A Multi Criteria Decision-Making Model for Selecting Sustainable Forklifts: A Case Study of a Warehouse Company in Nakhon Pathom Province

Napat Srinual[1] Rapee Udomsub[2] and Patchara Phochanikorn[3,*]

Received: August 1,2025 Revised: October 20,2025 Accepted: November 7,2025

Abstract

Sustainable logistics is currently vital for enhancing competitive advantage, yet warehouse companies face significant challenges in selecting material handling equipment that balances economic, environmental, and social criteria. This complexity often leads to decisions based on incomplete assessments, highlighting a gap in structured, holistic evaluation models. Therefore, the objective of this study is to develop and validate a hybrid multi-criteria decision-making (MCDM) framework for sustainable forklift selection in the context of a Thai warehouse company. The proposed model integrates the Stepwise Weight Assessment Ratio Analysis (SWARA) for weighting fifteen sub-criteria across three sustainability dimensions, and the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) for ranking four forklift alternatives. Data were gathered from ten experts, including managers and operators. The findings reveal that the economic dimension (41%) is prioritized over the environmental (32%) and social (27%) dimensions. Specifically, 'purchase cost,' 'energy efficiency,' and 'operator safety' were the most influential sub-criteria. The Electric Forklift Model 2 (ETFL2) was identified as the optimal sustainable alternative with an overall preference score of 0.852. This research provides a practical, data-driven decision support tool for managers to justify sustainable investments and contributes a validated application of the SWARA-FTOPSIS model to sustainable logistics.

Keywords: Forklift selection, SWARA, Fuzzy TOPSIS, Multi criteria decision making, Sustainability

[1,2] Faculty of Logistics and Transportation Management, Panyapiwat Institute of Management

[3] Rattanakosin International College of Creative Entrepreneurship, Rajamangala University of Technology Rattanakosin

*Corresponding author. E-mail: Patchara.pho@rmutr.ac.th

การพัฒนาแบบจำลองการตัดสินใจแบบหลายเกณฑ์ เพื่อการเลือกใช้รถยกอย่างยั่งยืน กรณีศึกษา ผู้ให้บริการคลังสินค้าพร้อมจัดส่งในจังหวัดนครปฐม

ณภัทร ศรีนวล[1] รฟี อุดมทรัพย์[2] และพัชรา โพชะนิกร[3,*]

วันรับบทความ: August 1,2025 วันแก้ไขบทความ: October 20,2025 วันตอบรับบทความ: November 7,2025

บทคัดย่อ

ความยั่งยืนทางด้านโลจิสติกส์ในปัจจุบันมีความสำคัญอย่างยิ่งต่อการเพิ่มขีดความสามารถในการแข่งขัน อย่างไรก็ตาม ผู้ให้บริการคลังสินค้ายังคงเผชิญความท้าทายในการเลือกอุปกรณ์เคลื่อนย้ายวัสดุที่ยั่งยืน โดยเฉพาะรถยกซึ่งส่งผลกระทบต่อมิติทางเศรษฐกิจ สิ่งแวดล้อม และสังคม สำหรับงานภายในคลังสินค้าพร้อมจัดส่ง งานวิจัยนี้นำเสนอแบบจำลองการตัดสินใจหลายเกณฑ์แบบบูรณาการที่ผสมผสานการวิเคราะห์อัตราส่วนการประเมินน้ำหนักแบบขั้นตอนหรือที่เรียกว่า วิธี SWARA และเทคนิคฟัซซีสำหรับลำดับความชอบตามความคล้ายคลึงกับทางออกที่เหมาะสมที่สุดหรือที่เรียกว่า วิธี FTOPSIS เพื่อประเมินและคัดเลือกรถยกที่ยั่งยืน แบบจำลองประกอบด้วยเกณฑ์หลัก 3 มิติ 15 เกณฑ์ย่อย และทางเลือกรถยก 4 รุ่น โดยใช้วิธี SWARA ในการกำหนดน้ำหนักสัมพัทธ์ของเกณฑ์ และ FTOPSIS ในการจัดลำดับความสำคัญของทางเลือก การศึกษาเก็บข้อมูลจากผู้มีส่วนได้ส่วนเสีย 10 คน ใน 4 กลุ่มจากผู้ให้บริการคลังสินค้าในจังหวัดนครปฐม ประเทศไทย ผลการศึกษาพบว่า มิติทางเศรษฐกิจมีความสำคัญสูงสุด (ร้อยละ 41) รองลงมาคือมิติสิ่งแวดล้อม (ร้อยละ 32) และมิติสังคม (ร้อยละ 27) ตามลำดับ ในส่วนของทางเลือกที่คะแนนรวมสูงสุดคือรถยกไฟฟ้ารุ่น ETFL2 (0.852) โดยงานวิจัยนี้มีส่วนช่วยพัฒนาองค์ความรู้ด้านโลจิสติกส์ยั่งยืนโดยนำเสนอเครื่องมือสนับสนุนการตัดสินใจที่ผ่านการตรวจสอบความถูกต้องซึ่งสามารถประยุกต์ใช้สนับสนุนการลงทุนที่ยั่งยืนในอุตสาหกรรมโลจิสติกส์และการจัดการคลังสินค้าได้อย่างมีประสิทธิภาพ

คำสำคัญ: การเลือกรถยก วิธี SWARA วิธี Fuzzy TOPSIS การตัดสินใจแบบหลายเกณฑ์ ความยั่งยืน

[1,2] คณะการจัดการโลจิสติกส์และการคมนาคมขนส่ง สถาบันการจัดการปัญญาภิวัฒน์

[3] วิทยาลัยผู้ประกอบการสร้างสรรค์นานาชาติรัตนโกสินทร์ มหาวิทยาลัยเทคโนโลยีราชมงคลรัตนโกสินทร์

*Corresponding author. E-mail: Patchara.pho@rmutr.ac.th

Introduction

The rapid expansion of e-commerce and the increasing complexity of global supply chains have significantly transformed the logistics landscape. This has catalyzed immense growth in Thailand's logistics sector, which now constitutes a significant 13.5% of the nation's GDP (NESDC, 2024). Especially for warehouse service providers in Thailand, these companies must now manage large volumes of orders with high levels of accuracy, speed, and adaptability, all while maintaining operational efficiency and minimizing environmental impact. In this context, material handling equipment, particularly forklifts, plays a crucial role in supporting warehouse productivity and service performance (Fazlollahtabar et al., 2019). Historically, internal combustion engine forklifts powered by diesel or LPG have been the backbone of warehouse operations. Study indicates that they can be directly responsible for a warehouse's CO_2 emissions (Ziółkowski et al., 2022). However, Pipawakorn and Pasunon (2023) stated that growing environmental concerns and tightening regulations have led to a shift toward more sustainable alternatives such as electric and hydrogen-powered forklifts (Zajac & Rozic, 2022). These technologies offer significant advantages in terms of emissions reduction, noise control, and operational costs, but they also introduce new challenges. These include high initial investment, charging infrastructure requirements, and battery life limitations (Huang et al., 2021). As such, selecting the appropriate forklift type is a complex decision involving multiple criteria, including environmental performance, operational capability, economic feasibility, and organizational readiness. To address such complexity, MCDM techniques have gained popularity as robust tools that enable decision-makers to evaluate alternatives across a diverse set of criteria, often under conditions of uncertainty or subjectivity (Govindan et al., 2015). MCDM models have been widely applied in various sustainable logistics decisions, including green supplier selection (Kannan et al., 2013), energy-efficient transportation planning (Mohammadpour et al., 2024), and renewable energy system evaluation (Hendiani & Walther, 2023). However, there remains a notable gap in the literature regarding their application to forklift selection, particularly in Southeast Asian logistics contexts where sustainability priorities are still emerging (Ortiz-Barrios et al., 2021). This study aims to address this gap by developing an MCDM-based model for selecting sustainable forklifts, using a case study of a warehouse service provider located in Nakhon Pathom, Thailand. The model integrates a comprehensive set of quantitative and qualitative criteria. These include lifecycle cost, emissions, energy consumption, operational reliability, and compatibility with existing warehouse infrastructure. Importantly, the framework also accounts for the inherent uncertainties in these factors and the ambiguity within expert judgments. The case company operates in a dynamic logistics environment that reflects broader trends in Thailand's industrial growth and environmental policy development. The primary contribution of this research lies in its practical integration of MCDM techniques with sustainable equipment selection for logistics operations. The proposed model not only offers a structured approach for evaluating trade-offs among forklift technologies but also provides actionable insights for managers and officers seeking to balance performance with environmental responsibility.

Literature Review

Sustainable forklift selection

Sustainable forklift selection has become an increasingly important topic in logistics and warehouse operations, particularly as firms aim to align their material handling equipment with environmental and operational goals. Traditionally, internal combustion engine forklifts dominate the market due to their durability and cost-effectiveness. However, electric and hydrogen-powered alternatives are gaining traction due to their lower environmental impact and reduced operational costs (Prusa et al., 2018; Mei & Chen, 2021). Early studies, such as those by Huskanović et al. (2023) and Dua (2023), primarily focused on the economic dimension, reflecting traditional procurement priorities that prioritized cost-effectiveness above all. Recognizing the growing importance of green logistics, more recent work by Chakraborty and Saha (2024) expanded this scope to integrate both economic and environmental factors. However, as summarized in Table 1, a comprehensive model that systematically integrates all three pillars of sustainability economic, environmental, and social within a single, unified decision framework remains a gap in the literature. This study directly addresses this gap by proposing a holistic model that considers all three dimensions concurrently, providing a more balanced and truly sustainable selection process.

Table 1 Classification of forklift selection studies ("/" = applies and "X" = does not consider)

Author (Year)	Sustainability dimensions			Country
	Economic	Environment	Social	
Huskanović et al. (2023)	/	X	X	Serbia
Dua (2023)	/	X	X	Vietnam
Chakraborty and Saha (2024)	/	/	X	India

Source: Analyzed and concluded by the author

Criteria for selecting a sustainable forklift

By giving less attention to sustainable dimensions in forklift selection, current studies have identified different issues. Nonetheless, the sustainable requirements will be highly subjective and differ from country to country. The literature reviews and surveys conducted by experts describe the various criteria for Thailand. The criteria are summarized in Table 2.

Table 2 Definition and types of criteria for sustainable forklift selection

Main criteria	Sub criteria	Definition	Type of criterion
Economic (EC)	Purchase cost (EC1)	Initial acquisition cost of the forklift, including price and delivery expenses.	Cost
	Operating cost (EC2)	Costs incurred directly from daily use of the forklift, including expenses for fuel, electricity, and other consumables required for material handling tasks.	Cost
	Maintenance cost (EC3)	Costs associated with keeping the forklift in optimal working condition, encompassing both preventive and corrective maintenance.	Cost
	Lifespan (EC4)	Expected operational lifetime of the forklift before replacement is needed.	Benefit
	Resale value (EC5)	Estimated residual value or trade-in price at the end of useful life.	Benefit

Main criteria	Sub criteria	Definition	Type of criterion
Environmental (EN)	Energy efficiency (EN1)	The forklift's ability to use energy efficiently, reducing consumption per unit of work done.	Benefit
	Waste generation (EN2)	Amount of hazardous or non-hazardous waste produced during operation and disposal.	Cost
	Noise pollution (EN3)	Level of noise generated by the forklift during operation, impacting work environment.	Cost
	Use of sustainable materials (EN4)	Degree to which eco-friendly or recyclable materials are used in forklift manufacturing.	Benefit
	Emissions (EN5)	Amount of greenhouse gases and pollutants emitted during forklift operation.	Cost
Social (SC)	Operator safety (SC1)	Features ensuring safety of forklift operators (e.g., stability, ergonomic design, safety alarms).	Benefit
	Ease of operation (SC2)	User-friendliness of controls and systems minimizing operator fatigue and errors.	Benefit
	Training requirements (SC3)	Level of complexity and time needed to train operators for safe and effective forklift use.	Benefit
	Impact on workplace health (SC4)	Influence on workers' health is beyond operators, such as emissions or ergonomic effects.	Benefit
	Community Impact (SC5)	Effects on the local community, including noise, air quality, and social acceptance.	Benefit

Source: Analyzed and concluded by the author

An existing application of MCDM in forklift selection

Recent studies have extended MCDM applications to sustainable logistics planning, addressing topics such as green vehicle routing, sustainable supplier selection, and warehouse site location (Streimikiene et al., 2024). However, research explicitly focusing on sustainable forklift selection within warehouse centers remains limited. This underscores the need for a structured, context-sensitive model that integrates practical constraints with sustainability indicators. The literature suggests a gap in context specific MCDM models for forklift selection particularly in Southeast Asian logistics settings where environmental regulations, market readiness, and operational priorities differ from Western contexts (Görçün et al., 2024). This study contributes to closing that gap through a practical model developed and applied within a warehouse service in Nakhon Pathom, Thailand.

Table 3 Drawbacks of existing MCDM methods in forklift selection

Method	Drawbacks	Author(s)
FUCOM – MOORA	- Subjective weighting from FUCOM, cumbersome with many criteria. - MOORA is sensitive to normalization and ignores criteria for interdependence.	Brauers and Zavadskas (2006), Pamucar et al. (2018)
CRITIC – MARCOS	- Lacks expert input (CRITIC's objective weighting) and sensitive to data correlation. - MARCOS has complex interpretation and depends heavily on ideal and anti-ideal solutions.	Stevic et al. (2020)
Entropy – COCOSO – PIV	- No expert involvement (Entropy) and sensitive to data variability. - COCOSO involves complex aggregation, and PIV (if less common) is less validated and transparent.	Dua (2023)

Source: Analyzed and concluded by the author

Justification for the Proposed Hybrid MCDM Framework

As the literature review demonstrates, the number of recent studies is very few. Moreover, there is a clear drawback in the publications as shown in Table 3. The reason why fuzzy sets theory is preferred is based on the ability of these sets in accounting for the inconsistency and uncertainty in the decision-making processes of the experts (D'Aniello, 2023). In addition, Cakmak (2023) explained that the managerial experience and expert judgment are highly valued in decision making method, especially when hard quantitative data is limited. The SWARA method is exceptionally suited for this environment. Its straightforward, step-wise process allows for the effective capture of expert priorities without being overly time-consuming. Moreover, the Fuzzy TOPSIS technique has gained significant attention since it performs well in the presence of conflicting criteria by incorporating the ambiguity and intangibility existing in the decision makers' evaluations and eliminating the effects of biased assessments (Srinual et al., 2025). By combining SWARA's strength in subjective weighting with Fuzzy TOPSIS's robustness in ranking under uncertainty, the proposed framework provides a model that is not only methodologically sound but also pragmatically aligned with the decision-making realities of a warehouse service provider in Thailand.

Research Objectives

1. To identify the set of main and sub criteria in sustainable forklift selection
2. To rank and select the most optimal sustainable forklift alternative
3. To propose a MCDM framework for choosing an optimal sustainable forklift

Research Scope

This study focuses on developing a Multi-Criteria Decision-Making (MCDM) model to support the selection of sustainable forklifts for a warehouse service provider in Nakhon Pathom, Thailand. The model evaluates electric and internal combustion engine forklifts against criteria encompassing environmental performance, economic feasibility, operational efficiency, and infrastructure compatibility. A hybrid MCDM technique is employed to accommodate uncertainty and subjectivity in expert judgments. While the case is context-specific, the framework is adaptable to similar logistics environments in emerging economies. The research addresses a gap in sustainable equipment selection and offers practical guidance for logistics managers seeking to align operational performance with environmental goals.

How research conducted

This study adopts a structured approach to develop and validate a multi-criteria decision-making (MCDM) model for selecting sustainable forklifts tailored to a warehouse service provider company in Nakhon Pathom, Thailand. The research methodology is divided into three main stages: data collection, the proposed combined MCDM technique, and a numeric case study application. The implementation of the novel MCDM model, combining SWARA and Fuzzy TOPSIS (FTOPSIS), is summarized in Figure1, illustrating the step-by-step approach for selecting and ranking sustainable forklift criteria.

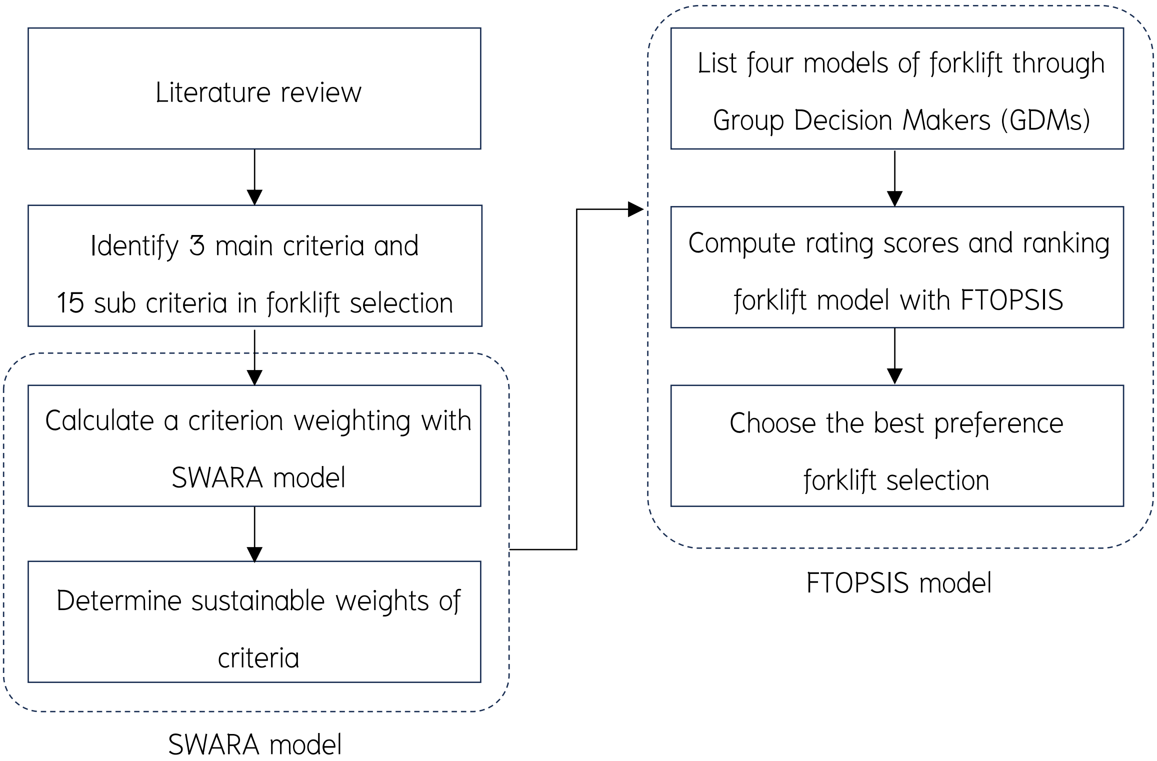

Figure 1 Flowchart of a hybrid MCDM procedure

Source: Analyzed and concluded by the authors

Data collection

Samples and Sampling Method

This study employed purposive sampling to construct an expert panel of ten key decision-makers from the case company. This non-probability technique was chosen to target participants possessing direct knowledge of forklift operations, safety, procurement, and logistics management. The sample size of ten experts is considered adequate and is consistent with established practices in numerous MCDM studies, where small, highly specialized panels are valued for their depth of expertise over statistical generalizability (Stević et al., 2020). Furthermore, this size is sufficient to achieve theoretical saturation, as the panel's diversity—encompassing four distinct functional areas—ensures that all critical perspectives and criteria for forklift selection are comprehensively represented.

Detail of decision makers in the case study

The group decision makers were selected by integrating a self-selection approach with subjective sampling as shown in Table 4. The group decision makers select and evaluate the appropriate criteria and suppliers considering their position and experience in the workplace.

Table 4 Detail of decision makers in this case study

Group Decision Maker (GDM)	Position	Number (person)
GDM 1	Senior logistics manager	2
GDM 2	Safety officer	2
GDM 3	Procurement Manager	3
GDM 4	Forklift operator	3

Source: Analyzed and concluded by the authors

The proposed combined MCDM method

This section presents the basics of SWARA and FTOPSIS methodology, which consists of two phases. In the first phase, the calculation procedure of the SWARA method, for determining the criteria weights, is summarized in Figure 2.

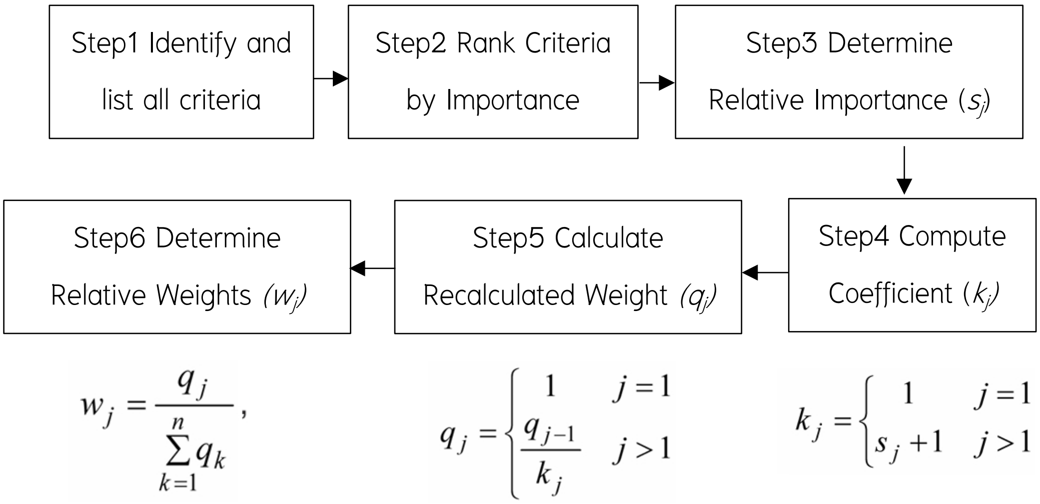

Figure 2 Flowchart of the SWARA procedure

Source: Analyzed and concluded by the authors

In the second phase, the calculation procedure of the FTOPSIS method, for ranking the alternatives of forklift scores, is summarized in Figure 3.

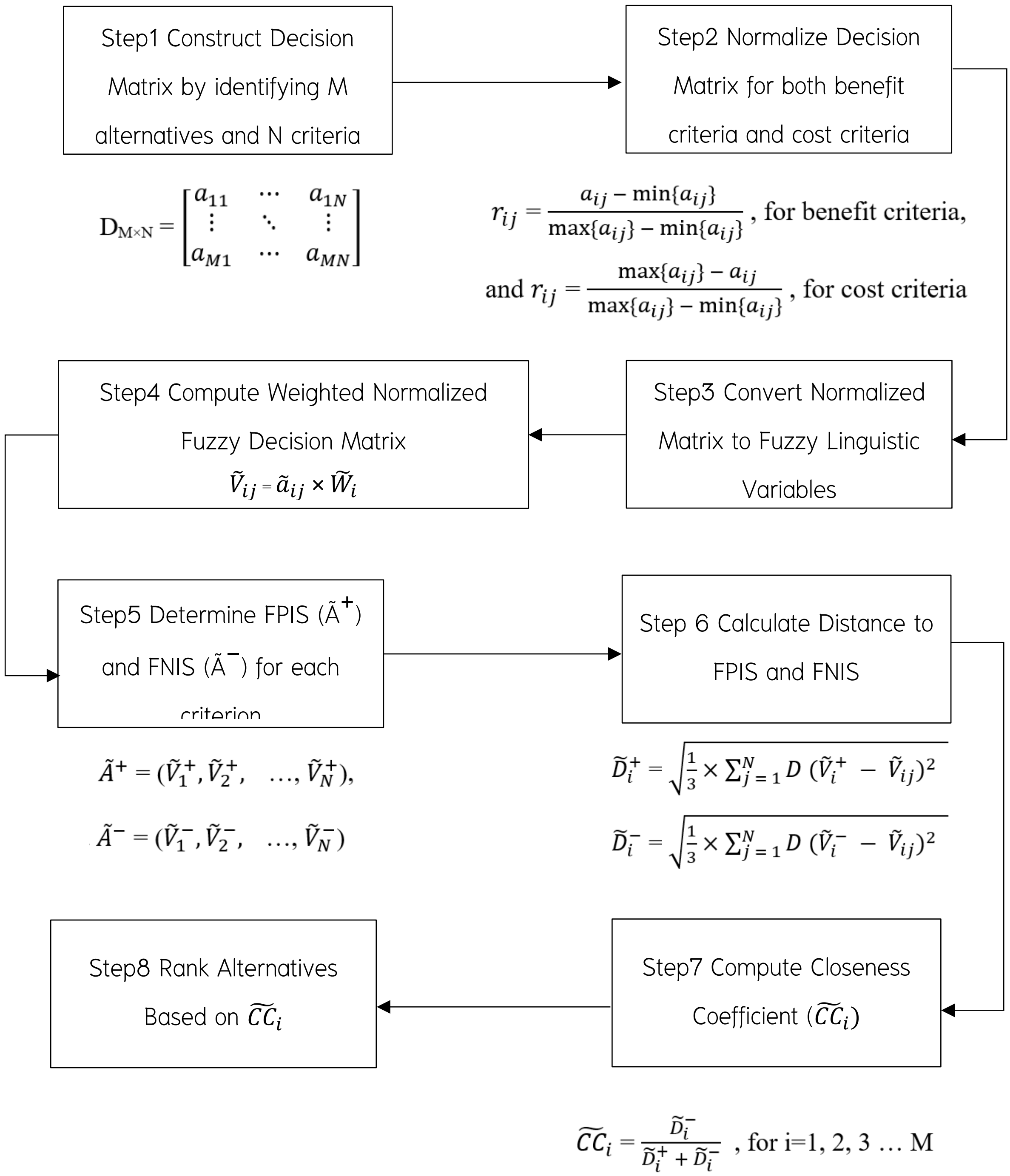

Figure 3 Flowchart of the FTOPSIS procedure

Source: Analyzed and concluded by the authors

Research Results

Determining the weights of sustainable criteria for selecting forklift

In choosing suitable forklift systems, the three fundamental criteria that guide sustainable selection are economic, environmental, and social. Table 5 and Table 6 present the overall weights of the main criteria and sub-criteria.

Table 5 Final sub criteria weights from SWARA method

Sub criteria	Weight (w_j)				Average Weight
	GDM1	GDM2	GDM3	GDM4	
EC1	0.37	0.20	0.24	0.20	0.26
EC2	0.20	0.20	0.18	0.20	0.19
EC3	0.21	0.26	0.24	0.26	0.24
EC4	0.18	0.15	0.18	0.13	0.16
EC5	0.15	0.12	0.18	0.15	0.15
EN1	0.24	0.22	0.23	0.25	0.24
EN1	0.21	0.15	0.18	0.23	0.19
EN3	0.22	0.14	0.17	0.17	0.18
EN4	0.18	0.15	0.18	0.16	0.16
EN5	0.22	0.21	0.26	0.23	0.23
SC1	0.19	0.19	0.27	0.22	0.22
SC2	0.18	0.20	0.21	0.24	0.21
SC3	0.15	0.14	0.27	0.25	0.20
SC4	0.15	0.22	0.22	0.22	0.20
SC5	0.12	0.16	0.23	0.17	0.17

Source: Analyzed and concluded by the authors

Table 6 represents the arithmetic mean of the weights assigned by the four different decision-makers (GDM1, GDM2, GDM3, and GDM4) for each main criterion.

Table 6 Global weights of main criteria (sustainable main criteria) in SWARA model

Main criteria	Weight (w_j)				Average Weight
	GDM1	GDM2	GDM3	GDM4	
Economic (EC)	0.36	0.35	0.51	0.42	0.41
Environment (EN)	0.32	0.30	0.29	0.34	0.32
Social (SC)	0.32	0.30	0.20	0.24	0.27

Source: Analyzed and concluded by the authors

According to the findings, the top five sub-criteria by global weight (%) are as follows: Purchase Cost (EC1 = 10.66%), Maintenance Cost (EC5 = 9.84%), Operating Cost (EC3 = 7.79%), Energy Efficiency (EN2 = 7.68%), and Emissions (EN4 = 7.36%). Figure 4 presents the overall global weights of the sub-criteria for selecting a sustainable forklift model.

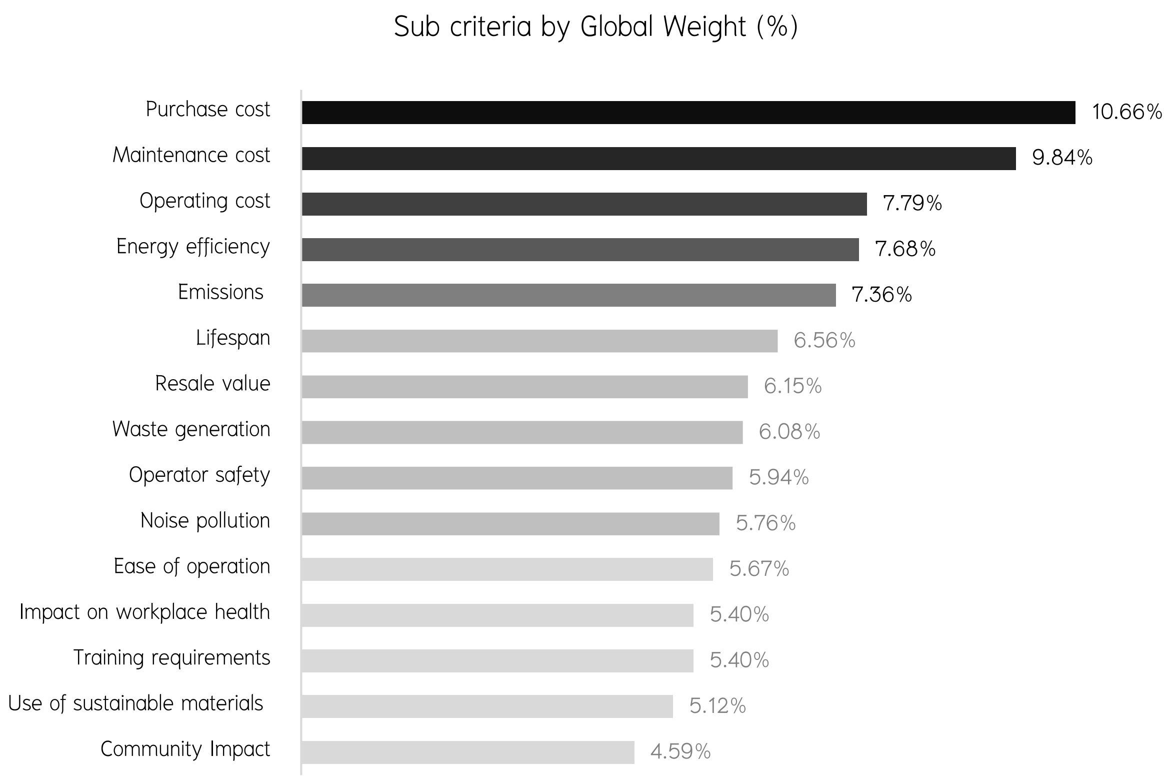

Figure 4 The overall global weights of the sub criteria for selecting a sustainable forklift

Source: Analyzed and concluded by the authors

Ranking of sustainable forklifts using the combined multi-criteria decision-making method

After applying the SWARA method to determine criterion weights, the Fuzzy TOPSIS method is used for the analysis to select and rank the forklift alternatives. Among the four forklifts (FL), different types of models are presented, as shown in Table 7.

Table 7 Forklift types and models

Alternative	ICFL1	ICFL2	ETFL1	ETFL2
Engine type	Internal Combustion (IC)	Internal Combustion (IC)	Electric (ET)	Electric (ET)

Source: Analyzed and concluded by the authors

Four group decision makers decide the linguistic rating for four forklift alternatives in each criterion by using linguistic variables from Table 8 below (Jiang et al., 2008).

Table 8 Linguistics scale for each alternative

Linguistic variable	**Triangular Fuzzy Numbers (TFNs) – *(a,b,c)***
Very Good (VG)	(7, 9, 10)
Good (G)	(5, 7, 9)
Medium (M)	(3, 5, 7)
Poor (P)	(1, 3, 5)
Very Poor (VP)	(0, 1, 3)

Source: Jiang, Y.-P., Fan, Z.-P., & Ma, J. (2008)

The alternative ranking is performed utilizing the Fuzzy TOPSIS methodology. According to the multi-criteria scores provided in Table 9, the ratings for each sustainable forklift system alternative are displayed.

Table 9 Fuzzy evaluation matrix for top 5 sub criteria

Sub criteria	Global Weight (%)	Type of Forklift			
		ICFL1	ICFL2	ETFL1	ETFL2
EC1	10.66%	(0.68, 0.78, 0.88)	(0.64, 0.74, 0.84)	(0.32, 0.42, 0.52)	(0.22, 0.32, 0.42)
EC5	9.84%	(0.38, 0.48, 0.58)	(0.44, 0.54, 0.64)	(0.74, 0.84, 0.94)	(0.84, 0.94, 1.00)
EC3	7.79%	(0.26, 0.36, 0.46)	(0.32, 0.42, 0.52)	(0.78, 0.88, 0.98)	(0.88, 0.98, 1.00)
EN2	7.68%	(0.22, 0.32, 0.42)	(0.28, 0.38, 0.48)	(0.82, 0.92, 1.00)	(0.92, 1.00, 1.00)
EN4	7.36%	(0.12, 0.22, 0.32)	(0.16, 0.26, 0.36)	(0.78, 0.88, 0.98)	(0.88, 0.98, 1.00)

Source: Analyzed and concluded by the authors

According to Table 10, the ranking order of four alternatives is ETFL2 > ETFL1 > ICFL2 > ICFL1. Thus, Electric Forklift Model 2 (ETFL2) is the optimal alternative sustainable forklift model.

Table 10 Fuzzy closeness index and ranking of forklift alternatives

Forklift	Fuzzy Closeness Index ($\widetilde{CC}_i$)	Defuzzified Value	Ranking
ICFL1	(0.268, 0.328, 0.388)	0.328	4
ICFL2	(0.296, 0.356, 0.416)	0.356	3
ETFL1	(0.684, 0.744, 0.804)	0.744	2
ETFL2	(0.792, 0.852, 0.912)	0.852	1

Source: Analyzed and concluded by the authors

Benefits

1. This study develops a combined SWARA-FTOPSIS framework for sustainable forklift selection, filling an important gap in material handling research. The integrated approach addresses the weaknesses of individual approaches by using SWARA's clear weight assessment process alongside FTOPSIS's ability to handle uncertain data, creating a more effective decision-making tool that can be applied to similar equipment selection challenges in developing countries.

2. The study offers valuable insights into how warehouse service companies in Thailand prioritize sustainability factors, showing that economic concerns remain more important than environmental and social factors.

Summary and discussion of results

The field of sustainable forklift selection in material handling operations has gained considerable attention in recent years, particularly with increasing emphasis on environmental sustainability and operational efficiency. However, in Thailand, limited research exists on sustainable material handling equipment selection using integrated MCDM approaches. For this case study, the results reveal that Purchase cost (10.66%), Maintenance cost (9.84%) and Operating cost (7.79%) are the three most important sub-criteria based on economic concerns, which aligns with the findings of Chakraborty & Saha (2024) and Facchini et al. (2016) who emphasized the dominance of financial factors in industrial equipment selection. This is also supported by previous research indicating that initial investment costs and operational expenses remain primary decision drivers in developing economies (Dua, 2023).

In addition, the results demonstrate that economic factors (41%) hold the highest weight among main criteria, followed by environmental (32%) and social (27%) factors respectively. This finding corresponds with Ulutas et al. (2023) who argued that economic considerations typically outweigh sustainability factors in industrial decision-making processes within emerging markets. The ranking results indicate that Electric Forklift Model 2 (ETFL2) achieved the highest closeness coefficient (0.852), followed by ETFL1 (0.744), ICFL2 (0.356), and ICFL1 (0.328) respectively. Although ETFL2 emerged as the optimal sustainable alternative, its relatively lower performance in purchase cost criterion reflects the typical trade-off between sustainability benefits and initial investment costs, which corresponds to findings by

Prusa et al. (2018) and Mei & Chen (2021) who highlighted the economic barriers to sustainable technology adoption in logistics operations.

Suggestions

Future research directions should address three key areas to enhance the proposed framework's applicability and robustness. First, the future should expand the study scope by including additional forklift alternatives such as hybrid models, hydrogen fuel cell systems, and autonomous material handling equipment, while focusing on sector-specific applications across different industries including cold storage facilities and e-commerce fulfillment centers to enhance practical applicability. Second, methodological validation through alternative fuzzy MCDM approaches is recommended to confirm the robustness of the SWARA-FTOPSIS integration and establish ranking consistency across different algorithmic frameworks. Third, group decision makers should be expanded beyond the current four groups, while conducting across different geographical and economic contexts to support broader adoption in diverse organizational settings.

References

Brauers, W.K.M. & Zavadskas E.K. (2006) The MOORA Method and Its Applications to Privatization in a Transition Economy. *Control and Cybernetics*, *35*(2), 445-469. http://eudml.org/doc/209425

Cakmak, E. (2023). Supplier selection for a power generator sustainable supplier park: Interval-valued neutrosophic SWARA and EDAS application. *Sustainability*, *15*(18), 1-24. https://doi.org/10.3390/su151813973

Chakraborty, S., & Saha, A. K. (2024). Selection of forklift unit for transport handling using integrated MCDM under neutrosophic environment. *FACTA Universitatis. Series: Mechanical Engineering*, *22*(2), 235-256. https://doi.org/10.22190/FUME220620039C

D'Aniello, G. (2023). Fuzzy logic for situation awareness: a systematic review. *Journal of Ambient Intelligence and Humanized Computing*, *14*, 4419–4438. https://doi.org/10.1007/s12652-023-04560-6

Dua, T. V. (2023). Forklift selection by multi-criteria decision-making methods. *Eastern-European Journal of Enterprise Technologies*, *5*(3), 95–101. https://doi.org/10.15587/1729-4061.2023.285791

Facchini, F., Mummolo, G., Mossa, G., Digiesi, S., Boenzi, F., & Verriello, R. (2016). Minimizing the carbon footprint of material handling equipment: Comparison of electric and LPG forklifts. *Journal of Industrial Engineering and Management*, *9*(5), 1035-1046. https://doi.org/10.3926/jiem.2082

Fazlollahtabar, H., Smailbašić, A., & Stević, Ž. (2019). FUCOM method in group decision-making: Selection of forklift in a warehouse. *Decision Making: Applications in Management and Engineering*, *2*(1), 49–65. https://doi.org/10.31181/dmame1901065f

Görçün, Ö. F., Tirkolaee, E. B., Küçükönder, H., & Garg, C. P. (2024). Assessing and selecting sustainable refrigerated road vehicles in food logistics using a novel multi-criteria group decision-making model. *Information Sciences, 661*, 1-26. https://doi.org/10.1016/j.ins.2024.120161

Govindan, K., Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research*, *240*(3), 603-626. https://doi.org/10.1016/j.ejor.2014.07.012

Hendiani, S., & Walther, G. (2023). Sustainability performance evaluation of renewable energy systems using a new multi-expert multi-criteria interval type-2 fuzzy distance to ideal solution approach. *Applied Energy*, *347*, 1-21. https://doi.org/10.1016/j.apenergy.2023.121436

Huang, X., Lin, Y., Lim, M. K., Tseng, M.-L., & Zhou, F. (2021). The influence of knowledge management on adoption intention of electric vehicles: Perspective on technological knowledge. *Industrial Management & Data Systems*, *121*(7), 1481–1495. https://doi.org/10.1108/IMDS-07-2020-0411

Huskanović, E., Stević, Ž., & Simić, S. (2023). Objective-subjective CRITIC-MARCOS model for selection forklift in internal transport technology processes. *Mechatronic Systems and Intelligent Transportation*, *2*(1), 20-31. https://doi.org/10.56578/mits020103

Jiang, Y.-P., Fan, Z.-P., & Ma, J. (2008). A method for group decision making with multi-granularity linguistic assessment information. *Information Sciences*, *178*(4), 1098-1109. https://doi.org/10.1016/j.ins.2007.09.007

Kannan, D., Khodaverdi, R., Olfat, L., Jafarian, A., & Diabat, A. (2013). Integrated fuzzy multi criteria decision making method and multi-objective programming approach for supplier selection and order allocation in a green supply chain. *Journal of Cleaner Production*, *47*, 355-367. https://doi.org/10.1016/j.jclepro.2013.02.010

Mohammadpour, M., Kelouwani, S., Gaudreau, M.-A., Zeghmi, L., Amamou, A., Bahmanabadi, H., Allani, B., & Graba, M. (2024). Energy-efficient motion planning of an autonomous forklift using deep neural networks and kinetic model. *Expert Systems with Applications*, *237*, 1-14. https://doi.org/10.1016/j.eswa.2023.121623

Mei, M., & Chen, Z. (2021). Evaluation and selection of sustainable hydrogen production technology with hybrid uncertain sustainability indicators based on rough-fuzzy BWM-DEA. *Renewable Energy*, *165*, 716–730. https://doi.org/10.1016/j.renene.2020.11.051

Office of the National Economic and Social Development Council (NESDC). (2024). *Thailand Logistics Report 2024* [Report].

Ortiz-Barrios, M., Cabarcas-Reyes, J., Ishizaka, A., Barbati, M., Jaramillo-Rueda, N., & Carrascal-Zambrano, G. J. (2021). A hybrid fuzzy multi-criteria decision-making model for selecting a sustainable supplier of forklift filters: A case study from the mining industry. *Annals of Operations Research*, *307*(1), 443–481. https://doi.org/10.1007/s10479-020-03737-y

Pamucar, D. S., Pejcic Tarle, S., & Parezanovic, T. (2018). New hybrid multi-criteria decision-making DEMATEL MAIRCA model: Sustainable selection of a location for the development of multimodal logistics centre. *Economic Research-Ekonomska Istraživanja*, *31*(1), 1641–1665. https://doi.org/10.1080/1331677X.2018.1506706

Pipawakorn, A., & Pasunon, P. (2023). The Documentary Research to Synthesize Components of Sustainable Business Development Concept for Small and Medium Enterprises. *University of the Thai Chamber of Commerce Journal Humanities and Social Sciences*, *43*(4), 142–163. https://so06.tci-thaijo.org/index.php/utccjournalhs/article/view/263738 [in Thai]

Průša, P., Jovčić, S., Němec, V., & Mrázek, P. (2018). Forklift truck selection using TOPSIS method. *International Journal for Traffic and Transport Engineering*, *8*(3), 390-398. https://doi.org/10.7708/ijtte.2018.8(3).10

Srinual, N., & Boonraksa, N. (2025). A Multicriteria Decision-Making Model for Selecting Warehouse Rack Systems. *Business Administration and Management Journal Review*, *17*(1), 271–290. https://so01.tci-thaijo.org/index.php/bahcuojs/article/view/275913

Stević, Ž., Pamučar, D., Puška, A., & Chatterjee, P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS). *Computers & Industrial Engineering, 140*, 1-15. https://doi.org/10.1016/j.cie.2019.106231

Streimikiene, D., Kiausiene, I., & Makunaite, G. (2024). The importance of corporate image and social responsibility for consumer engagement in sustainable consumption. *E&M Economics and Management, 27*(2), 125–141. https://doi.org/10.15240/ tul/001/2024-2-008

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, 1-16. https://doi.org/10.3390/axioms12050467

Zajac, P., & Rozic, T. (2022). Energy consumption of forklift versus standards, effects of their use and expectations. *Energy*, *239*, 1-16. https://doi.org/10.1016/j.energy.2021.122187

Ziółkowski, A., Fuć, P., Jagielski, A. & Bednarek, M. (2022). Analysis of emissions and fuel consumption from forklifts by location of operation. *Combustion Engines*, *189*(2), 30–35. https://doi.org/10.19206/CE-141741