International Journal of Engineering Research and Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 21, Issue 6 (June 2025), PP 84-89

Optimizing Warehouse Layout with Racking Systems to Improve Storage Capacity and Accessibility

Singgih Saptadi[1], Ary Arvianto[1*], Heru Prastawa[1], Sriyanto[1], Zam Zam Mu'arifah[1], Dhimas Wachid Nur Saputra[1]
[1]*Department of Industrial Engineering, Faculty of Engineering, Diponegoro University, Indonesia*
**Corresponding Author*

ABSTRACT
This research addresses the underutilization of vertical space in the warehouse, which results in suboptimal storage and difficulty managing fluctuating demand. Additionally, the product allocation across warehouse floors is inefficient, such as placing heavy or fast-moving products on the 3rd floor. The aim of this research is to propose a new layout for warehouse storage and product allocation, optimizing vertical space to increase warehouse capacity. The research focuses on two aspects. First, product allocation to each floor using the ELECTRE TRI method, based on criteria such as product weight, space requirements, order frequency, and popularity. After classification, alternatives are ranked by the global concordance index, with products having higher values placed closer to the I/O point. Second, a racking system is proposed to maximize vertical space utilization and increase storage capacity. The proposed layout utilizes a racking system to optimize the entire warehouse space. The maximum warehouse capacity increased by 45.29% after implementing the vertical space optimization, although space utilization decreased by 22.68%. Despite the decrease in utilization, accessibility to products improved, and the warehouse became neater and more organized. The travel distance during the warehousing process was also reduced by 8.9%, improving operational efficiency.

Date of Submission: 06-06-2025 Date of acceptance: 16-06-2025

I. INTRODUCTION

The supply chain plays a crucial role in ensuring the accuracy of products being delivered, including the product type, quantity, target customers, delivery time and location, product condition, and price [1]. Warehouses play an important role in this process [2]. A warehouse is a facility that has four role operations such as, receiving, storage, order picking and shipping [3], [4]. The storage function is useful for storing products that are still in the form of raw materials, work in process (WIP) inventory, finished products, or wholesale or retail inventory waiting to be distributed to customers [5].

Once products have been completed and stored in the warehouse, they undergo the picking and shipping processes to be delivered to customers. Accuracy in picking and shipping from the warehouse impacts the accuracy of the product type and quantity delivered to customers. In addition, the warehouse also ensures that products leaving the warehouse are in good condition and free from damage [6]. Maintaining product quality contributes to increased customer satisfaction and helps foster customer loyalty [7].

In an increasingly competitive business environment, warehouses are expected to continuously enhance productivity and accuracy while simultaneously reducing costs and improving service quality [8]. However, some companies still face challenges in managing the layout of finished products in their warehouses. This often results in a decrease in storage utility or efficiency. Inefficient product placement can also lead to underutilized space, making storage capacity very limited. In situations where warehouse storage space is full, companies need to improve their inventory management system in the warehouse to enhance efficiency and productivity. Therefore, optimizing product layout can be the best solution for improving space utilization in warehouses and is more cost-efficient than constructing a new warehouse [9].

Based on observations and data collection at a plastic manufacturing industry company, it was found that the company's warehouse measures 614.2 m^3 with an available storage capacity of 1,206.67 m^3. However, from this available capacity, the company only utilizes a maximum product storage space of 521.91 m^3. This condition indicates a low warehouse space utilization rate, at only approximately 50.90%. This highlights the potential for unutilized space, particularly vertical space. Furthermore, the placement of each product is still random and solely based on product categories, without considering specific criteria that could influence placement efficiency. Addressing these issues, this research aims to redesign the layout and allocation of finished products in the warehouse and increase storage capacity by maximizing the utilization of the warehouse's vertical space. To achieve these objectives, this research utilizes the 2.1. Elimination Et Choix Traduisant la Realité" Termes de Reference Multicritère Interactifs (ELECTRE TRI) method, a multi-criteria decision-making method that enables product allocation based on specific criteria for each alternative.

The rest of the paper has the following writing structure: section 2 contains details related to the materials and methods used in the research, section 3 contains the results of the research that has been conducted, and finally section 4 contains the discussion, conclusions, and future research that can be developed for further research.

II. MATERIAL AND METHODS

Elimination Et Choix Traduisant la Realité" Termes de Reference Multicritère Interactifs (ELECTRE TRI) is a method used to group or rank several options (alternatives) into predefined categories [10]. Mousseau *et al.* (2000) [11] define the steps in the ELECTRE TRI method as follows:

Step 1: Calculate concordance partial index c_j (a, b_h) and c_j (b_h, a), $\forall_j \in F$:

$$c_j(a, b_h) = \begin{cases} 0 \rightarrow if\ g_j(b_h) - g_j(a) \geq p_j \\ 1 \rightarrow if\ g_j(b_h) - g_j(a) \geq q_j \\ \frac{p_j - g_j(a) + g_j(b_h)}{p_j - q_j}\ otherwise \end{cases} \quad (1)$$

$$c_j(b_h, a) = \begin{cases} 0 \rightarrow if\ g_j(a) - g_j(b_h) \geq p_j \\ 1 \rightarrow if\ g_j(a) - g_j(b_h) \leq q_j \\ \frac{p_j - g_j(a) + g_j(b_h)}{p_j - q_j}\ otherwise \end{cases} \quad (2)$$

Step 2: Calculate concordance global index c_j (a, b_h) dan c_j (b_h, a):

$$c(a, b_h) = \frac{\sum_{j \in F} k_j c_j(a, b_h)}{\sum_{j \in F} k_j} \quad (3)$$

$$c(b_h, a) = \frac{\sum_{j \in F} k_j c_j(b_h, a)}{\sum_{j \in F} k_j} \quad (4)$$

Step 3: Calculate discordance index d_j (a,b_h):

$$d_j(a, b_h) = \begin{cases} 0 \rightarrow if\ g_j(b_h) \leq p_j(b_h) + g_j(a) \\ 1 \rightarrow if\ g_j(b_h) > v_j(b_h) + g_j(a) \\ \in [0,1]\ otherwise \end{cases} \quad (5)$$

$$d_j(b_h, a) = \begin{cases} 0 \rightarrow if\ g_j(a) \leq p_j(b_h) + g_j(b_h) \\ 1 \rightarrow if\ g_j(a) > v_j(b_h) + g_j(b_h) \\ \in [0,1]\ otherwise \end{cases} \quad (6)$$

Step 4: Calculate credibility (σ (a, b_h) from outranking relation:

$$\sigma(b_h, a) = c(a, b_h) \times \prod_{j \in F} \frac{1 - d_j(a, b_h)}{1 - c(a, b_h)} \quad (7)$$

Were, $\bar{F} = \{j \in F: d_j(a, b_h) > c(a, b_h)\}$

After determining the value of σ and cutting level (λ) it is necessary to define the fuzzy relation to obtain the crispy outranking relation ($\lambda \in [0.5,1]$). The credibility degree values and cutting level determine the preference situation between a dan b_h, as follows:

- $\sigma(a, b_h) \geq \lambda$ and $\sigma(b_h, a) \geq \lambda \rightarrow aSb_h$ and $b_hSa \rightarrow aIb_h$, indicates a is indifferent to b_h.
- $\sigma(a, b_h) \geq \lambda$ and $\sigma(b_h, a) < \lambda \rightarrow aSb_h$ and is not $b_hSa \rightarrow a > b_h$, it shows that a is superior to b_h.
- $\sigma(a, b_h) < \lambda$ and $\sigma(b_h, a) \geq \lambda \rightarrow$ not aSb_h and $b_hSa \rightarrow b_h > a$, it shows that b_h is superior to a.
- $\sigma(a, b_h) < \lambda$ and $\sigma(b_h, a) < \lambda \rightarrow$ not aSb_h and is not $b_hSa \rightarrow aRb_h$, it indicates that a cannot be compared to b_h.

In this study, empirical data from PT. XYZ, which stores a total of 212 product variations, was used. The data processing in this study was carried out through the following stages:

Step 1: Categorize the products on each floor of the warehouse using the ELECTRE TRI multi-criteria decision-making method. Products are categorized based on criteria: weight (g_1), space requirements (g_2), demand (g_3), and popularity (g_4).

Step 2: Create a proposed rack design to increase the use of vertical space in the warehouse.

Step 3: Allocate products according to category and synthesize an improved layout for the warehouse.

III. RESULTS

Warehouse management is an area that requires continuous improvement, one of which can be achieved by enhancing space utilization [12]. The current space utilization in the warehouse is relatively low, at around 50.51%. Despite the low utilization rate, the warehouse often experiences overcapacity. This is due to the underutilization of available vertical space, which is why a racking system has been proposed as a solution to this issue [13]. However, the use of forklifts or stackers for material handling in the warehouse is not feasible due to the limited space and the multi-story structure of the warehouse, as well as the relatively light weight of the products being moved. Additionally, the cost of procuring material handling equipment is high. Therefore, the proposed solution is a shelving system.

In this study, the use of a shelving system needs to be supported by material handling equipment to ensure optimal performance in both product retrieval and storage. Therefore, a rolling ladder, equipped with wheels for easy mobility, is proposed as the material handling equipment for the finished goods warehouse. This recommendation is based on the consideration that the shelf height is not too high, at only 4 meters, the stored items are relatively light, allowing manual operations to be feasible, and the procurement cost for such equipment is more affordable. Figure 1 show the proposed shelf one dimension, Figure 2 show the proposed shelving system and rolling ladder design.

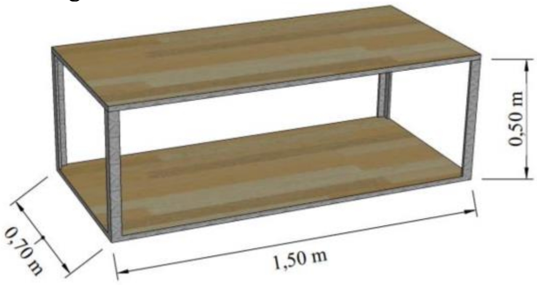
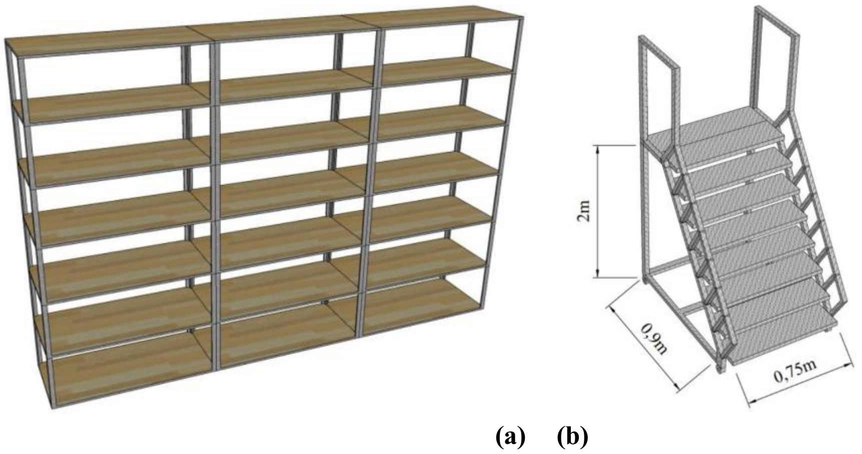


Figure 1: Proposed Shelf One Dimension



(a) (b)

Figure 2: (a) Proposed Shelving System; (b) Rolling Ladder Design

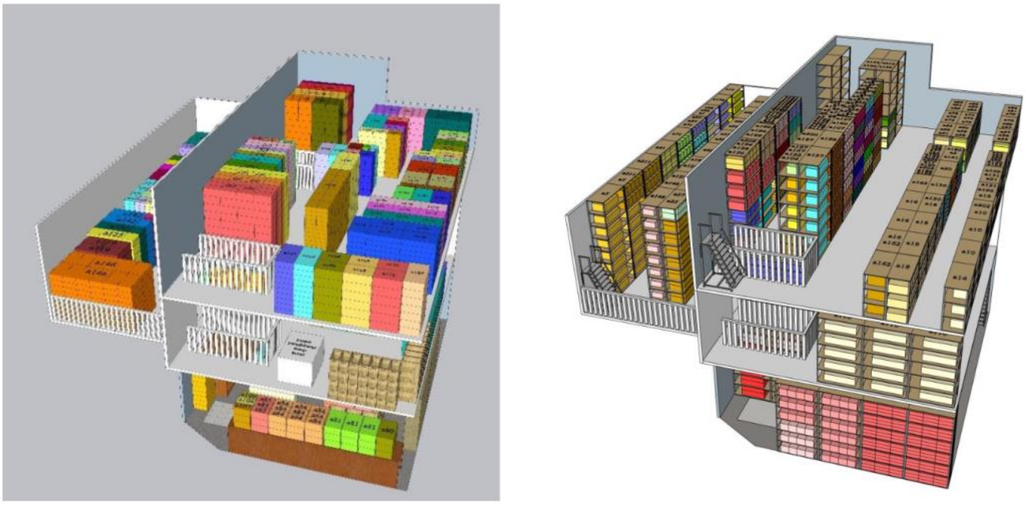
In the layout design, several factors need to be considered, including aisles, obstacles, and product allocation. Table 1 show allocation product for each category and Figure 3 to 6 shows the recommendation proposed layout.

- Determining Aisles: Aisles are determined based on the area needed for material movement in a diagonal direction. Therefore, the width of the aisles is set to 1.2 meters to facilitate the movement of material handling equipment.
- Obstacles: Obstacles are objects or elements that can affect the operational flow and the efficiency of the warehouse layout. These obstacles include walls, pipes, stairs, lifts, and others. In the finished goods warehouse, the total space occupied by these obstacles is 68.72 m^3.
- Product Allocation: The storage location for the products is designed using the previously proposed shelving system. Single-sided bays are placed next to the walls to optimize space utilization. If double-sided bays were placed near the walls, additional aisles would be required to provide access to the shelves, resulting in a reduction in storage capacity. The products are then placed in the shelves based on the categorization results using the ELECTRE TRI method and sorted according to the global concordance index, as shown in Table 1. Products in category 1 are placed on the first floor, products in category 2 are placed on the second floor, and

products in category 3 are placed on the third floor. The products with the highest concordance index are positioned near the entrance/exit (I/O point) to optimize both retrieval and storage processes

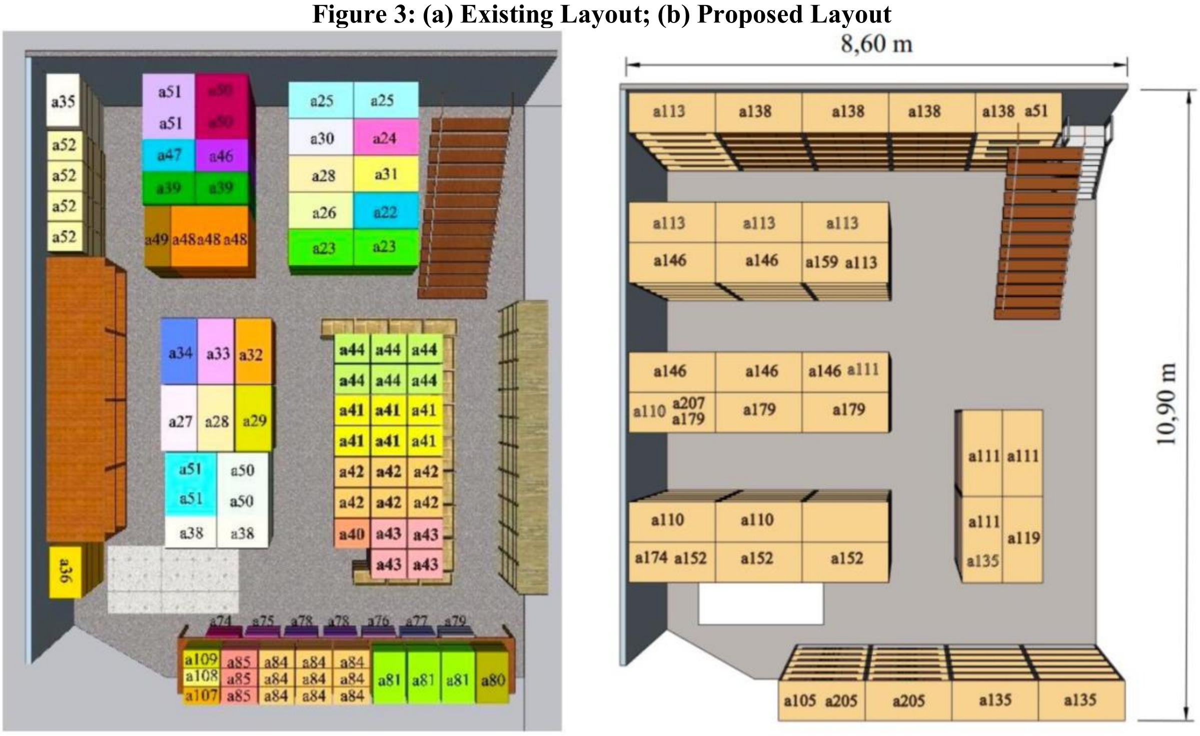
Table 1: Allocation Product

Category	Product
C1	a105, a205, a135, a174, a152, a110, a207, a179, a146, a159, a119, a111, a113, a138, a116, a151, a5, a51, a80, a211
C2	a195, a100, a101, a102, a103, a157, a137, a206, a168, a134, a192, a124, a126, a133, a140, a145, a147, a148, a123, a177, a193, a170, a153, a176, a143, a161, a188, a164, a172, a112, a171, a114, a173, a175, a182, a25, a27, a37, a41, a42, a43, a44, a50, a52, a53, a66, a71, a83, a87, a92, a94, a97, a98
C3	a106, a117, a210, a150, a14, a139, a181, a178, a127, a144, a1, a10, a104, a122, a167, a187, a200, a156, a128, a166, a194, a160, a198, a208, a162, a107, a190, a197, a18, a16, a165, a130, a202, a121, a12, a196, a131, a141, a2, a20, a180, a199, a204, a11, a109, a203, a21, a120, a125, a209, a15, a17, a108, a118, a149, a154, a163, a169, a183, a184, a185, a186, a191, a115, a158, a201, a136, a142, a3, a4, a6, a7, a8, a9, a13, a19, a22, a23, a24, a26, a28, a29, a30, a31, a32, a33, a34, a35, a36, a38, a39, a40, a45, a46, a47, a48, a49, a54, a55, a56, a57, a58, a59, a60, a61, a62, a63, a64, a65, a67, a68, a69, a70, a72, a73, a74, a75, a76, a77, a78, a79, a81, a82, a84, a85, a86, a88, a89, a90, a91, a93, a95, a96, a99, a129, a132, a155, a189, a212



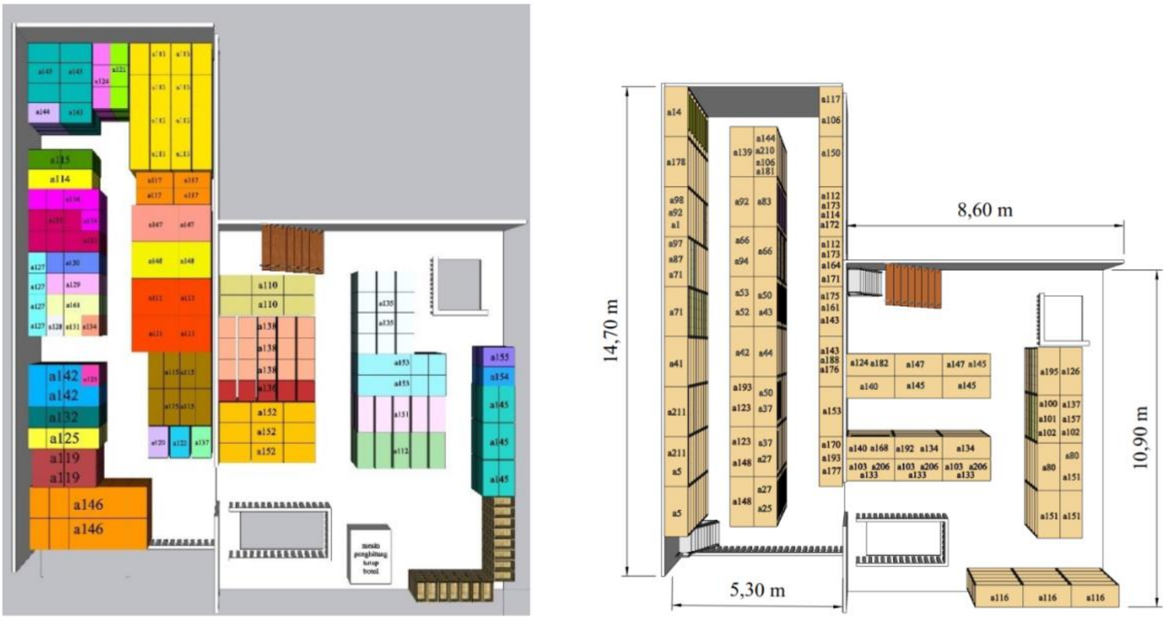
(a) (b)

Figure 3: (a) Existing Layout; (b) Proposed Layout



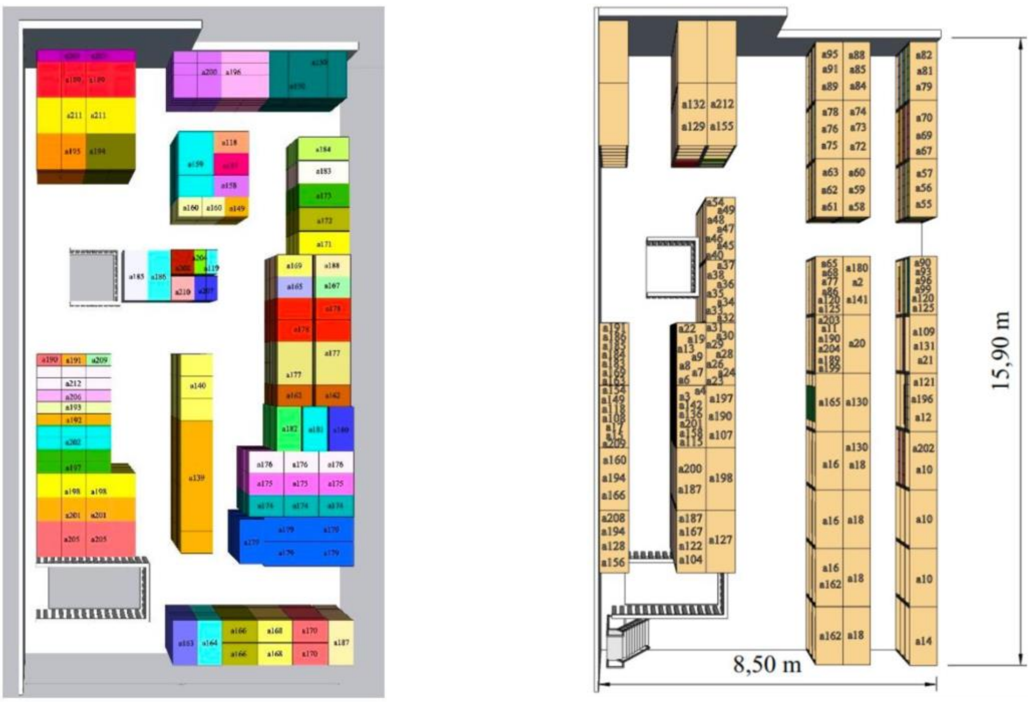
(a) (b)

Figure 4: (a) Existing Layout 1st Floor; (b) Proposed Layout 1st Floor



(a) (b)

Figure 5: (a) Existing Layout 2nd Floor; (b) Proposed Layout 2nd Floor



(a) (b)

Figure 6: (a) Existing Layout 3rd Floor; (b) Proposed Layout 3rd Floor

IV. DISCUSSION AND CONCLUSION

This proposed layout is one of the outputs of this research. The layout features a racking system for the entire warehouse. The purpose of using this racking system is to optimize vertical space utilization, minimize the risk of product damage, and facilitate better organization and inventory management. According to the proposed layout, there are 31 racks on the first floor, 56 on the second floor, and 50 on the third floor, with a total storage capacity of 641.3 m³. This capacity is deemed sufficient to handle demand fluctuations, as the current average daily space usage is 614.2 m³. The proposed layout results in a 45.29% increase in the maximum warehouse capacity, indicating that optimizing vertical space can enhance the warehouse's maximum capacity. However, this capacity increase leads to a 22.68% reduction in warehouse utilization. Despite the decrease in utilization, accessibility to products is improved, and product arrangement becomes tidier and more organized.

In the current warehouse configuration, the FIFO (First In, First Out) system cannot be applied. However, in the proposed layout, the FIFO system is feasible. FIFO is crucial for reducing product damage risk, as prolonged storage can degrade product quality. Additionally, the racking system facilitates stocktaking and inventory management. In terms of distance traveled, the proposed layout reduces the overall distance for picking and storing products by 8.9%, equivalent to approximately 308,977.15 meters per year. This improvement is due to the well-allocated product storage, which takes into account several predefined criteria.

Based on the results of this study, several suggestions for future research can be made. First, product allocation in this study did not consider product type as a criterion. Therefore, future research could incorporate this criterion into the categorization process. By considering product type, the efficiency of product retrieval in the warehouse can be optimized, making it easier to access the required items. Second, in this study, the proposed layout only utilized a racking system overall. Thus, future research could further explore the use of a hybrid storage system, combining ground storage and racking storage, to optimize storage space utilization.

REFERENCES

[1] Saeid Dokhanian, Abolfazl Sodagartojgi, Kian Tehranian, Zahra Ahmadirad, Parisa Khorashadi Moghaddam, and Mahsa Mohsenibeigzadeh, "Exploring the impact of supply chain integration and agility on commodity supply chain performance," *World Journal of Advanced Research and Reviews*, vol. 22, no. 1, pp. 441–450, Apr. 2024, doi: 10.30574/wjarr.2024.22.1.1119.

[2] T. H. D. Ho, J. Daniel, S. P. Nadeem, J. A. Garza-Reyes, and V. Kumar, "Improving the Reliability of Warehouse Operations in the 3PL Industry: An Australian 3PL Case Study," in *2018 International Conference on Production and Operations Management Society (POMS)*, IEEE, Dec. 2018, pp. 1–7. doi: 10.1109/POMS.2018.8629453.

[3] M. Živičnjak, K. Rogić, and I. Bajor, "Case-study analysis of warehouse process optimization," *Transportation Research Procedia*, vol. 64, pp. 215–223, 2022, doi: 10.1016/j.trpro.2022.09.026.

[4] Vail Karakale, "Erection and structural design errors of structural steel warehouses," *World Journal of Advanced Research and Reviews*, vol. 24, no. 3, pp. 400–406, Dec. 2024, doi: 10.30574/wjarr.2024.24.3.3567.

[5] J. Saderova, A. Rosova, M. Sofranko, and P. Kacmary, "Example of Warehouse System Design Based on the Principle of Logistics," *Sustainability*, vol. 13, no. 8, p. 4492, Apr. 2021, doi: 10.3390/su13084492.

[6] I. H. Mohamud, Md. A. Kafi, S. A. Shahron, N. Zainuddin, and S. Musa, "The Role of Warehouse Layout and Operations in Warehouse Efficiency: A Literature Review," *Journal Européen des Systèmes Automatisés*, vol. 56, no. 1, pp. 61–68, Feb. 2023, doi: 10.18280/jesa.560109.

[7] S. T. Ponis, G. Plakas, K. Agalianos, E. Aretoulaki, S. P. Gayialis, and A. Andrianopoulos, "Augmented Reality and Gamification to Increase Productivity and Job Satisfaction in the Warehouse of the Future," *Procedia Manuf*, vol. 51, pp. 1621–1628, 2020, doi: 10.1016/j.promfg.2020.10.226.

[8] Y. Fernando, M. Adib, I. S. Wahyuni TD, and Y. Omar, "Improving Warehouse Capacity, Productivity and Sustainability," *International Journal of Productivity and Quality Management*, vol. 1, no. 1, p. 1, 2022, doi: 10.1504/IJPQM.2022.10046115.

[9] P.-W. Albert, M. Rönnqvist, and N. Lehoux, "Trends and new practical applications for warehouse allocation and layout design: a literature review," *SN Appl Sci*, vol. 5, no. 12, p. 378, Dec. 2023, doi: 10.1007/s42452-023-05608-0.

[10] F. Trojan *et al.*, "Class Thresholds Pre-Definition by Clustering Techniques for Applications of ELECTRE TRI Method," *Energies (Basel)*, vol. 16, no. 4, p. 1936, Feb. 2023, doi: 10.3390/en16041936.

[11] V. Mousseau, R. Slowinski, and P. Zielniewicz, "A user-oriented implementation of the ELECTRE-TRI method integrating preference elicitation support," *Comput Oper Res*, vol. 27, no. 7–8, pp. 757–777, Jun. 2000, doi: 10.1016/S0305-0548(99)00117-3.

[12] R. Micale, C. M. La Fata, and G. La Scalia, "A combined interval-valued ELECTRE TRI and TOPSIS approach for solving the storage location assignment problem," *Comput Ind Eng*, vol. 135, pp. 199–210, Sep. 2019, doi: 10.1016/j.cie.2019.06.011.

[13] H. Min, "Application of a decision support system to strategic warehousing decisions," *International Journal of Physical Distribution & Logistics Management*, vol. 39, no. 4, pp. 270–281, May 2009, doi: 10.1108/09600030910962230.