are temporarily kept. The weights of the criterion are not significantly different for these two criteria, with the condition property carrying a weight of 0.113 and the infrastructure carrying a weight of 0.055. Environmental management criteria are those with a weight value of less than 0.034.

This study prioritized and identified the criterion to select a logistics center location, but the weighting results for the criteria may differ depending on the type and context of the logistics center. Different criteria will produce different hierarchical models so that the pairwise comparison questionnaire which is the main input to get results in the form of criterion weighting values will be different. Decision-making that involves stakeholder groups then incorporates individual preferences, significantly more reflective of real-world decision-making.

Table 5. Ideal solution

Sub-criteria	MM	JB	GI	RC	K^+	K^-
Pc_1	0.026	0.024	0.024	0.025	0.026	0.024
Pc_2	0.039	0.034	0.049	0.037	0.049	0.034
Pc_3	0.036	0.036	0.034	0.037	0.037	0.034
Pc_4	0.027	0.027	0.018	0.022	0.027	0.018
Pc_5	0.030	0.028	0.021	0.038	0.021	0.038
Pc_6	0.036	0.033	0.036	0.043	0.033	0.043
Pc_7	0.020	0.019	0.019	0.022	0.019	0.022
Pc_8	0.014	0.012	0.014	0.016	0.012	0.016
Pc_9	0.020	0.027	0.020	0.018	0.027	0.018
Pc_{10}	0.014	0.014	0.013	0.015	0.015	0.013
Pc_{11}	0.021	0.020	0.020	0.022	0.022	0.020
Pc_{12}	0.123	0.123	0.118	0.133	0.133	0.118
Pc_{13}	0.049	0.049	0.049	0.046	0.049	0.046
Pc_{14}	0.012	0.013	0.009	0.012	0.013	0.009
Pc_{15}	0.011	0.011	0.009	0.011	0.011	0.009
Pc_{16}	0.005	0.005	0.005	0.005	0.005	0.005
Pc_{17}	0.011	0.011	0.011	0.011	0.011	0.011
Pc_{18}	0.006	0.006	0.006	0.006	0.006	0.006

Table 6. Preference value

Alternatives	$d*$	d^-	$v*$
MM	0.015	0.018	0.555
JB	0.022	0.011	0.846
GI	0.025	0.009	0.256
RC	0.044	0.035	0.445

3.3. Alternative assessment

Weights are projected by multiplied the weights obtained from the fuzzy AHP data processing results by the TOPSIS normalized matrix. The weight values for the sub-criteria, as well as the helpful or harmful values, may be retained for defuzzification and conversion of the assessment findings to a triangular fuzzy number. The optimal approach for the sub-criteria ($Pc1$) is to use the largest value in the weighted normalized matrix. Table 5 summarizes the results from calculating the positive ideal solution together with negative ideal solution for every sub-criterion.

The ratio of the distance from the positive ideal solution into the negative ideal solution is the preference value for the alternative. Table 6 shows the preferred value for the alternate site of the bonded logistics facility. The preference value is the criterion used to rank all possible sites for bonded logistics facilities. Each choice will have a preference value associated with it. Applying the TOPSIS fuzzy approach, the greatest preference value is 0.846 for JB. This indicates that JB is located closest to the positive ideal solution.

4. CONCLUSION

Fuzzy numbers are used to convey linguistic factors and to deal with incomplete and unclear data. The site selection is critical for the company. Appropriate criteria and sub-criteria are required to accomplish this purpose. The primary factor influencing the placement of the bonded logistics centre is the complexity and ambiguity of the stakeholders. As a result, decision makers' tastes and experiences are altered via the use of language phrases. This study proposes a methodology for selecting the site of bonded logistics center by combining the fuzzy AHP and fuzzy TOPSIS extensions. Regulation, accessibility, cost, property condition, infrastructure, and environmental management are the ultimate weighted priority criterion.

This research has limitations in that it did not investigate the link between two criteria. Future study may take this interaction into account and integrate a multi-criteria decision making model using a mathematical model solution approach. The suggested methodological procedure may be validated over a bigger region using a variety of different criteria.

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