Location Selection for a Lumber Drying Facility *via* a Hybrid Pythagorean Fuzzy Decision-making Approach

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The strategic selection of facility locations plays a critical role in optimizing operational efficiency, reducing costs, and enhancing customer satisfaction, thereby contributing significantly to the success and competitiveness of businesses. In this study, an interval-valued Pythagorean fuzzy decision-making framework is proposed to select the best location for the lumber drying industry. A four-level hierarchical model is devised with four main criteria, 16 subcriteria, and five alternatives. The opinions of different experts are gathered to obtain input data. The weights of the criteria are calculated using the interval-valued Pythagorean fuzzy analytic hierarchy process (AHP) method. The interval-valued Pythagorean fuzzy weighted aggregated sum product assessment (WASPAS) method is employed to evaluate the alternative locations. A sensitivity analysis is conducted to support the validity of the model results. The study concludes by revealing the optimal location for the lumber drying industry in Turkey. This study presents its novelty by formulating the lumber drying facility location selection problem as a complex fuzzy multicriteria decision-making problem and integrating the Pythagorean fuzzy AHP and WASPAS methods to solve the problem.

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Keywords: Lumber drying facility; Location analysis; AHP; WASPAS; Pythagorean fuzzy set

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INTRODUCTION

The lumber drying industry encompasses a range of processes and technologies dedicated to reducing the moisture content of freshly cut lumber to levels suitable for its intended use in construction, woodworking, or other applications. Lumber drying helps prevent warping, cracking, and decay, thereby enhancing the quality and durability of wood products. To achieve optimal drying outcomes, various methods such as kiln drying, air drying, and steam drying are employed, coupled with specialized equipment and controls. Efficient lumber drying processes contribute significantly to reducing waste and maximizing the value of timber resources. Furthermore, the lumber drying industry plays an important role in economic growth by supporting downstream industries, generating employment opportunities, and contributing to the global trade of wood products (Vikberg 2015).

With the rising global demand for wood products, the need for efficient and strategically positioned lumber drying facilities has become increasingly pronounced. The process of selecting facility locations involves determining the best geographical spots for facilities such as manufacturing plants, distribution centers, or service outlets to enhance efficiency, minimize costs, and meet customer demand effectively. This decision-making process employs analytical methods, such as mathematical programming models, geographic information systems, and multicriteria decision-making (MCDM) approaches, to assess and compare different location options based on quantitative and/or qualitative criteria. Choosing the best facility location is pivotal for ensuring the long-term success and competitiveness of businesses (Athawale *et al*. 2012).

The MCDM serves as a valuable technique for identifying the most favorable option among various alternatives, particularly when faced with numerous and conflicting criteria. Hence, MCDM stands out as a favorable tool for addressing facility location selection challenges. The MCDM process involves defining decision problems, selecting criteria, evaluating alternatives, and making decisions based on objectives. Some popular MCDM methods are the analytic hierarchy process (AHP), the technique for order preference by similarity to ideal solution (TOPSIS), the evaluation based on distance from average solution (EDAS), and the weighted aggregated sum product assessment (WASPAS). Through employing MCDM methods, decision-makers can make well-informed and balanced decisions that align with the specific needs and priorities of a given decision problem (Sahoo and Goswami 2023).

The complexity of decision problems, cognitive limitations, subjectivity, and data constraints make obtaining precise numerical judgments difficult in many applications. Decision-makers often lean towards employing verbal labels in the decision-making process (Chen *et al*. 2021). The integration of fuzzy sets with MCDM methods emerges as an important strategy. Fuzzy set theory provides a more realistic approach to decision-making. It facilitates the integration of verbal expressions into the decision-making process. In traditional set theory, an element either belongs to a set or does not, with no middle ground. Fuzzy set theory allows for the representation of partial membership. This flexibility makes fuzzy sets a suitable tool for capturing the imprecise nature of human judgments and the uncertainty inherent in decision problems (Tseng 2011).

Several fuzzy extensions have been developed to solve decision problems. One notable extension is the Pythagorean fuzzy set. Through incorporating degrees of membership, non-membership, and indeterminacy, this extension allows decision-makers to articulate their preferences with greater nuance (Meng *et al*. 2024). The interval-valued Pythagorean fuzzy set takes a step beyond by assigning an interval to each element. The interval width provides additional information about the level of uncertainty associated with each element. Incorporating the interval-valued Pythagorean fuzzy set into MCDM methods enhances the quality and reliability of decision outcomes (Alrasheedi and Jeevaraj 2023). In this study, the problem of selecting the most suitable location for a lumber drying facility is formulated as a complex fuzzy MCDM problem. An integrated interval-valued Pythagorean fuzzy AHP-WASPAS approach is proposed to handle this problem. The decision to employ the Pythagorean fuzzy AHP and WASPAS methods is based on their advantages, proven effectiveness, and novelty.

The AHP is a structured approach for dealing with complex decision-making situations. This method begins by identifying a decision problem and establishing a hierarchical structure comprising three main levels: goals, criteria, and alternatives. Once the AHP hierarchy is defined, decision-makers conduct pairwise comparisons between elements at each level using an evaluation scale. The AHP method employs a consistency check mechanism to identify and rectify inconsistencies in the judgments of decision-makers (Liu *et al*. 2023). Pairwise comparison matrices are formed and utilized to derive the weights of decision elements. The AHP hierarchy helps in organizing and understanding the components of decision problems. The AHP method allows for the incorporation of both quantitative and qualitative factors in the decision-making process and helps decision-makers express their preferences in a consistent and quantitative manner (Pires *et al*. 2011; Kim *et al*. 2020). In this study, the interval-valued Pythagorean fuzzy AHP method is used for the prioritization of decision criteria. This method has been successfully employed to solve various decision problems such as risk assessment (Ilbahar *et al*. 2018), rail transportation system assessment (Demir *et al*. 2023), wooden outdoor furniture selection (Singer and Özşahin 2023), evaluation of supply resilience performance (Çalik *et al*. 2023), supplier selection (Erdebilli *et al*. 2023), and building smartness assessment (Milošević *et al*. 2023).

WASPAS is a decision support tool employed for ranking alternatives. Its practicality and emphasis on ranking accuracy make it a valuable approach in decision-making processes. The WASPAS method leverages the strengths of both the weighted sum model (WSM) and weighted product model (WPM). Through amalgamating these approaches, the WASPAS method enhances the accuracy of priority rankings (Baykasoğlu and Gölcük 2019). The WASPAS method offers several advantages. One notable strength lies in its straightforward and efficient calculation steps, which are both short and easy to follow (Menekşe and Camgöz Akdağ 2023). The amalgamation of the WSM and WPM approaches endows the WASPAS method with a heightened accuracy level during the decision-making process. The reliability of decision results can be scrutinized through sensitivity analysis, where variations in the threshold parameter of the method are explored (Ali *et al*. 2021). Furthermore, the WASPAS method exhibits remarkable resistance against the rank reversal phenomenon (Chakraborty and Zavadskas 2014). In this study, the interval-valued Pythagorean fuzzy WASPAS method is employed to rank different location options. This method has demonstrated success in addressing diverse decision problems, including retail store performance measurement (Ilbahar and Kahraman 2018), technology selection (Boltürk and Kahraman 2020), evaluation of renewable energy sources (Al-Barakati *et al*. 2022), vaccine selection (Gedikli and Cayir Ervural 2022), and drone selection (Aktas and Kabak 2022).

There are several studies aimed at addressing facility location selection problems in the field of wood science (Azizi and Memariani 2004; Azizi 2008; Azizi *et al*. 2015; Üçüncü *et al*. 2017; Yeşilkaya 2018; Singer and Özşahin 2020). However, the previous studies have deficiencies in dealing with uncertainties. Furthermore, the relevant literature has a gap in determining the best location for the lumber drying industry using intelligent decision-support tools. In this study, an integrated interval-valued Pythagorean fuzzy AHP-WASPAS approach is proposed to determine the most suitable location for the lumber drying industry. The interval-valued Pythagorean fuzzy AHP method is applied to assign weights to decision criteria, while the interval-valued Pythagorean fuzzy WASPAS method is employed to rank different location alternatives. This study presents its novelty by formulating the lumber drying facility location selection problem as a complex fuzzy MCDM problem and integrating the Pythagorean fuzzy AHP and WASPAS methods to solve the problem.

EXPERIMENTAL

Interval-valued Pythagorean Fuzzy AHP-WASPAS Approach

Fuzzy set theory offers a convenient framework for managing linguistic terms and uncertainties. The Pythagorean fuzzy set is a fuzzy variant characterized by two main parameters: membership degrees ($\mu_{\tilde{P}}(x)$) and non-membership degrees ($v_{\tilde{P}}(x)$). The sum of the parameters is allowed to surpass 1. However, the maximum value for the sum of their squares is 1 (Yanmaz *et al*. 2020). The interval-valued Pythagorean fuzzy set extends the Pythagorean fuzzy set by introducing intervals to represent uncertain information. Eq. 1 defines the interval-valued Pythagorean fuzzy set (Ren and Du 2023):

$$\widetilde{P} = \left\{ \langle x, \widetilde{P}[\mu_{\tilde{P}_L}(x), \mu_{\tilde{P}_U}(x)], [v_{\tilde{P}_L}(x), v_{\tilde{P}_U}(x)]\rangle \,;\; x \epsilon X \right\} \tag{1}$$

The parameters take values within the range of zero to one. Some arithmetic operations for two interval-valued Pythagorean fuzzy numbers ($\tilde{A}$ and $\tilde{B}$) are explained below (Yanmaz *et al*. 2020):

$$\tilde{A} \oplus \tilde{B} = \left(\begin{bmatrix} \sqrt{(\mu_A^L)^2 + (\mu_B^L)^2 - (\mu_A^L)^2 (\mu_B^L)^2}, \\ \sqrt{(\mu_A^U)^2 + (\mu_B^U)^2 - (\mu_A^U)^2 (\mu_B^U)^2} \end{bmatrix}, [v_A^L v_B^L, v_A^U v_B^U] \right) \tag{2}$$

$$\tilde{A} \otimes \tilde{B} = \left([\mu_A^L \mu_B^L, \mu_A^U \mu_B^U], \begin{bmatrix} \sqrt{(v_A^L)^2 + (v_B^L)^2 - (v_A^L)^2 (v_B^L)^2}, \\ \sqrt{(v_A^U)^2 + (v_B^U)^2 - (v_A^U)^2 (v_B^U)^2} \end{bmatrix} \right) \tag{3}$$

$$\lambda \tilde{A} = ([\sqrt{1 - (1 - (\mu_A^L)^2)^{\lambda}}, \sqrt{1 - (1 - (\mu_A^U)^2)^{\lambda}}], [(v_A^L)^{\lambda}, (v_A^U)^{\lambda}]) \tag{4}$$

$$\tilde{A}^{\lambda} = ([(\mu_A^L)^{\lambda}, (\mu_A^U)^{\lambda}], [\sqrt{1 - (1 - (v_A^L)^2)^{\lambda}}, \sqrt{1 - (1 - (v_A^U)^2)^{\lambda}}]) \tag{5}$$

The interval-valued Pythagorean fuzzy AHP-WASPAS approach applied in this study consists of two main phases: (i) Evaluation of decision criteria, and (ii) prioritization of location options. The steps of this approach are elucidated below.

Step 1: Pairwise comparison matrices ($[\tilde{a}_{ij}]_{m \times m}$) are created to evaluate criteria.

Step 2: The Saaty's classical consistency ratio process is carried out by matching linguistic terms with the crisp AHP scale (Saaty 1977).

Step 3: Different matrices are specified using the following Eqs. 6 and 7:

$$d_{ij_L} = \mu_{ij_L}^2 - v_{ij_U}^2 \tag{6}$$

$$d_{ij_U} = \mu_{ij_U}^2 - v_{ij_L}^2 \tag{7}$$

Step 4: Interval of multiplicative matrices are created using Eqs. 8 and 9:

$$s_{ij_L} = \sqrt{1000^{d_{ij_L}}} \tag{8}$$

$$s_{ij_U} = \sqrt{1000^{d_{ij_U}}} \tag{9}$$

Step 5: Determinacy values are derived through the utilization of Eq. 10.:

$$\tau_{ij} = 1 - (\mu_{ij_U}^2 - \mu_{ij_L}^2) - (v_{ij_U}^2 - v_{ij_L}^2) \tag{10}$$

Step 6: Weight matrices are generated based on Eq. 11:

$$t_{ij} = \left(\frac{s_{ij_L} + s_{ij_U}}{2}\right)\tau_{ij} \tag{11}$$

Step 7: Weights are acquired through the application of Eq. 12.

$$w_i = \frac{\sum_{j=1}^{m} t_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{m} t_{ij}} \tag{12}$$

Step 8: The performance of alternatives is evaluated based on criteria.

Step 9: WSM and WPM results are calculated *via* Eqs. 13 and 14, respectively:

$$\widetilde{Q}_i^{(1)} = \sum_{j=1}^{m} \tilde{x}_{ij}\, w_j \tag{13}$$

$$\widetilde{Q}_i^{(2)} = \prod_{j=1}^{m} \tilde{x}_{ij}^{\ w_j} \tag{14}$$

where $\tilde{x}_{ij}$ is the performance of alternative i under criterion j.

Step 10: WSM and WPM results are combined using the threshold parameter (λ).

$$\widetilde{Q}_i = \lambda\widetilde{Q}_i^{(1)} + (1-\lambda)\widetilde{Q}_i^{(2)} \tag{15}$$

Step 11: The defuzzification formula is utilized to prioritize alternatives.

$$p = \frac{\mu_L + \mu_U + \sqrt{1 - v_L^2} + \sqrt{1 - v_U^2}}{4} + \frac{\mu_L \mu_U - \sqrt{\sqrt{1 - v_L^2}\sqrt{1 - v_U^2}}}{4} \tag{16}$$

Decision-making Framework

The lumber drying industry plays an important role in ensuring the quality and durability of wood materials for various manufacturing applications. The demand for wood products is steadily rising due to several factors such as population growth, urbanization, and increased construction activities. Efficient and strategically positioned lumber drying facilities are crucial for meeting this demand. Lumber drying facilities play a significant role in processing raw materials into usable materials by reducing their moisture content to suitable levels. The strategic positioning of these facilities is essential to optimize production efficiency, minimize costs, and enhance customer satisfaction.

In this study, an interval-valued Pythagorean fuzzy decision-making framework is suggested to examine the lumber drying facility location selection problem. The initial phase of the study focuses on problem structuring. Subsequently, the interval-valued Pythagorean fuzzy AHP method is employed to unveil the significance of decision criteria. The interval-valued Pythagorean fuzzy WASPAS method is implemented to rank alternative locations. In the last phase, a sensitivity analysis is conducted by varying the λ coefficient of the WASPAS method. The steps of this study are shown in Fig. 1.

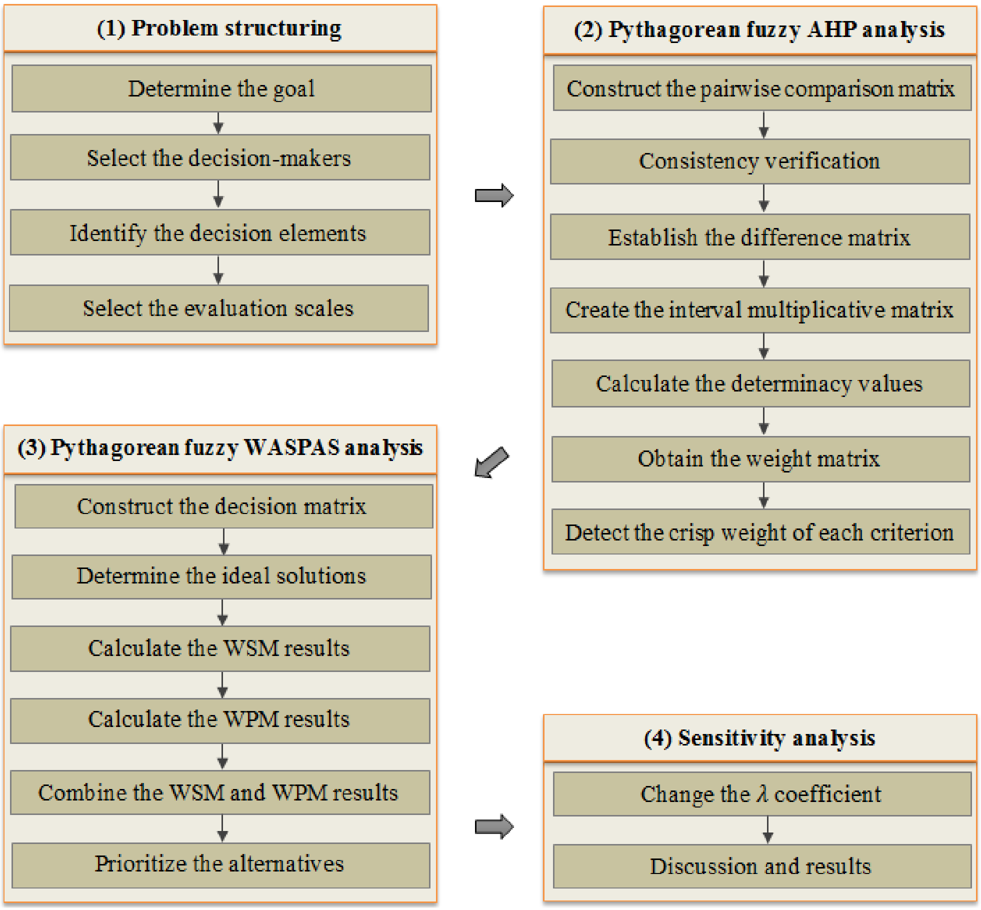

Fig. 1. Decision-making framework

This study examines a real-world example of the location selection problem for the lumber drying industry. Data are collected in five cities of Turkey: “Kastamonu”, “Düzce”, “Kayseri”, “Bayburt”, and “Trabzon” (see Fig. 2).

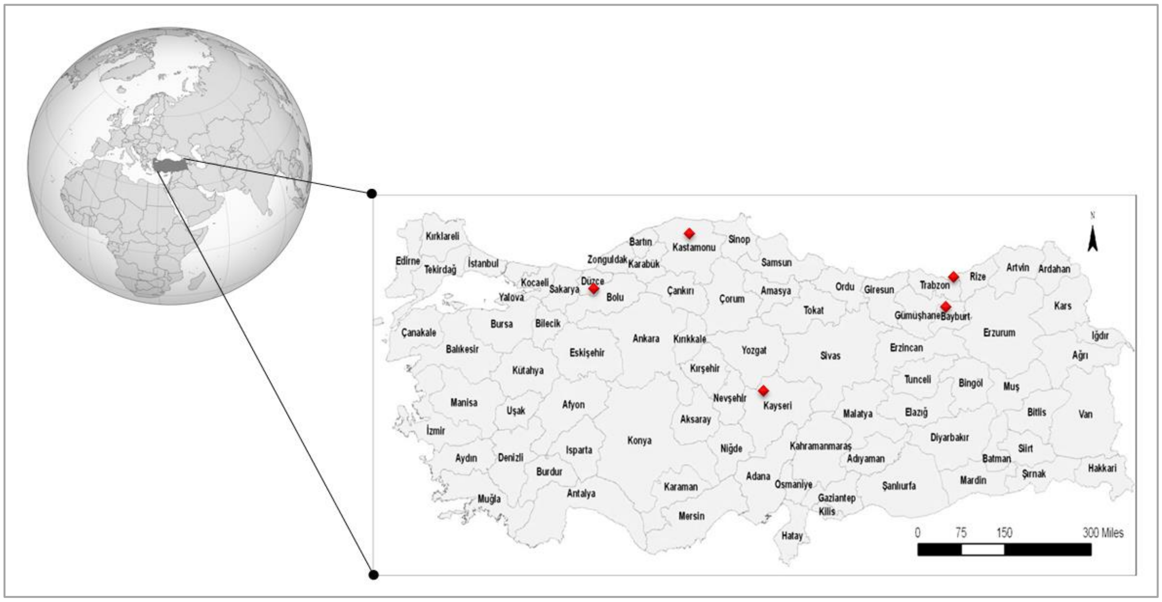

Fig. 2. Study area

An expert team is established to identify and evaluate the decision elements of the model. Various factors are taken into consideration when selecting experts, such as: (i) education (preferably post-graduate), (ii) experience (at least 5 years), (iii) publications relevant to location selection problems (specifically, international research papers), and (iv) prior participation in MCDM research. The literature review yields a list of criteria. Potential criteria are identified through an analysis of the location selection studies within the paper. The list obtained from the literature is refined and expanded by the team members based on their individual knowledge, expertise, and the specific requirements of the problem at hand. The criteria are identified through collective efforts and rigorous discussions. Sixteen subcriteria are finalized under four main criteria. The alternatives considered in the model are determined based on the preferences of the decision-makers. The hierarchical structure of the problem is illustrated in Fig. 3.

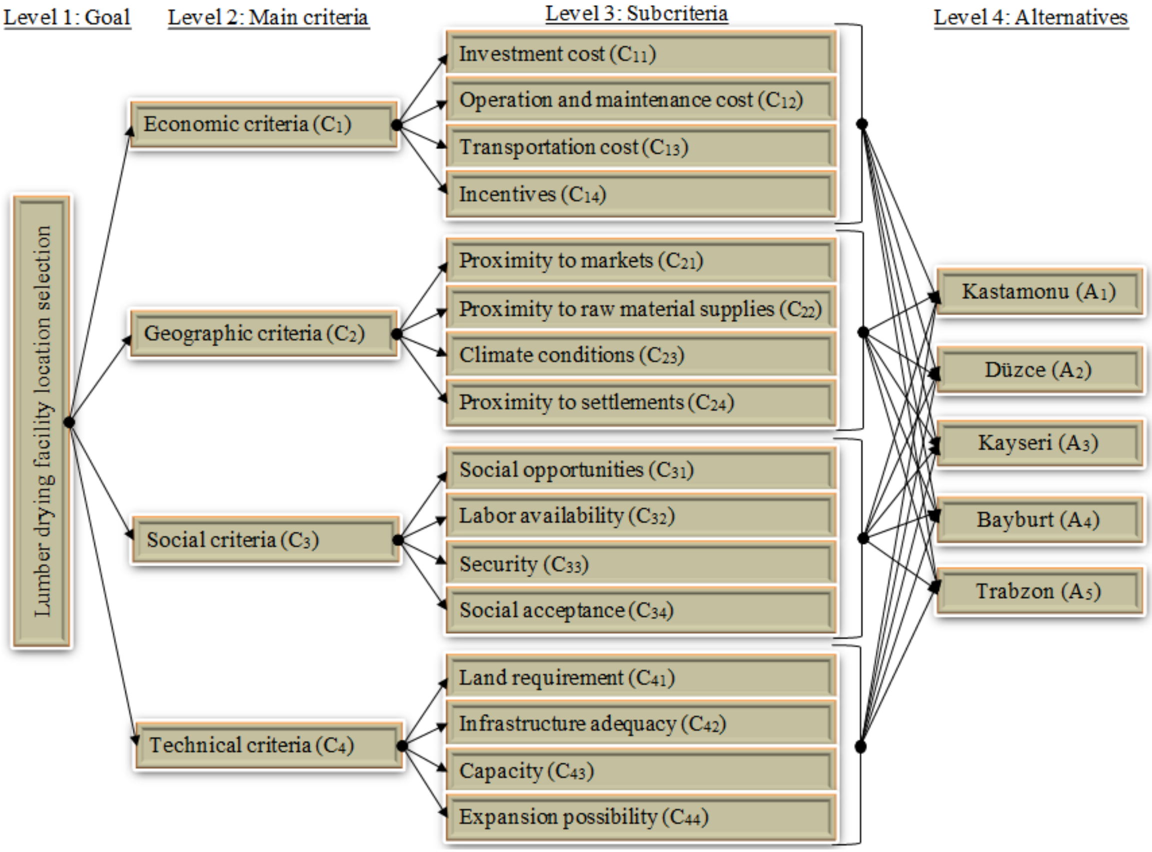

Fig. 3. Decision hierarchy

RESULTS AND DISCUSSION

This study applies a hybrid Pythagorean fuzzy AHP-WASPAS methodology to the lumber drying facility location selection problem. The decision model consists of four main criteria, sixteen subcriteria, and five alternatives. The evaluation of the decision elements is conducted by the expert team. To ensure the acquisition of high-quality and unbiased data, the study considers face-to-face interviews. The consensus-building process is used for collaborative decision-making. After three rounds of consolidating opinions, consensus is achieved.

The interval-valued Pythagorean fuzzy AHP method necessitates pairwise comparisons of criteria to determine their weights. Hence, the experts are tasked with providing pairwise comparisons for the identified criteria. They respond to questions such as, “How important is criterion *A* compared to criterion *B* in achieving the goal?” This process is carried out using the following scale: certainly low importance - ⟨[0, 0], [0.9, 1]⟩, very low importance - ⟨[0.1, 0.2], [0.8, 0.9]⟩, low importance - ⟨[0.2, 0.35], [0.65, 0.8]⟩, below average importance - ⟨[0.35, 0.45], [0.55, 0.65]⟩, average importance - ⟨[0.45, 0.55], [0.45, 0.55]⟩, above average importance - ⟨[0.55, 0.65], [0.35, 0.45]⟩, high importance - ⟨[0.65, 0.8], [0.2, 0.35]⟩, very high importance - ⟨[0.8, 0.9], [0.1, 0.2]⟩, certainly high importance - ⟨[0.9, 1], [0, 0]⟩, exactly equal - ⟨[0.1965, 0.1965], [0.1965, 0.1965]⟩. The experts express their preference comparisons through linguistic terms. The linguistic expressions are then transformed into the corresponding interval-valued Pythagorean fuzzy numbers. The resulting pairwise comparison matrices are analyzed to determine the weight of each criterion. The obtained results are presented in Tables 1 to 5.

Table 1. Pairwise Comparison Results for the Main Criteria

Criterion	C_{1}	C_{2}	C_{3}	C_{4}	Weight
C_{1}	⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	⟨[0.65, 0.8], [0.2, 0.35]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	0.450
C_{2}		⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	0.266
C_{3}			⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.45, 0.55], [0.45, 0.55]⟩	0.135
C_{4}				⟨[0.197, 0.197], [0.197, 0.197]⟩	0.149

Table 2. Pairwise Comparison Results for the Subcriteria of “Economic Criteria”

Criterion	C_{11}	C_{12}	C_{13}	C_{14}	Weight
C_{11}	⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.2, 0.35], [0.65, 0.8]⟩	⟨[0.2, 0.35], [0.65, 0.8]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	0.104
C_{12}		⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.45, 0.55], [0.45, 0.55]⟩	⟨[0.8, 0.9], [0.1, 0.2]⟩	0.518
C_{13}			⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.65, 0.8], [0.2, 0.35]⟩	0.321
C_{14}				⟨[0.197, 0.197], [0.197, 0.197]⟩	0.057

Table 3. Pairwise Comparison Results for the Subcriteria of “Geographic Criteria”

Criterion	C_{21}	C_{22}	C_{23}	C_{24}	Weight
C_{21}	⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.45, 0.55], [0.45, 0.55]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	⟨[0.8, 0.9], [0.1, 0.2]⟩	0.395
C_{22}		⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.65, 0.8], [0.2, 0.35]⟩	⟨[0.8, 0.9], [0.1, 0.2]⟩	0.458
C_{23}			⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	0.099
C_{24}				⟨[0.197, 0.197], [0.197, 0.197]⟩	0.048

Table 4. Pairwise Comparison Results for the Subcriteria of "Social Criteria"

Criterion	C_{31}	C_{32}	C_{33}	C_{34}	Weight
C_{31}	⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.1, 0.2], [0.8, 0.9]⟩	⟨[0.35, 0.45], [0.55, 0.65]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	0.071
C_{32}		⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.65, 0.8], [0.2, 0.35]⟩	⟨[0.9, 1], [0, 0]⟩	0.747
C_{33}			⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.65, 0.8], [0.2, 0.35]⟩	0.147
C_{34}				⟨[0.197, 0.197], [0.197, 0.197]⟩	0.036

Table 5. Pairwise Comparison Results for the Subcriteria of "Technical Criteria"

Criterion	C_{41}	C_{42}	C_{43}	C_{44}	Weight
C_{41}	⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.2, 0.35], [0.65, 0.8]⟩	⟨[0.35, 0.45], [0.55, 0.65]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	0.126
C_{42}		⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	⟨[0.8, 0.9], [0.1, 0.2]⟩	0.615
C_{43}			⟨[0.197, 0.197], [0.197, 0.197]⟩	⟨[0.55, 0.65], [0.35, 0.45]⟩	0.185
C_{44}				⟨[0.197, 0.197], [0.197, 0.197]⟩	0.074

According to the pairwise comparison results, "economic criteria" is the most significant main criterion. The subcriteria possessing the highest local importance are: "operation and maintenance cost" in the "economic criteria" group, "proximity to raw material supplies" in the "geographic criteria" group, "labor availability" in the "social criteria" group, and "infrastructure adequacy" in the "technical criteria" group. Global weights are derived by synthesizing the local weights acquired through the matrices to prioritize all the subcriteria. The results are graphically depicted in Fig. 4. According to the results, the most important subcriteria are "operation and maintenance cost", "transportation cost", and "proximity to raw material supplies".

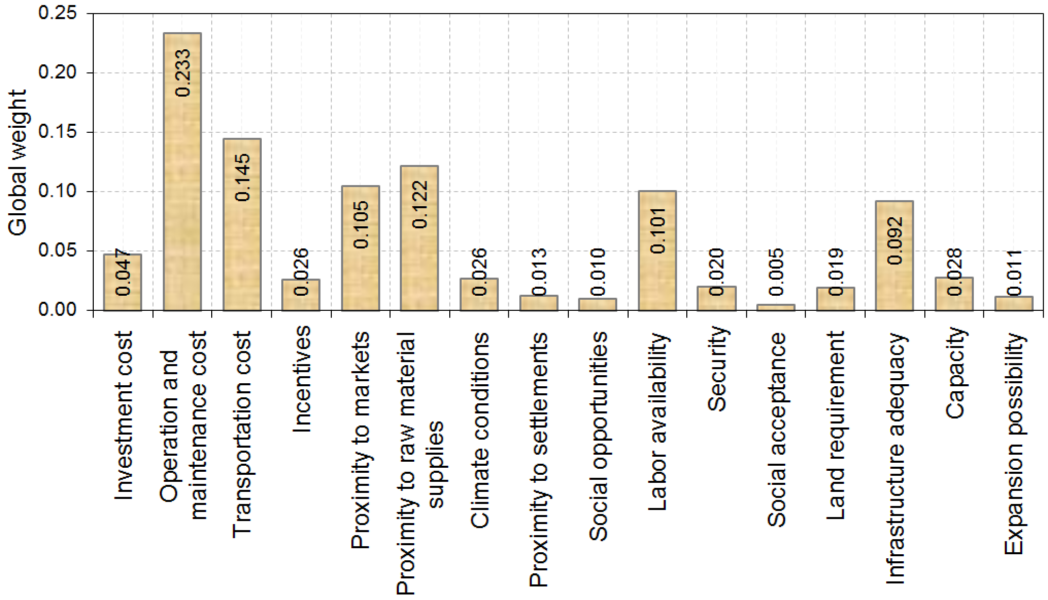

Fig. 4. Global importance of the subcriteria

The weights assigned to the criteria serve as input for the interval-valued Pythagorean fuzzy WASPAS method. The alternatives are evaluated based on the criteria. The experts employ the following evaluation scale: absolutely good - ⟨[0.7, 0.9], [0.1, 0.2]⟩, very good - ⟨[0.6, 0.8], [0.2, 0.3]⟩, good - ⟨[0.5, 0.7], [0.3, 0.4]⟩, moderate - ⟨[0.4, 0.6], [0.4, 0.5]⟩, poor - ⟨[0.3, 0.4], [0.5, 0.7]⟩, very poor - ⟨[0.2, 0.3], [0.6, 0.8]⟩, and absolutely poor - ⟨[0.1, 0.2], [0.7, 0.9]⟩. The verbal expressions are transformed into the corresponding interval-valued Pythagorean fuzzy numbers to carry out mathematical computations. It is important to note that all the elements share the same unit, and the evaluations are conducted as benefit oriented. The resulting matrix is given in Table 6.

Table 6. Decision Matrix for the Alternatives

	C_{11}	C_{12}	C_{13}	C_{14}
A_1	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩
A_2	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩
A_3	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.7, 0.9], [0.1, 0.2]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩
A_4	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.3, 0.4], [0.5, 0.7]⟩
A_5	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩
	C_{21}	C_{22}	C_{23}	C_{24}
A_1	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩
A_2	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩
A_3	⟨[0.7, 0.9], [0.1, 0.2]⟩	⟨[0.3, 0.4], [0.5, 0.7]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.7, 0.9], [0.1, 0.2]⟩
A_4	⟨[0.2, 0.3], [0.6, 0.8]⟩	⟨[0.2, 0.3], [0.6, 0.8]⟩	⟨[0.3, 0.4], [0.5, 0.7]⟩	⟨[0.3, 0.4], [0.5, 0.7]⟩
A_5	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩
	C_{31}	C_{32}	C_{33}	C_{34}
A_1	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩
A_2	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.3, 0.4], [0.5, 0.7]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩
A_3	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.3, 0.4], [0.5, 0.7]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩
A_4	⟨[0.3, 0.4], [0.5, 0.7]⟩	⟨[0.3, 0.4], [0.5, 0.7]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩
A_5	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩
	C_{41}	C_{42}	C_{43}	C_{44}
A_1	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩
A_2	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩
A_3	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩	⟨[0.6, 0.8], [0.2, 0.3]⟩
A_4	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.3, 0.4], [0.5, 0.7]⟩	⟨[0.3, 0.4], [0.5, 0.7]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩
A_5	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩	⟨[0.4, 0.6], [0.4, 0.5]⟩	⟨[0.5, 0.7], [0.3, 0.4]⟩

The WSM and WPM values are calculated, and the threshold parameter is set to the widely used value of 0.5. The WSM and WPM results are combined to determine the overall performance of the alternatives. The model results are presented in Table 7. The ranking of the alternatives in descending order, determined by their performance score, is as follows: “Kayseri”, “Düzce”, “Kastamonu”, “Trabzon”, and “Bayburt”. This ranking implies that the optimal choice is “Kayseri”.

To validate the model results, a sensitivity analysis is conducted by adjusting the threshold parameter from 0 to 1 in increments of 0.10. The resulting performance scores of the alternatives are presented in Table 8, and the corresponding priority orders are visually depicted in Fig. 5. It is evident that the priority order of the alternatives remains consistent. This observation underscores the robustness of the applied approach, implying that the results are reliable and not significantly influenced by variations. Consequently, “Kayseri” is the optimal choice for the handled problem.

Table 7. Model Outputs for the Alternatives

Alternative	$\tilde{Q}^{(1)}$	$\tilde{Q}^{(2)}$	$\tilde{Q}$	Score	Ranking
A_1	⟨[0.496, 0.698], [0.304, 0.406]⟩	⟨[0.484, 0.685], [0.320, 0.419]⟩	⟨[0.490, 0.691], [0.312, 0.413]⟩	0.613	3
A_2	⟨[0.553, 0.754], [0.247, 0.350]⟩	⟨[0.542, 0.740], [0.264, 0.367]⟩	⟨[0.547, 0.747], [0.255, 0.358]⟩	0.663	2
A_3	⟨[0.601, 0.807], [0.193, 0.308]⟩	⟨[0.562, 0.743], [0.260, 0.391]⟩	⟨[0.582, 0.778], [0.224, 0.347]⟩	0.692	1
A_4	⟨[0.363, 0.530], [0.444, 0.590]⟩	⟨[0.324, 0.466], [0.477, 0.651]⟩	⟨[0.344, 0.500], [0.460, 0.620]⟩	0.463	5
A_5	⟨[0.473, 0.674], [0.327, 0.428]⟩	⟨[0.467, 0.668], [0.335, 0.434]⟩	⟨[0.470, 0.671], [0.331, 0.431]⟩	0.595	4

Table 8. Effect of the Change in the Threshold Value on Performance Scores

Alternative	Threshold Parameter										
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
A_1	0.607	0.608	0.609	0.610	0.612	0.613	0.614	0.615	0.616	0.617	0.618
A_2	0.657	0.659	0.660	0.661	0.662	0.663	0.665	0.666	0.667	0.668	0.669
A_3	0.666	0.672	0.677	0.682	0.687	0.692	0.697	0.702	0.706	0.711	0.715
A_4	0.441	0.445	0.450	0.455	0.459	0.463	0.468	0.472	0.476	0.481	0.485
A_5	0.592	0.593	0.593	0.594	0.594	0.595	0.596	0.596	0.597	0.597	0.598

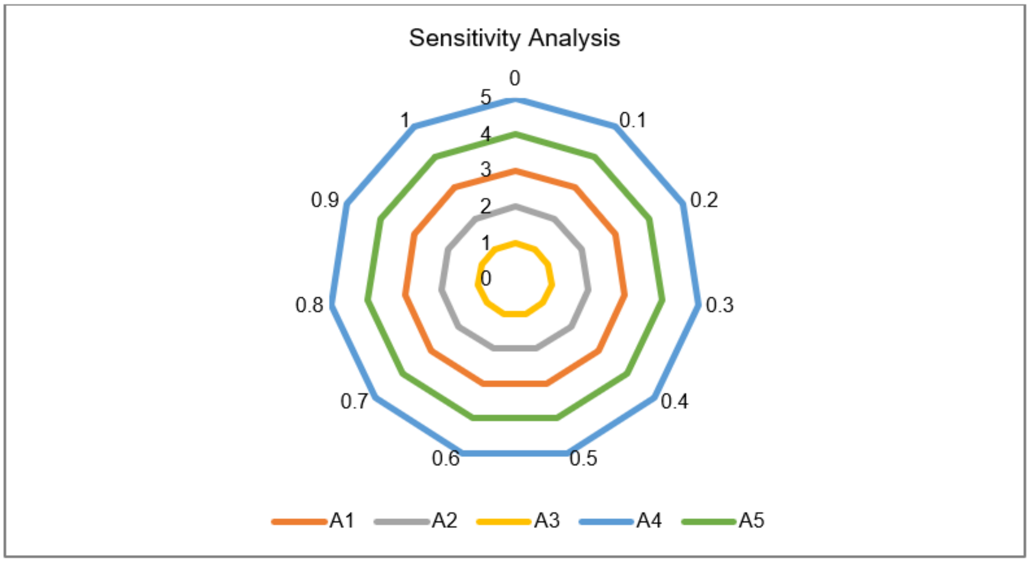

Fig. 5. Rankings of the alternatives based on the sensitivity analysis results

This study utilizes a hybrid Pythagorean fuzzy decision-making approach for selecting the optimal location for the lumber drying industry. The value of the current study can be elucidated as follows: (i) the lumber drying facility location selection problem is formulated as a complex fuzzy MCDM problem; (ii) the study presents the first implementation of the interval-valued Pythagorean fuzzy AHP/WASPAS-based decision-making approach in this field and provides a novel perspective; (iii) the decision problem is examined from an expert viewpoint; (iv) the study reveals the importance weights of the decision elements under the interval-valued Pythagorean fuzzy decision-making environment; (v) a real-life study in Turkey is presented; (vi) the study presents a valuable guide for decision-makers to improve their location selection strategies. In future studies, the proposed decision-making framework can be applied to examine different facility location selection problems, and different decision support tools can be incorporated into the problem.

CONCLUSIONS

1. In this study, an expert knowledge-based Pythagorean fuzzy AHP-WASPAS approach is proposed to select the best location for a lumber drying facility. Within the model, four main criteria, sixteen subcriteria, and five alternatives are defined. The interval-valued Pythagorean fuzzy AHP procedure is utilized to determine the importance of the criteria. The alternatives are prioritized by considering the interval-valued Pythagorean fuzzy WASPAS procedure. The proposed framework is applied to a case study in Turkey.
2. According to the model results, “economic criteria” is the highest priority group. The priority order of the subcriteria is obtained as follows: “operation and maintenance cost”, “transportation cost”, “proximity to raw material supplies”, “proximity to markets”, “labor availability”, “infrastructure adequacy”, “investment cost”, “capacity”, “climate conditions”, “incentives”, “security”, “land requirement”, “proximity to settlements”, “expansion possibility”, “social opportunities”, and “social acceptance”. Prioritization suggests that minimizing operational and maintenance expenses is the foremost concern, followed by reducing transportation costs and ensuring proximity to raw material supplies.
3. The model results highlight “Kayseri” as the most suitable alternative among the candidate locations for the lumber drying industry. The obtained result can be attributed to the ability of the location to meet the criteria effectively.
4. The sensitivity analysis performed in the study supports the acceptability and reliability of the model results. The priority order of the alternative locations remains unchanged. Therefore, it can be concluded that the applied methodology is stable in response to the changes in the model parameter.
5. The proposed framework presents a different viewpoint as it contributes to selecting the optimal locations for forestry and wood products industries. The findings of the current study will assist decision-makers in making informed choices.

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