A Multicriteria Decision-Making Model for Selecting Warehouse Rack Systems

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Abstract

Selecting the right racking system in warehouses significantly affects costs, productivity, and efficiency. This decision is complex due to various subjective factors. This study proposes a multicriteria decision making approach combining the Analytical Hierarchy Process (AHP) with Neutrosophic Sets (NSs) to manage uncertainty, ambiguity, and indeterminacy in the decision-making process. The study employs an AHP-NS model to determine criteria weights and rank potential racking storage systems. Five options were evaluated: Selective, Double-reach, Drive-in, Drive-through, and Push-back racks. These were assessed based on four primary criteria and ten sub-criteria, identified through literature review and experts. Six decision-makers from diverse roles, including top management, finance, engineering, procurement, and operations, were selected using stratified random sampling. Their input was crucial in evaluating the alternatives against the established criteria. The results revealed that "Speed" was the most critical factor, accounting for 37% of the decision weight, followed by utilization, cost, and type of access. Interestingly, LIFO and FIFO access methods were ranked least important at 3% and 4%, respectively. The Selective racking system emerged as the top choice, scoring 75% overall. This comprehensive approach offers a structured method for warehouse managers to make informed decisions on racking systems, considering multiple factors and stakeholder perspectives.

Keywords: Multicriteria Decision Making, Analytical Hierarchy Process, Neutrosophic Sets, Warehouse Rack Systems

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Introduction

The impact of material handling on product costs is substantial, accounting for 30-75% of a product's overall expense. Implementing effective material handling strategies can lead to significant cost reductions in production systems, with potential savings ranging from 15% to 30% (Chan, 2002). In the realm of logistics and production, material handling equipment (MHE) plays a crucial role. Well-designed MHE can enhance operational efficiency, improve product quality, and reduce operational costs, making it a critical consideration for companies (Kučera, 2019). As logistics systems evolve, MHE has become an integral component, with its importance growing across various industries (Onut, 2009). The rapid expansion of warehousing operations has complicated the process of selecting appropriate MHE. Decision-makers face a challenging task in choosing equipment that aligns with industry requirements, given the complexity and breadth of options available. Patel et al. (2022) proposed a classification system for MHE, dividing it into four main categories: industrial trucks, storage systems, conveyor systems, and engineered systems (as illustrated in Figure 1). This categorization helps to organize the diverse range of equipment options available to logistics professionals. In this context, the selection of optimal MHE has become a critical decision point for companies looking to streamline their operations and maintain competitiveness in an increasingly complex logistics landscape.

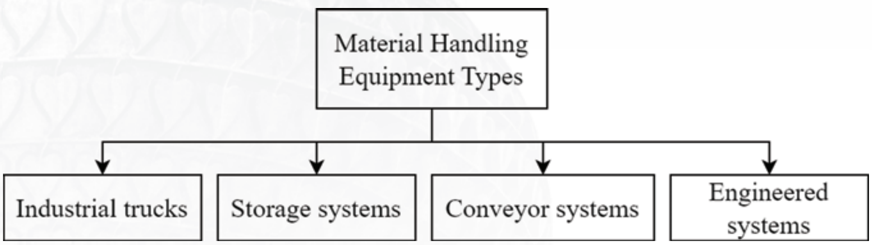

Figure 1 Types of material handling equipment

Note. From "Various types of material handling system," by H. N. Patel, M. Parmar, & D. Bhavsar, 2022, *The International Journal of Creative Research Thoughts*, *10*(3), 50-52 (https://www.ijcrt.org/papers/IJCRT21X0028.pdf).

In addition, the field of material handling equipment (MHE) selection has been extensively studied, with researchers employing various approaches including expert systems, mathematical models, and multi-criteria decision making (MCDM) methods. For instance, Dua (2023) explored the use of crisp numbers in MCDM for forklift selection, while Nguyen et al.

(2016) applied fuzzy AHP and fuzzy ARAS to conveyor equipment selection. Despite the abundance of research on general MHE selection, there's a notable gap in studies specifically addressing storage racking selection as an MHE problem. The complexity of MHE selection calls for sophisticated mathematical approaches. MCDM methods have proven especially effective in navigating the intricacies of selection problems involving multiple, often conflicting criteria that are frequently expressed in different units and scales. These methods assist decision-makers in making informed choices from a wide array of options. MCDM techniques have demonstrated their versatility across various fields, including energy, manufacturing, material selection, automotive industry, supplier selection, and location planning. This wide applicability underscores the potential of MCDM in addressing complex decision-making scenarios. In the context of warehouse management, investing in an appropriate racking system is a critical decision. The selection process extends beyond cost considerations, encompassing various factors that render it a multi-attribute decision-making challenge. To navigate this complexity, decision-makers require a systematic, logical, and scientifically grounded approach. The need for effective evaluation and justification of warehouse storage systems calls for a mathematical tool or method capable of guiding decision-makers towards optimal choices in the face of multiple, often conflicting criteria. Such an approach would provide a robust framework for addressing the nuanced challenges of storage system selection in modern warehousing operations.

Objectives

1. To identify the significant criteria weights for choosing a rack system in warehouse.
2. To choose the optimum rack system in warehouse.
3. To propose a hybrid multicriteria decision making model.

Literature Review

This section discusses comprehensive works related to existing application of multicriteria decision-making (MCDM) approaches, Neutrosophic Sets (NSs), and criteria in material handling equipment systems selection.

1. MCDM approaches in material handling system selection

Over the past three decades, researchers have increasingly focused on applying various Multi-Criteria Decision Making (MCDM) techniques to address material handling equipment selection challenges. Table 1 summarizes a range of studies that have employed diverse methodologies, including expert systems, mathematical models, and MCDM methods.

Table 1 Multicriteria decision-making techniques for material handling equipment selection

Author(s)	Technique(s)	Material handling equipment type			
		Industrial trucks	Storage systems	Conveyor systems	Engineered systems
Nguyen et al. (2016)	Fuzzy AHP-Fuzzy ARAS			/	
Pruša et al. (2018)	TOPSIS	/			
Setiyani and Sukarno (2022)	AHP	/			
Satoglu and Türkekul (2021)	AHP-MOORA				/
Soufi et al. (2021)	AHP	/			
Chatterjee and Chakraborty (2023)	R-method			/	
Ulutaş et al. (2023)	Fuzzy BWM-Fuzzy MCRAT	/			
Sabnis et al. (2024)	WSM				/
Authors (the proposed method)	AHP-NS		/		

In the realm of conveyor selection, Nguyen et al. (2016) proposed an integrated MCDM model combining fuzzy Analytic Hierarchy Process (AHP) with fuzzy Additive Ratio Assessment (ARAS). This approach aimed to enhance the evaluation and selection process for conveyor systems. For forklift system selection, Pruša et al. (2018) utilized the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) model. Their method focused on comparing alternatives based on their proximity to ideal and anti-ideal solutions. In the domain of industrial trucks, Setiyani and Sukarno (2022) applied AHP as an MCDM method to guide purchase decisions. Similarly, Satoglu and Türkekul (2021) developed a selection system for hand pallet trucks using a combination of AHP and Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) to address uncertainties in the decision-making process. Soufi et al. (2021) explored the use of AHP specifically for conveyor equipment selection, while Chatterjee and Chakraborty (2023) investigated the stability and robustness of the R technique in ranking material handling equipment options. More recently, Ulutaş et al. (2023) presented an integrated model that combines fuzzy sets with Best-Worst Method (BWM) and Multi-Criteria Ranking Analysis Technique (MCRAT) to tackle industrial truck selection problems. Sabnis et al. (2024) demonstrated the application of AHP in selecting optimal material handling equipment for specific types of material handling tasks. This diverse body of research illustrates the ongoing efforts to refine and adapt MCDM techniques for various material handling equipment selection scenarios, reflecting the complexity and importance of these decisions in modern logistics and manufacturing environments.

2. The applications of Neutrosophic Sets (NSs) theory

In traditional Multi-Criteria Decision-Making (MCDM) methods, input variables are typically treated as precise and well-defined sets. However, in practical decision-making scenarios, these variables often come as qualitative data. Such qualitative information, which is provided by decision-makers (DMs) or experts, can be conveniently represented using linguistic variables. Due to constraints such as time pressure or limited knowledge, decision-makers opt for linguistic variables to manage imprecise data (Zadeh, 1975). Despite this, classical fuzzy set theory faces challenges in dealing with the ambiguity and inconsistencies inherent in real-world information. It struggles with issues like discontinuities and inconsistencies in the data. To address these limitations, Neutrosophic Set (NS), introduced by Wang et al. (2010), offers a solution. The Neutrosophic Set is designed to handle uncertainty, imprecision, indeterminacy, and inconsistency more effectively than traditional fuzzy sets. Building on this, Majumdar (2015) extended the application of NS by integrating it with soft sets to enhance the processing of uncertain data in decision-making processes.

3. Literature review of criteria for selecting storage systems

The criteria for selecting material handling equipment are determined based on type of racking systems and context of the problem. Table 2 provides definitions relevant to these criteria, and it illustrates which criteria are addressed in each study. By examining Table 2, one can identify the criteria discussed across various studies.

Table 2 Explanation of criteria for choosing rack storage systems

Criteria	Brief definition	Author(s)
Initial cost	The expense associated with purchasing the racking system.	Shin et al. (2023)
Maintenance cost	The ongoing costs required to keep the racking system functional.	Mumali and Kałkowska (2023)
Installation cost	The costs involved in setting up the racking system within the warehouse.	Sequeira (2019)
Height utilisation	The effective use of the available vertical space in the warehouse.	He et al. (2023)
Volume utilisation	The capacity of the storage system to handle and store materials.	He et al. (2023)
FIFO system	A method where the first pallet placed into the racking system is the first to be removed.	Nirmala (2024)
LIFO system	A method where the most recently added pallet is the first to be retrieved.	Sequeira (2019)
Stock cycle speed	The rate at which items are added to and removed from the racks.	Ming and Zheng (2024)
Retrieval speed	The rate at which items can be retrieved using the equipment.	Yanling et al. (2022)
Storage speed	The rate at which items can be stored using the equipment.	Safronov and Nosko (2017)

Methodology

This study examines the selection process for warehouse racking systems, focusing on the relatively underdeveloped aspects of material handling equipment. Data was gathered through a questionnaire directed at decision-makers. The methodology section details the data collection process and describes the approach used to assist in each selection. A multi-criteria decision-making (MCDM) model, specifically a combined AHP-NS model, was employed in this study. The implementation of this model is illustrated in Figure 2.

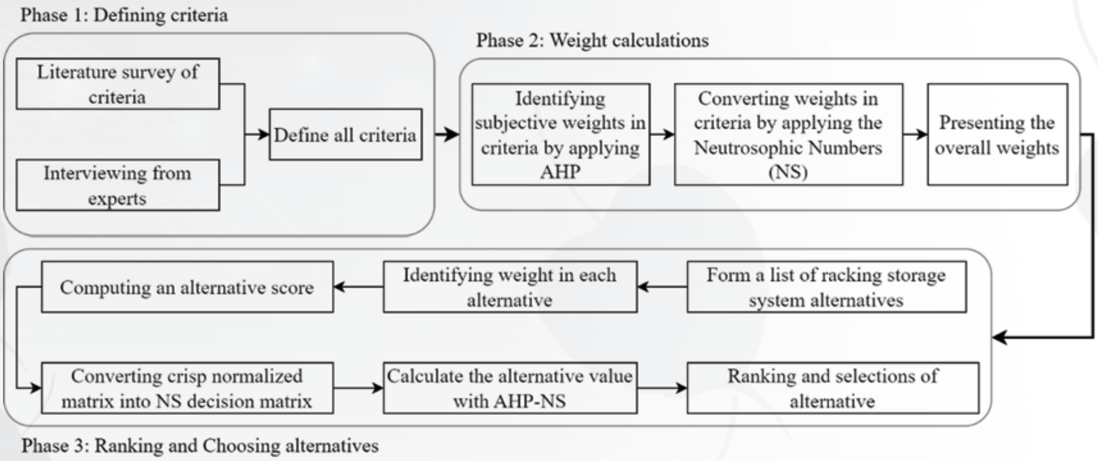

Figure 2 Process of the proposed AHP-NS method

Figure 2 presents a step-by-step process of the proposed Analytic Hierarchy Process-Neutrosophic Set (AHP-NS) method for evaluating and selecting warehouse racking systems. The process can be divided into the following stages:

In the first stage, all criteria are defined. This involves a comprehensive literature survey to identify possible criteria for evaluating racking systems, followed by interviews with subject matter experts to refine and validate the criteria identified from the literature.

In the second stage, weighing the criteria is performed. Subjective weights are assigned to each criterion by applying the Analytic Hierarchy Process (AHP), incorporating expert judgment and preference. These subjective weights are then converted using Neutrosophic Numbers (NS), which allows for handling uncertainty and indeterminacy in the weighting process. Finally, the overall weights for each criterion are presented.

The third stage involves the evaluation and ranking of alternatives. A list of potential racking storage system alternatives is created for evaluation. The weight for each alternative is identified according to the previously established criteria, and a score is computed for each alternative based on these weights. The scores are then normalized and converted into a Neutrosophic Set (NS) decision matrix, enabling further analysis under conditions of indeterminacy. The AHP-NS model is subsequently applied to calculate a final value for each alternative, integrating both the AHP and NS methodologies.

In the fourth and final stage, the alternatives are ranked based on their final values, which facilitates the selection of the most suitable racking storage system. This structured process enables systematic decision-making in the selection of warehouse racking systems, combining subjective expert judgment with quantitative evaluation under conditions of uncertainty.

1. Data collection

This study was carried out at a warehouse provider company located in Samutprakarn. The selection process focused on five distinct categories of racking storage systems. The study employed a stratified random sampling approach for participant selection, with the researcher having a clear understanding of the required sample units. The target population was limited to senior management level over three years' experience from specific departments, namely purchasing, finance, engineering, and warehouse operations. Sample selection was further refined based on the relevance of employees' job responsibilities to warehouse racking operations within the company. The study involved a panel of six randomly chosen experts, as illustrated in Table 3.

Table 3 Detail of decision makers in this study

Position	Top-level manager	Financial manager	Warehouse engineer	Purchasing manager	Operational staff
No. of decision maker	2	1	1	1	1

1. The integrated Analytic Hierarchy Process based on Neutrosophic Sets (AHP-SN)

The Analytic Hierarchy Process (AHP) is recommended for assessing the chosen material handling equipment (MHE) systems due to its ability to offer decision-makers a streamlined and more suitable approach to MHE analysis (Jun, 2014). This method allows for more flexible judgments, which aligns better with natural decision-making processes compared to rigid evaluations. However, a notable limitation of the traditional AHP is its inability to account for the ambiguity inherent in human thought processes. To address this shortcoming, the integration of neutrosophic set theory enhances the flexibility of expert assessments. The methodology for combining neutrosophic set theory with the AHP involves the following steps. The initial step of the proposed approach involves constructing a decision hierarchy that organizes the requirements and available options. At the top level, the overarching goal is positioned, followed by the criteria for evaluation in the middle level, and the alternatives are placed at the bottom level.

The second step involves developing a comparison matrix. This requires establishing neutrosophic preferences by conducting pairwise comparisons between each criterion and its sub-criteria C_j (j=1, 2, ⋯, n). Let a neutrosophic preference relation A be.

$$A=\begin{bmatrix}(T_{11,}I_{11,}F_{11,}) & \cdots & (T_{1n,}I_{1n,}F_{1n,}) \\ \vdots & \ddots & \vdots \\ (T_{n1,}I_{n1,}F_{n1,}) & \cdots & (T_{nn,}I_{nn,}F_{nn,})\end{bmatrix}$$

where (T_{ij}, I_{ij}, F_{ij}) indicates the relative preference of the criterion Ci to the criterion C_j with the conditions, $T_{ij}, I_{ij}, F_{ij} \in [0,1]$. The intervals T_{ij}, I_{ij}, F_{ij} represent the truth-membership degree, the indeterminacy membership degree and the falsity membership degree.

In the subsequent phase, a pairwise comparison of alternatives is constructed using neutrosophic numbers, aligning with the Saaty scale as depicted in Table 4.

The third step involves the calculation of relative normalized weights. This process allows for the application of varying weights to sub-criteria and factors, based on diverse input data, enabling the derivation of appropriate weightings.

The fourth step entails a consistency verification. A Consistency Ratio (CR) value below 0.1 is deemed acceptable, validating the judgment matrix. The methodology for CR assessment, as adapted by Radwan et al. (2016) in Eq. (1) for neutrosophic applications, is employed in this process.

$$CR = \frac{1}{2(n-1)(n-2)} * \sum_{i=1}^{n} \sum_{j=1}^{n} \left(\left| T'_{ij}-T_{ij} \right| + \left| I'_{ij}-I_{ij} \right| + \left| F'_{ij}-F_{ij} \right| \right) \quad (1)$$

Table 4 Scale of preference between two parameters in AHP-NS

Linguistic Terms	Numerical scales	Neutrosophic Triangular Scale	Explanation
Absolute Importance	9	$\tilde{9}=\langle(9, 9, 9); 1.00, 0.00, 0.00\rangle$	An activity is considered significantly superior
Strong Importance	7	$\tilde{7}=\langle(6, 7, 8); 0.90, 0.10, 0.10\rangle$	An activity is distinctly favored over another

Table 4 Scale of preference between two parameters in AHP-NS (continued)

Linguistic Terms	**Numerical scales**	**Neutrosophic Triangular Scale**	**Explanation**
Moderate Importance	5	$\tilde{5}=\langle(4, 5, 6); 0.80, 0.15, 0.20\rangle$	One activity is favored over another based on substantial experience and judgment.
Slight Importance	3	$\tilde{3}=\langle(2, 3, 4); 0.30, 0.75, 0.70\rangle$	One activity is marginally preferred over another, as indicated by experience and judgment.
Equal Importance	1	$\tilde{1}=\langle(1, 1, 1); 0.50, 0.50, 0.50\rangle$	Both activities are deemed equally valuable in achieving the objective.
Intermediate Importance	2 4 6 8	$\tilde{2}=\langle(1, 2, 3); 0.40, 0.65, 0.60\rangle$ $\tilde{4}=\langle(3, 4, 5); 0.60, 0.35, 0.40\rangle$ $\tilde{6}=\langle(5, 6, 7); 0.70, 0.25, 0.30\rangle$ $\tilde{8}=\langle(7, 8, 9); 0.85, 0.10, 0.15\rangle$	Represents compromises between the preference weights of 1, 3, 5, 7, and 9.
Reciprocals	Opposites		Applied for inverse comparisons between activities.

The fifth step is to defuzzified Neutrosophic weights of criteria using Eq. (2)

$$S(N_1) = (3+t_1-2i_1-f_1)/4 \tag{2}$$

, where N_1 is a single valued neutrosophic number, the score function is convert into the single crisp output as $S(N_1)$.

The sixth step, the weights of deneutrospohied weights are normalized and their sum must equal to 1.

Finally, ranking the highest score are the optimum alternatives to select.

Numerical Example

To demonstrate and validate the AHP-NS for choosing a warehouse racking system, a case study is presented. The following description outlines the comprehensive process of applying this hybrid methodology to storage system selection.

Step1: The hierarchical framework of the warehouse racking selection is shown in Figure 3.

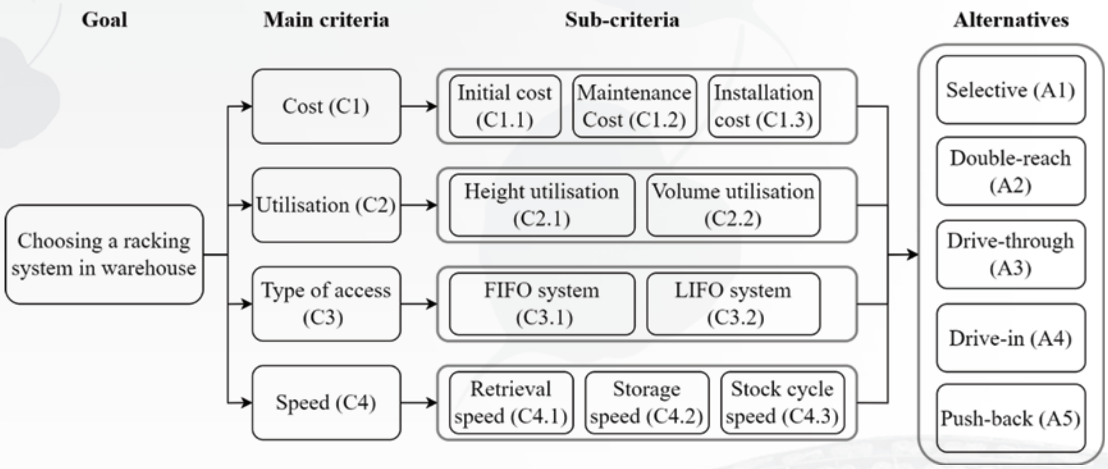

Figure 3 AHP structure for selecting warehouse rack systems

Figure 3 shows that the code names in various criteria can be explained as follows.

AAAA (B.x)

Criterion name

Criteria dimension

x = sub-criteria level 1

For example, Initial cost (C1.1)

Criterion name = Initial cost

Criteria dimension = C (Cost dimension)

x = 1 (sub-criteria level 1 in 1st main criteria or Cost dimension)

Step 2: The pair-wise comparison matrix for the main criteria and sub-criteria is presented in the example shown in Tables 5 and 6.

Table 5 The neutrosophic comparison matrix of main criteria

Main criteria	C1	C2	C3	C4
C1	$\tilde{1}$	$1/\tilde{3}$	$\tilde{2}$	$\tilde{2}$
C2	$\tilde{3}$	$\tilde{1}$	$\tilde{4}$	$\tilde{4}$
C3	$1/\tilde{2}$	$1/\tilde{4}$	$\tilde{1}$	$1/\tilde{2}$
C4	$1/\tilde{2}$	$1/\tilde{4}$	$\tilde{2}$	$\tilde{1}$

Table 6 The neutrosophic comparison matrix of sub-criteria under cost dimension (C1)

C1 (Cost)	C1.1	C1.2	C1.3
C1.1	$\tilde{1}$	$1/\tilde{5}$	$\tilde{9}$
C1.2	$\tilde{5}$	$\tilde{1}$	$1/\tilde{3}$
C1.3	$1/\tilde{9}$	$\tilde{3}$	$\tilde{1}$

Step3: To obtain the neutrosophic weights of the criteria, the normalized comparison matrix and the calculated weights are presented in Tables 7 and 8.

Table 7 Pairwise comparison matrix with respect in main criteria

Main criteria	C1	C2	C3	C4
C1	(0.50,0.50,0.50)	(0.25,0.75,0.75)	(0.40,0.65,0.60)	(0.40,0.65,0.60)
C2	(0.75,0.25,0.25)	(0.50,0.50,0.50)	(0.60,0.35,0.40)	(0.60,0.35,0.40)
C3	(0.60,0.35,0.40)	(0.40,0.65,0.60)	(0.50,0.50,0.50)	(0.60,0.35,0.40)
C4	(0.60,0.35,0.40)	(0.40,0.65,0.60)	(0.40,0.65,0.60)	(0.50,0.50,0.50)
Weight (W)	(0.42,0.59,0.57)	(0.64,0.33,0.36)	(0.56,0.41,0.43)	(0.48,0.54,0.52)

Table 8 Pairwise comparison matrix for the sub criteria under cost (C1)

C1 (Cost)	C1.1	C1.2	C1.3	Weight (W)
C1.1	(0.50,0.50,0.50)	(0.75, 0.25, 0.25)	(0.40, 0.65, 0.60)	(0.42,0.59,0.57)
C1.2	(0.25,0.75,0.75)	(0.50,0.50,0.50)	(0.60, 0.35, 0.40)	(0.33,0.66,0.66)
C1.3	(0.60, 0.35, 0.40)	(0.40, 0.65, 0.60)	(0.50,0.50,0.50)	(0.47,0.54,0.52)

Step4: According to equation (1), Consistency Ratio (CR) which is advanced by Xu et al., (2014) is applied to calculate consistent preference relations.

Consistency Ratio in Cost (CR_{C1})

$$= \frac{1}{2(4-1)(4-2)} \sum_{x=1}^{n} . \sum_{x=1}^{n} . \left(\left|12.41\text{-}12.41\right| + \left|12.41\text{-}12.41\right| + \left|12.41\text{-}12.41\right|\right) = 0.0 < 0.1$$

Results

1. Weighting of the warehouse racking systems criteria

The selection of the appropriate racking storage systems depends on factors such as cost, utilization, type of access, and speed. The overall weights of the main criteria and sub-criteria are presented in Table 9.

Table 9 The overall score of various criteria

Main criteria	Weight	Sub-criteria	Local weight	Global weight (%)
Cost (C1)	0.250	Initial cost (C1.1)	0.49	12.3
		Maintenance cost (C1.2)	0.16	4.0
		Installation cost (C1.3)	0.35	8.8
Utilisation (C2)	0.308	Height utilisation (C2.1)	0.53	16.4
		Volume utilisation (C2.2)	0.47	14.6
Type of access (C3)	0.100	FIFO system (C3.1)	0.56	3.9
		LIFO system (C3.2)	0.44	3.1
Speed (C4)	0.368	Retrieval speed (C4.1)	0.56	20.7
		Storage speed (C4.2)	0.11	4.1
		Stock cycle speed (C4.3)	0.33	12.2

Based on the AHP-NS method calculations, the results indicate that the Speed (C4) criterion holds the greatest weight, followed by Cost (C1), Utilisation (C3), and Type of Access (C2) criteria, as illustrated in Figure 4.

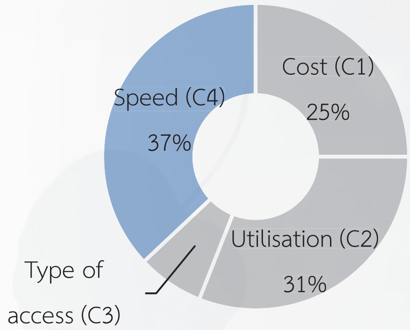

Figure 4 The importance weight of main criteria

According to the findings, the sub-criteria in global weight was determined as follows: Retrieval speed ($w_{C4.1}$ = 0.207), Height utilisation ($w_{C2.1}$ = 0.164), Volume utilisation ($w_{C2.2}$ = 0.146), Initial cost ($w_{C1.1}$ = 0.123), Stock cycle speed ($w_{C4.3}$ = 0.122), Installation cost ($w_{C1.3}$ = 0.088), Storage speed ($w_{C4.2}$ = 0.040), Maintenance cost ($w_{C1.2}$ = 0.040), FIFO system ($w_{C3.1}$ = 0.039) and, LIFO system ($w_{C3.2}$ = 0.031). Figure 5 presents the overall sub-criteria for selecting a racking system.

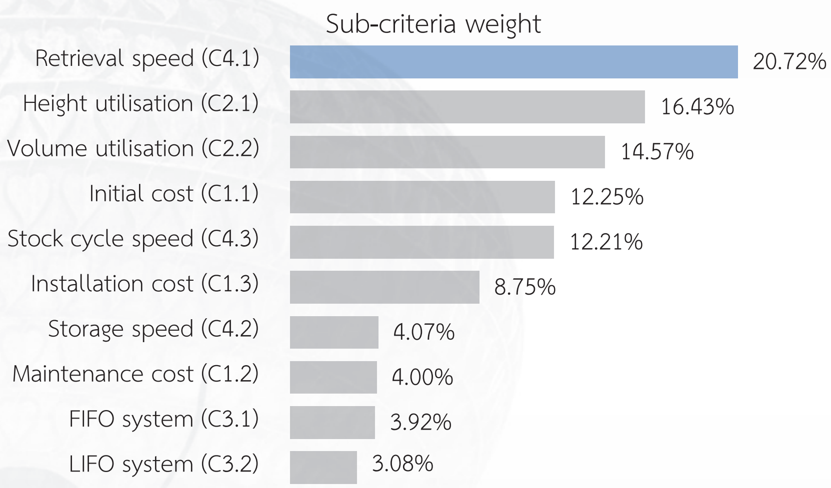

Figure 5 The importance weight of sub-criteria

2. Selection of warehouse racking systems ranking

The alternative ranking is performed utilizing the AHP-NS methodology. According to the multi-criteria scores provided in Table 10, the ratings for each warehouse racking system alternative are displayed.

Table 10 The scores of each alternative among criteria

Sub-criteria	Alternatives				
	Selective (A1)	Double-reach (A2)	Drive-in (A3)	Drive-through (A4)	Push-back (A5)
C1.1	0.636	0.636	0.455	0.636	0.462
C1.2	0.727	0.727	0.545	0.818	0.462
C1.3	0.818	0.727	0.545	0.818	0.538
C2.1	0.818	0.636	0.727	0.545	0.385
C2.2	0.818	0.727	0.545	0.818	0.538
C3.1	0.909	0.727	0.636	0.818	0.769
C3.2	0.545	0.909	0.545	0.818	0.769
C4.1	0.818	0.545	0.909	0.545	0.615
C4.2	0.545	0.545	0.636	0.909	0.615
C4.3	0.636	0.545	0.909	0.545	0.769

The relative ranking scores for each alternative are calculated as follows.

Score $A1_{Selective\ rack} = w_{C1.1}*A1_{C1.1} + w_{C1.2}*A1_{C1.2} + w_{C1.3}*A1_{C1.3} + w_{C2.1}*A1_{C2.1} + w_{C2.2}*A1_{C2.2} + w_{C3.1}*A1_{C3.1} + w_{C3.2}*A1_{C3.2} + w_{C4.1}*A1_{C4.1} + w_{C4.1}*A1_{C4.2} + w_{C4.2}*A1_{C4.2} + w_{C4.3}*A1_{C4.3}$ =(0.636*0.123) + (0.727*0.040) + (0.818*0.088) + (0.818*0.164) + (0.818*0.145) + (0.909*0.039) + (0.545*0.031) + (0.818*0.207) + (0.545*0.041) + (0.636*0.122) = 0.754

Table 11 presents the storage systems rating matrix for each criterion.

Table 11 Ranking of warehouse rack systems

Racking systems	Selective (A1)	Double-reach (A2)	Drive-in (A3)	Drive-through (A4)	Push-back (A5)
Weight	0.754	0.640	0.691	0.665	0.564
Ranking	1	4	2	3	5

According to Table 11 and Figure 6, the ranking order of five alternatives is A1>A3>A4>A2>A5

Thus, Selective rack system (A1) is the optimal alternative racking system.

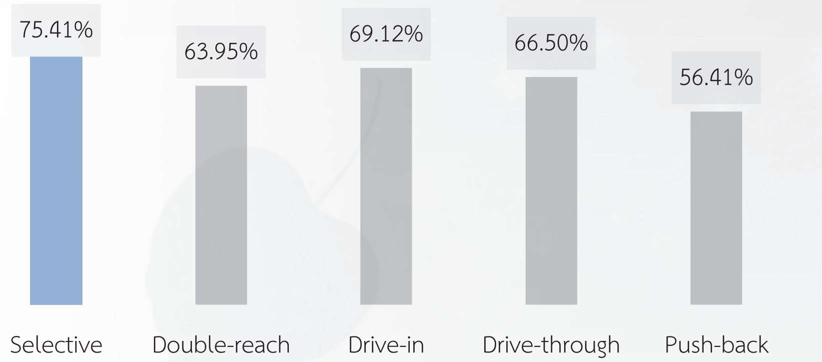

Figure 6 An alternative score for each racking system

The findings indicate that employing neutrosophic sets for warehouse racking selection offers advantages over fuzzy and intuitionistic fuzzy logic approaches. This method more accurately reflects human thought processes, as it addresses limitations in other approaches. Specifically, fuzzy logic lacks the ability to express falsehood membership, while intuitionistic fuzzy logic struggles to handle information indeterminacy. The study demonstrates the practical application of AHP-NS in decision-making scenarios. It's important to note that alterations in priorities and objectives can lead to different outcomes. Shifts in priorities will consequently affect the resulting scores. Based on the current set of priorities outlined in the criteria and sub-criteria, the analysis concludes that the Selective rack system emerges as the optimal choice.

Conclusion

In the application of the AHP-NS methodology, the primary criteria were weighted as follows: cost (25%), utilization (31%), type of access (7%), and speed (37%). Among the sub-criteria influencing storage rack system selection for the case study warehouse, retrieval speed emerged as the most significant factor (20.72%), followed by height utilization (16.43%) and volume utilization (14.57%). The analysis concluded that the selective rack system was the most suitable option for the warehouse under consideration. However, it's important to note that this study's scope was confined to a single warehouse environment. To enhance the breadth of findings, future research could extend the application to fulfilment centres, allowing for comparative analysis. Additionally, we propose that subsequent studies consider contrasting the outcomes of this warehouse racking selection problem with solutions derived from Single-Valued Neutrosophic Sets and Fuzzy AHP methodologies. This comparative approach could provide valuable insights into the relative efficacy of different decision-making tools in this context.

Discussion

The weights assigned to main criteria in warehouse racking selection vary with the weighting method, consistent with findings by Patel et al. (2022) and Nguyen et al. (2016). Retrieval speed (C4.1) is the most critical sub-criterion (20.72%), highlighting the emphasis on efficient item retrieval for productivity. Height utilization (C2.1) and volume utilization (C2.2) are also significant, stressing the need for optimal space usage, while initial cost (C1.1) and stock cycle speed (C4.3) further reflect the balance between cost and inventory turnover, aligning with Sequeira (2019) and Sabnis et al. (2024). The criteria's importance remains consistent across multi-criteria decision-making methods, as noted by Soufi et al. (2021). Among alternatives, selective racking scores highest (75.41%) due to its accessibility and flexibility. Drive-in (69.12%) and drive-through (66.50%) follow, balancing density and accessibility, while double-reach (63.95%) and push-back (56.41%) rank lower due to limited selectivity.

Recommendation

This study underscores the efficacy of neutrosophic sets in warehouse racking selection, prompting a recommendation for warehouse management professionals to integrate this approach into their decision-making frameworks. The method provides a more sophisticated representation of cognitive processes, effectively addressing the shortcomings inherent in fuzzy and intuitionistic fuzzy logic systems. Although the study identified the selective rack system as the optimal choice for the specific case study warehouse, it is crucial for organizations to conduct individualized assessments based on their unique priorities and operational environments. The adaptability of the AHP-NS methodology facilitates tailored applications to meet the distinct requirements of each warehouse facility. To bridge the existing research gap, we advocate for enhanced collaboration between academic researchers and industry experts. This partnership could foster the development of more comprehensive and practically applicable models for material handling equipment selection.

References

Chan, F. T. S. (2002). Design of material handling equipment selection system: An integration of expert system with analytic hierarchy process approach. *Integrated Manufacturing Systems*, *3*(1), 58-68. https://shorturl.asia/IZnPN

Chatterjee, S. & Chakraborty, S. (2023). Application of the R method in solving material handling equipment selection problems. *Decision Making: Applications in Management and Engineering*, *6*(2), 74–94. https://shorturl.asia/24scd

Dua, T. V. (2023). Forklift selection by multi-criteria decision-making methods. *Eastern-European Journal of Enterprise Technologies*, *5*(3), 95–101. https://shorturl.asia/y271a

He, M., Guan, Z., Wang, C. & Hou, G. (2023). Multiple-Rack Strategies Using Optimization of Location Assignment Based on MRCGA in Miniload Automated Storage and Retrieval System. *Processes*, *11*(3), 950. https://doi.org/10.3390/pr11030950

Jun, Y. (2014). A multi criteria decision-making method using aggregation operators for simplified Neutrosophic Sets. *Journal of Intelligent & Fuzzy Systems*, *26*(5), 2459-2466. https://doi.org/10.3233/IFS-130916

Kučera, T., (2019). Application of the activity-based costing to the logistics cost calculation for warehousing in the automotive industry. *Communications-Scientific Letters of the University of Zilina, 21*(4), 35–42. https://shorturl.asia/Y5NRP

Majumdar, P. (2015). Neutrosophic sets and its applications to decision making. In D. P. Acharjya, S. Dehuri, S. Sanyal. (Eds.). *Computational Intelligence for Big Data Analysis: Frontier Advances and Applications* (pp. 97–115). Springer. https://shorturl.asia/RuFan

Ming, Z. & Zheng, W. (2024). Optimizing rack locations in the mobile-rack picking system: A method of integrating rack heat and relevance, *Mathematics*, *12*(3), 413. https://shorturl.asia/zx4kp

Mumali, F. & Kałkowska, J. (2023). Intelligent support in manufacturing process selection based on artificial neural networks, fuzzy logic, and genetic algorithms: Current State and future perspectives. *Computers & Industrial Engineering*, *193*, 1-20. https://shorturl.asia/LnP2l

Nguyen, H. T., Md Dawal S. Z., Nukman Y., P. Rifai A., & Aoyama H. (2016). An integrated MCDM Model for conveyor equipment evaluation and selection in an FMC based on a Fuzzy

AHP and Fuzzy ARAS in the presence of vagueness. *PLoS ONE*, *11*(4), 1-26. https://shorturl.asia/XLDNH

Nirmala, I. (2024). FIFO Method Improvement and Adjustment Design for PT. ABC Warehouse Plans. *Journal Ilmiah Manajemen Kesatuan*, *12*(3), 637–648. https://shorturl.asia/zw5VS

Onut, S., Kara, S. S. & Mert, S. (2009). Selecting the suitable material handling equipment in the presence of vagueness. *The International Journal of Advanced Manufacturing Technology*, *44*, 818–828. https://shorturl.asia/sxae4

Patel, H. N., Parmar,M. & Bhavsar, D. (2022). Various types of material handling system. *The International Journal of Creative Research Thoughts*, *10*(3), 42-69. https://shorturl.asia/qkQ1A

Pruša, P., Jovčić, S., Nemec, V. & Mrázek, P. (2018). Forklift truck selection using TOPSIS method. *International Journal for Traffic and Transport Engineering*, *8*(3), 290-398. https://shorturl.asia/Hkcwr

Radwan,N., Senousy, M. B. & Riad, M. (2016). Neutrosophic Logic Approach for Evaluating Learning Management. *Neutrosophic Sets and Systems*, *11*, 3-7. https://shorturl.asia/1Rfvq

Sabnis, D., Patil, M., & Wankhede, S. (2024). Selection of automated guided vehicles for industrial application using weighted sum method. *Lecture notes in electrical engineering*, 357–365. https://shorturl.asia/cG5K2

Safronov, E. & Nosko, A. (2019). A method to determine allowable speed for a unit load in a pallet flow rack. *Acta Mechanica et Automatica, 13*(2)*, 80-85.* https://doi.org/10.2478/ama-2019-0011

Satoglu, S. I. & Türkekul, I. (2021). Selection of material handling equipment using the AHP and MOORA. *Journal Teknik Industry*, *22*(1), 113-124. https://shorturl.asia/t7qvn

Sequeira, A. A. (2019). A mathematical programming model to determine a suitable pallet storage system to improve storage space utilization. *Journal of Research and Development*, *4*(1), 50-61. https://doi.org/10.12816/0052834

Setiyani, D .R. & Sukarno, I. (2022). Material handling equipment selection using Analytical Hierarchy Process (AHP) method. *Journal Logistics Indonesia*, *6*(2), 91- 100. https://shorturl.asia/45FYe

Shin, D. Y., Lee, J. & Seok, H. (2023). A study of layout determination of mobile rack warehouse. *AIMS Environmental Science, 10*(4), 467-477. https://shorturl.asia/hUK3N

Soufi, Z., David, P. & Yahouni, Z. (2021). A methodology for the selection of material handling equipment in manufacturing systems. *IFAC-PapersOnLine*, *54*(1), 122-127. https://shorturl.asia/uDy7g

Ulutaş, A., Topal, A., Karabasevic, D. & Balo, F. (2023). Selection of a forklift for a cargo company with Fuzzy BWM and Fuzzy MCRAT methods. *Axioms*, *12*(5), 467. https://shorturl.asia/4tl1O

Wang, H., Smarandache, F., Zhang, Y., & Sunderraman, R. (2010). Single valued neutrosophic sets. In F. Smarandache (Eds.). *Neutrosophic Transdisciplinarity (100 Collected Papers of Sciences)* (Vol. IV, pp. 410-413)., North-European Scientific. https://shorturl.asia/UZSvd

Xu, Z. & Liao, H. (2014). Intuitionistic fuzzy analytic hierarchy process. *IEEE Transactions on Fuzzy Systems*, *22*(4), 749-761. https://shorturl.asia/9wqWD

Yanling, Z., Yun, Z., Hassini, E., Yufei, Y., & Xiangpei, H. (2022). Rack retrieval and repositioning optimization problem in robotic mobile fulfillment systems. *Transportation Research Part E: Logistics and Transportation Review*, 167, 102920. https://doi.org/10.1016/j.tre.2022.102920

Zadeh, L. A. (1975). Fuzzy logic and approximate reasoning (In Memory of Grigore Moisil). *Synthese*, *30*(3/4), 407-428. https://www.jstor.org/stable/20115038