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INTEGRATED MCDM MODEL FOR FORKLIFT SELECTION IN WAREHOUSE

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Abstract

Forklifts represent essential equipment within internal transport and material-handling systems, particularly in high-rack warehouses where lifting height, maneuvering precision, and reliability are critical for process efficiency. The proper selection of a forklift has a direct impact on warehouse operational productivity, operator safety, and space utilization optimization. However, given the wide variety of forklift types available on the market and their differing technical and economic characteristics, determining the optimal model constitutes a complex multi-criteria decision-making problem. In this study, a methodology based on Multi-Criteria Decision-Making (MCDM) techniques is proposed for selecting the optimal forklift intended for warehouse operations. The Entropy method was applied to determine the criterion weights, while the WASPAS (Weighted Aggregated Sum Product Assessment) method was used for the final ranking of alternatives.

***Keywords**: Forklift selection, logistics systems, MCDM, Entropy, WASPAS .*

1 INTRODUCTION

The rapid development of logistics systems and the increasing complexity of warehouse operations have created a need for the efficient selection of transport and material-handling equipment. In modern distribution centers, forklifts represent a critical component of internal logistics, as they directly influence warehouse performance, employee safety, and overall operational costs [1, 2]. Therefore, selecting an appropriate type of forklift is essential for the optimal utilization of warehouse space, the efficiency of material flows, and the flexibility of warehousing processes.

In such environments, the decision-making process becomes a multi-criteria problem, as it requires the simultaneous analysis of multiple, often mutually conflicting factors, including the purchase price of the equipment, capacity, maintenance costs, supplier availability, and delivery time [2]. Due to the complexity and interdependence of these parameters, traditional approaches based on subjective judgment often fail to provide sufficiently objective, consistent, and reliable results. To address this issue, Multi-Criteria Decision-Making methods have been increasingly applied in both research and practice [3, 4]. These methods enable a systematic evaluation and ranking of alternatives based on a combination of quantitative and qualitative criteria, thereby reducing subjectivity and enhancing the transparency and reliability of the decision-making process.

In this study, an integrated Entropy+WASPAS model is applied to the problem of selecting the optimal type of forklift for a warehouse. The analysis encompasses three spatial warehouse configurations, with each layout evaluated using a defined set of electric forklift alternatives assessed across multiple criteria. The objective of the research is to develop a quantitative and systematic decision-making model that enables a reliable selection of forklifts, thereby contributing to improved warehouse system efficiency and more rational planning of logistics processes in modern storage environments.

2 LITERATURE REVIEW

Fazlollahtabar, Smailbašić, and Stević [5] examined the problem of forklift selection for warehouses using a hybrid MCDM model. The authors first applied the FUCOM method to determine the weighting coefficients of the criteria, and then employed the WASPAS method for the evaluation and ranking of forklift alternatives. Chakraborty and Saha [6] developed an integrated MCDM model for forklift selection under uncertainty, utilizing the FUCOM method in a neutrosophic environment to determine criterion weights. The MOORA method was applied for ranking the alternatives, while sensitivity analysis allowed for the assessment of the robustness of the obtained solutions. This study demonstrates the application of complex MCDM models for selecting material-handling equipment in situations involving imprecise or uncertain data, making it relevant for research that integrates both objective and fuzzy/neutrosophic approaches. Keleş [7] developed a comprehensive MCDM framework for forklift selection, applying the MEREC method for the objective determination of criterion weights. The study considers 13 alternative forklifts and 6 criteria, while employing 21 different MCDM methods, including WASPAS, for ranking. The obtained results were aggregated through consensus ranking using the Borda and Copeland methods, achieving a robust and systematic selection of the optimal alternative. This work demonstrates the application of a combination of objective weighting and multiple ranking methods for making reliable decisions in the context of warehouse equipment. Dua [8] investigated forklift selection using multiple MCDM methods, employing the COCOSO and PIV methods for ranking, while the Entropy and MEREC methods were applied for criterion weighting. The study considers six criteria, including lifting height, fork length, and cost, and analyzes six types of forklifts. The results indicate that the best and worst forklifts were consistently identified across all method combinations, confirming the reliability of the applied MCDM approaches in the decision-making process for warehouse equipment selection.. Huskanović and Stević [9] developed an integrated model for forklift selection by applying the CRITIC method for the objective determination of criterion weights, taking into account both the contrast and correlations among criteria. The MARCOS method was employed for ranking the alternatives, enabling compromise ranking relative to ideal and anti-ideal solutions. Sensitivity analysis and comparison with other MCDM approaches demonstrated the robustness of the model, providing a practical and reliable framework for decision-making in the context of warehouse equipment selection. Saricali and Kundakci [10] applied the KEMIRA-M method to evaluate different types of forklifts, considering criteria such as performance, efficiency, and cost. The analysis demonstrates that the method enables reliable ranking of alternatives even when the available data are limited or imprecise. The results illustrate the practical application of MCDM methods for forklift selection in real industrial and logistics environments.

3 MULTI - CRITERIA DECISION - MAKING

Multi-Criteria Decision-Making (MCDM) methods enable the systematic evaluation and ranking of alternatives when a decision depends on multiple competing criteria. They integrate quantitative and qualitative factors, reduce subjectivity in the decision-making process, and enhance the reliability of the results. [11].

3.1. Entropy method

The Entropy method represents an objective approach for determining criterion weights in multi-criteria decision-making problems, based on the analysis of data variability. The method's principle is grounded in information theory, where criteria exhibiting greater differences in values among alternatives are assigned higher weights, while criteria with lower variability are given lower significance. In this way, subjectivity in criterion weighting is reduced, enabling a quantitatively justified ranking of alternatives. [11].

3.2. WASPAS method

The WASPAS (Weighted Aggregated Sum Product Assessment) method is a multi-criteria decision-making approach that combines additive (Weighted Sum Model – WSM) and multiplicative (Weighted Product Model – WPM) ranking techniques. The method allows for the integration of different criteria into a single performance index, achieving more accurate and stable rankings compared to the use of a single model. WASPAS is particularly suitable for problems that require a balance between linear and non-linear performance evaluation and an objective assessment of competing alternatives [5].

4 CASE STUDY

For a specific company, it was necessary to determine the configuration of selective pallet racks for a warehouse space with an available surface area of A = 1768 m². The pallet rack length of L_R = 42 m and the width is B = B_R = 42.1 m. Several variants of handling equipment (forklifts) that can be used in the facility were considered. At the front side of the warehouse, an additional zone for pallet reception and dispatch is provided, with a length of l_0 = 5 m, resulting in a total warehouse length of L = 47 m.

Euro-pallets are planned for storage, with base dimensions $x_{pal} \times y_{pal} = 0.8 \times 1.2$ m, while the pallet height varies up to a maximum of z_{pal} = 1.2 m. On the rear side of the storage zone, an additional aisle is included so that forklifts from both sides of the warehouse can access the racks. A total of N = 5 levels of selective racks is planned vertically.

Each rack bay accommodates ξ = 3 pallets, positioned transversely. The distance between the top pallets and the warehouse ceiling is Δh = 1.5 m. The horizontal spacing between adjacent pallets is Δl = 7.5 cm, while the spacing between the uprights of the selective rack is Δ = 10 cm. The minimum vertical clearance between the top-layer pallets and the upper rack beams is Δz = 20 cm. The width of the rack uprights as well as the height of the horizontal beams is δ = 7.5 cm. The duration of one work shift is T = 7 h.

Racks data: l_R = 2.7 m, b_R = 1.2 m, h_R = 1.4 m; H_R = 6.5 m, H_{max} = 7.025 m, $H = H_{max} + \Delta h$ = 8.525 m; l_1 = 3.075 m - back aisle.

Within the conducted analysis, three types of material-handling equipment were considered:

Type A – counterbalanced forklift;
Type B – reach truck;
Type C – side-loading forklift.

For each variant, three alternatives from different manufacturers: Jungheinrich, Linde, and STILL were considered.

Each configuration was analyzed in accordance with the spatial constraints of the warehouse, the width of the operating aisles, and the number of rack rows.

Type A: Counterbalanced forklift
Aisle width: b_A = 3.5 m;
$B_A = b_A + 2 \cdot b_R + \Delta b$ = 6 m;

$$k_A = \frac{B}{B_A} = \frac{42}{6} = 7 \text{ - number of aisle possible}$$

k_A = 7, ρ = 14, $M\rho$ = 14, except $M\rho_1 = M\rho_{14}$ = 15;
n_{pal} = 2970, $n_{pal}(*)$ = 594 pallets per level,
η_A = 32.25%, η_V = 27.54%; θ_A = 1.50 pallets per m^2,
θ_V = 0.18 pallets per m^3;

The set of alternatives considered under **Type A** includes the following:

A_1 – Jungheinrich electric EFG 112;
A_2 – Linde electric Xi 12;
A_3 – STILL electric RXE 13.

Type B: reach truck
Aisle width: b_A = 2.75 m;
$B_A = b_A + 2 \cdot b_R + \Delta b$ = 5.25 m;
k_A = 8, ρ = 16, $M\rho$ = 14, except $M\rho_1 = M\rho_{16}$ = 15;

$n_{pal} = 3390$, $n_{pal}(*) = 678$ pallets per level,
$\eta_A = 36.81\%$, $\eta_V = 30.26\%$, $\theta_A = 1.92$ pallets per m^2,
$\theta_V = 0.26$ pallets per m^3;

The set of alternatives considered under **Type B** includes the following:
A_1 – Jungheinrich electric ETV 212;
A_2 – Linde electric R 12 B;
A_3 – STILL electric FM-X 12.

Type C: Side-loading forklift
Aisle width: $b_A = 1.7$ m;
$B_A = b_A + 2 \cdot b_R + \Delta b = 4.2$ m;
$k_A = 10$, $\rho = 20$, $M\rho = 14$, except $M\rho_1 = M\rho_{20} = 15$;
$n_{pal} = 4230$, $n_{pal}(*) = 846$ pallets per level,
$\eta_A = 45.93\%$, $\eta_V = 37.75\%$, $\theta_A = 2.39$ pallets per m^2,
$\theta_V = 0.33$ pallets per m^3;

The set of alternatives considered under **Type C** includes the following:
A_1 – Jungheinrich electric EKX 412;
A_2 – Linde electric A 5224;
A_3 – STILL electric MX-X.

Figure 1 shows the horizontal layout of the warehouse area, highlighting the main elements of the storage space: the positions of selective racks, working aisles, the reception and dispatch area for pallets, and the side passages for forklift access.

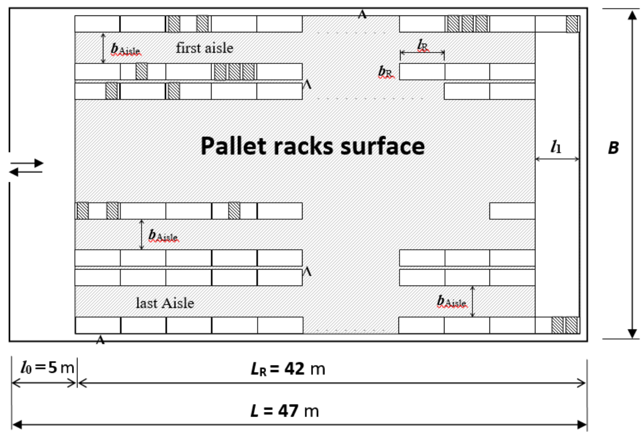

***Fig. 1** Warehouse layout*

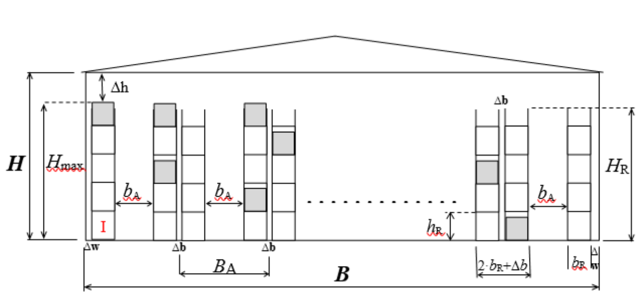

***Fig. 2** Warehouse side view*

Figure 2 shows a side view of the warehouse, providing insight into the vertical organization of the space and the positioning of racks by height. This illustration indicates the number of rack levels, the height of individual rack locations, the maximum pallet lifting height, and the clearance between the top of the pallets and the warehouse ceiling.

The set of criteria considered in this study includes the following:
C_1 – Forklift price (relative purchase cost of the equipment) includes initial acquisition, installation, and commissioning costs, expressed relatively to allow comparison between different forklift types;
C_2 – Capacity (number of pallets that can be handled): represents the maximum number of pallets the forklift can handle within a given time or space, including handling efficiency and storage capabilities;
C_3 – Forklift maintenance (frequency and cost of maintenance – Saty scale): encompasses regular servicing, part replacement, and labor costs, reflecting the reliability and longevity of the equipment;
C_4 – Supplier availability (procurement capability and manufacturer support – Saty scale): includes delivery speed, availability of spare parts, and quality of technical support, impacting the continuity of warehouse operations;
C_5 – Forklift delivery time (lead time in weeks): measures how quickly the forklift can be delivered and operational, which is critical for warehouse planning);
C_6 – Lifting height (maximum lifting height in meters): determines the maximum vertical reach of the forklift and its compatibility with high-bay warehouses, affecting space optimization and pallet accessibility.

The decision matrix was constructed using the relative values of all criteria and alternatives (Tables 1–3). The weighting coefficients of the criteria were determined using the Entropy method, which provides an objective assessment of criterion significance (Table 4). Table 5 presents the ranking of alternatives obtained using the WASPAS method, which combines the SAW and WPM approaches to achieve a higher level of stability and reliability in the results.

Table 1 Decision matrix (type A)

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	1	439	7.66	9	12	7
A_2	0.880	608	6.33	5	14	8
A_3	0.720	442	5.33	5	10	6

Table 2 Decision matrix (type B)

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	1	438	7.66	7	16	7.4
A_2	0.636	451	6.66	5	12	7
A_3	0.454	505	5.66	3	14	8

Table 3 Decision matrix (type C)

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	1	285	8.66	3	20	8.5
A_2	0.500	294	6.33	3	20	9
A_3	0.330	323	5.33	7	18	12

Table 4 Weight coefficients based on the Entropy method

	C_1	C_2	C_3	C_4	C_5	C_6
w_1	0.102	0.135	0.121	0.463	0.104	0.075
w_2	0.400	0.016	0.062	0.452	0.057	0.012
w_3	0.417	0.007	0.098	0.416	0.006	0.056

Table 5 Ranks of alternatives based on the WASPAS method

	$Type_1$	$Rang_1$	$Type_2$	$Rang_2$	$Type_3$	$Rang_3$
A_1	0.903	1	0.740	2	0.449	3
A_2	0.715	2	0.743	1	0.571	2
A_3	0.693	3	0.690	3	0.958	1

Based on Table 4, we can see that criterion C4 – Supplier availability is the dominant criterion with the highest values for the first two types, type A and type B, while for type C, the criteria C1 – Forklift price and C4 – Supplier availability have approximately the same values.

Based on Table 5, it can be observed that the weighting coefficients did not significantly influence the final ranking of the alternatives. For Type A (counterbalanced forklift), the best alternative is A1 – Jungheinrich EFG 112. For Type B (reach truck), the most favorable alternative is A2 – Linde R 12 B, while for the last category, Type C (trilateral turret truck), the best-performing alternative is A3 – STILL MX-X.

CONCLUSION

The conducted analysis showed that the selection of an appropriate type of forklift depends on the type of warehouse, the spatial arrangement of the racks, and the available working space within the warehouse hall. By applying the integrated Entropy + WASPAS model, it is possible to obtain a reliable and quantitatively grounded solution for selecting the optimal warehouse equipment. The research results indicate that each analyzed type of handling equipment has a dominant alternative that represents the best solution for the specific conditions of a high-bay warehouse.

- Jungheinrich EFG 12 for the spatial layout of type A,
- Linde R 12 B for the spatial layout of type B,
- STILL MX – X for the spatial layout of type C.

The obtained results confirm that different warehouse configurations require the use of different types of handling equipment, which further emphasizes the importance of multi-criteria decision-making methods in the process of selecting warehouse equipment. The proposed integrated Entropy + WASPAS model proved to be an effective tool for the systematic evaluation of alternative solutions, as it enables the consolidation of quantitative and qualitative criteria into a unified decision-making process

In future research, it is planned to expand the set of criteria to include additional factors, such as maintenance costs, ergonomics, and operational safety. Furthermore, it would be worthwhile to consider optimization within a single dominant forklift type with the aim of identifying a universal solution capable of meeting the requirements of multiple warehouse configurations.

In this way, further development of the model could contribute to the creation of a universal decision support system for the selection of material-handling equipment in modern logistics centers.

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