JNEST EISSN: 2961-8738 ● PISSN: 2961-8916 ● DOI: 10.56741/jnest.v5i03.2328
Article Received 26 May 2026, Revised 01 Sep 2026

From Priority-Based Storage to Integrated Multi-Criteria Optimization: A Class-Based Storage Model Incorporating Throughput and Product Similarity

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***Abstract*—Warehouses without a structured storage system can lead to inefficiencies in operational activities, such as increased travel distances, longer retrieval times, and low storage space utilization. This study aims to design a more efficient warehouse layout using the Class-Based Storage (CBS) method with an approach that integrates throughput and product similarity factors in determining the priority of goods placement. The data used includes the number of Stock Keeping Units (SKUs), the frequency of incoming and outgoing goods movements, and product dimensions to calculate storage space requirements. Performance evaluation was conducted based on three main indicators: space utilization, travel distance, and operational time, analyzed simultaneously. The results indicate that the proposed layout significantly improves warehouse operational efficiency. The throughput-based alternative increased space utilization by 11.54% and reduced travel distance and time by 49.38%. Meanwhile, the alternative integrating throughput and product similarity yields the best results, with a 26.73% increase in space utilization and a 57.09% reduction in travel distance and time. The integration of these two factors results in a more structured and efficient storage grouping compared to a single-priority-based approach. Thus, this study demonstrates that a multi-criteria Class-Based Storage approach is capable of improving warehouse layout performance more comprehensively.**

***Index Terms*—ABC Analysis, Class-Based Storage, Storage Efficiency, Warehouse Layout.**

I. INTRODUCTION

Warehouses are a key component of the supply chain system, playing a role in the storage, control, and distribution of goods [1]. In practice, warehouses serve not only as storage facilities but also as control centers for material flow, which impacts the smooth operation of a company. However, many warehouses still use storage systems that lack structured grouping based on product movement rates and characteristics. This situation leads to inefficiencies in material flow, as evidenced by long movement distances, prolonged retrieval times, and low storage space utilization.

Warehouse layout plays a crucial role in determining the efficiency of operational activities, particularly in the processes of storing and retrieving goods. A layout that is not systematically designed can lead to intersecting material flows, increased operational time, and disorganization in goods storage [2]. Furthermore, placing goods without considering product movement rates can result in high-frequency products not being located in strategic spots. This leads to increased travel distances for operators and longer retrieval times. According [3] to warehouse operational efficiency is highly influenced by storage assignment policies and warehouse flow arrangements. In addition, an effective warehouse layout can minimize travel distance and improve product retrieval efficiency within warehouse operations [2].

When evaluating warehouse layout performance, indicators are needed that can comprehensively describe the level of operational efficiency. Several key indicators commonly used include space utilization, travel distance, and operational time, which are interrelated in determining the performance of the storage system. Space utilization indicates the level of warehouse capacity utilization, while travel distance and time reflect the efficiency of material handling activities within the warehouse. Therefore, warehouse layout design must consider all three indicators simultaneously to achieve an optimal storage system.

In addition to operational efficiency, product characteristics are also a key factor in the design of storage systems. In warehouses storing products with expiration dates, such as medical devices, a storage system is required that can ensure product quality and safety throughout the storage period. One commonly used principle is First Expired First Out (FEFO), a method of issuing goods based on the nearest expiration date [4]. The application of this principle adds complexity to warehouse management because the storage system is not only focused on efficiency but also on product quality control.

Various previous studies have shown that the implementation of the Class-Based Storage (CBS) method combined with ABC analysis can improve warehouse operational efficiency. Study [5] demonstrates that grouping items based on their movement rates can significantly improve order fulfillment efficiency. Similar results are also shown by studies [6] and [7], which state that the implementation of CBS can improve space utilization and reduce the distance and time required for goods movement. Research conducted by [8] also states that the implementation of Class-Based Storage can improve storage accessibility by grouping products according to movement characteristics and operational activity levels. Furthermore, a data-driven approach to layout design is supported by the concept of Warehouse & Distribution Science, which emphasizes the importance of optimizing distance and time in warehouse operations [9].

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Nevertheless, most previous studies have focused on improving the layout of existing warehouses by using one or two performance indicators separately. Previous studies also tended to consider only the level of goods movement as the basis for determining placement priorities, without integrating other relevant factors in warehouse storage management. In addition, warehouse layout optimization should also consider product relationships and storage allocation simultaneously in order to improve warehouse organization and operational efficiency [10]. Furthermore, layout performance evaluations have generally not been conducted simultaneously while comprehensively considering the relationships between performance indicators. This situation highlights the limitations of warehouse layout design approaches that remain fragmented and lack integration. According to [11] warehouse layout design requires a comprehensive approach that integrates storage accessibility, operational flow, and product relationships within a single analytical framework.

Based on this gap, this study proposes a warehouse layout design approach that simultaneously integrates several key aspects into a single analytical model. This study not only employs the Class-Based Storage method based on ABC classification but also combines throughput and product similarity factors in determining item placement priorities. The integration of these two factors allows for the grouping of goods not only based on activity levels but also based on the relationships between product characteristics, resulting in a more systematic storage structure. Additionally, layout evaluation is conducted by considering three key performance indicators—space utilization, travel distance, and operational time—in an integrated manner during the decision-making process.

Thus, the main contribution of this study lies in the development of a Class-Based Storage model that is not only based on movement priorities but also simultaneously integrates product similarity and multi-indicator evaluation. This approach offers a new perspective on warehouse layout design that is more comprehensive than previous studies, which tended to use a single-factor approach. In addition to improving operational efficiency, the proposed model is also capable of supporting more structured storage management in warehouses with diverse product characteristics. Therefore, this study is expected to serve as a reference in the development of warehouse layout design methods based on multi-criteria integration.

II. Research Methodology

This study employs a quantitative approach utilizing a case study method to analyze a warehousing system. The data used includes Stock Keeping Unit (SKU) data, the number of incoming and outgoing goods during the January–December 2025 period, product dimensions, storage facility capacity, and the existing warehouse layout. Data collection was conducted through direct observation and warehouse operational documentation. The data obtained was then systematically processed to produce an optimal warehouse layout design model.

This study proposes a warehouse layout design model based on Class-Based Storage that integrates three main aspects: throughput (T), popularity (P), and product similarity (S). Throughput represents the actual activity level of products in the warehouse, popularity indicates the frequency of product use, while similarity describes the common characteristics among products. The integration of these three aspects is used to determine the priority of goods placement in a more comprehensive manner compared to conventional approaches. According to [12] warehouse storage policies significantly influence operational efficiency because product placement directly affects travel distance and picking performance.

A. Proposed Research Model

The research model developed in this study integrates three main variables: throughput (T), popularity (P), and product similarity (S). These three variables are used simultaneously to determine the priority of item placement within the storage system. Throughput and popularity serve to represent the level of product activity, while similarity is used to group products based on shared characteristics. Thus, the proposed model considers not only the frequency of item movement but also the relationships between products within the warehouse.

Conceptually, this model can be represented as a multi-criteria optimization approach, where the primary objectives are to minimize travel distance and time while maximizing storage space utility. This approach is consistent with warehouse optimization concepts proposed by [13] which emphasize the importance of integrating storage assignment and travel distance reduction within warehouse systems. The priority of item placement is determined based on the Priority Index (PI_i) value, while location clustering is determined based on product characteristic similarity. The integration of activity and similarity aspects results in a more systematic and efficient storage structure. Therefore, this model provides a more comprehensive approach compared to conventional Class-Based Storage methods.

The model proposed in this study operates by integrating the three main variables into the process of determining storage priorities and groupings. The throughput (T_i) and popularity (P_i) variables are used to determine the level of product activity, while similarity (S_i) is used to identify relationships between products within the storage system. The integration process is carried out by calculating priority values (PI_i) as the basis for item placement and product grouping based on similar characteristics. Thus, this model produces a layout that is not only operationally efficient but also structured in terms of storage grouping.

The implementation framework of the proposed model is carried out through a structured sequence of analytical steps to ensure alignment between theoretical concepts and practical application. The process begins with data collection and processing, followed by the calculation of key parameters such as throughput (T_i), popularity (P_i), and space requirements (S_i). These parameters are then integrated into the Priority Index (PI_i) as the basis for determining storage priorities. Thus, the proposed model is able to generate more structured and data-driven storage decisions.

Furthermore, product similarity (S_i) is incorporated to

support grouping decisions based on product characteristics. This integration enables products with similar attributes to be placed in close proximity, thereby improving picking efficiency. In addition, this approach helps reduce operational complexity within warehouse activities because relationships between products become more clearly defined. Therefore, the grouping process is not only activity-based but also considers product relationships.

The results of the model are then translated into warehouse zoning and layout design. Each storage zone is determined based on product classification and priority values, resulting in optimal space utilization and reduced travel distance. This process also considers material flow to avoid crossing operational activities. Thus, this implementation framework provides both theoretical and practical contributions to warehouse layout optimization.

The integration of throughput, popularity, and product similarity in the proposed model follows a sequential decision-making framework rather than a weighted optimization approach. As illustrated in Figure 1, throughput is first calculated to represent the operational activity level of each Stock Keeping Unit (SKU). Subsequently, popularity is incorporated together with throughput to establish storage priorities through ABC classification and priority ranking. Once the priority levels have been determined, product similarity is evaluated to group products with similar characteristics within the same storage zone. This sequential integration ensures that storage assignment considers both operational importance and product relationships, resulting in a more systematic and efficient warehouse layout. The overall decision-making framework of the proposed model is illustrated in Figure 1.

B. Stages of Research Methodology

1. Evaluation of Existing Warehouse Layout

The evaluation was conducted to assess the initial performance of the warehouse layout. The indicators used included space utilization (%), total travel distance (meters), and operational time (minutes). Distance was calculated using the rectilinear distance method, while time was calculated based on the average movement speed of operators (m/s). The evaluation results were used as a benchmark against the proposed layout.

This approach is widely used in warehouse layout research because it provides more systematic and measurable results in improving operational efficiency [14]. By utilizing data on goods movement and product characteristics, the layout design can be tailored to the actual conditions of the warehouse, thereby yielding a more optimal solution [15]. The movement distance is calculated using the rectilinear distance method with the following formula:

$$d_{ij} = |x_i - x_j| + |y_i - y_j| \quad (1)$$

where d_{ij} is the distance between two points, and x and y are the location coordinates. The travel time is calculated based on the operator's average speed.

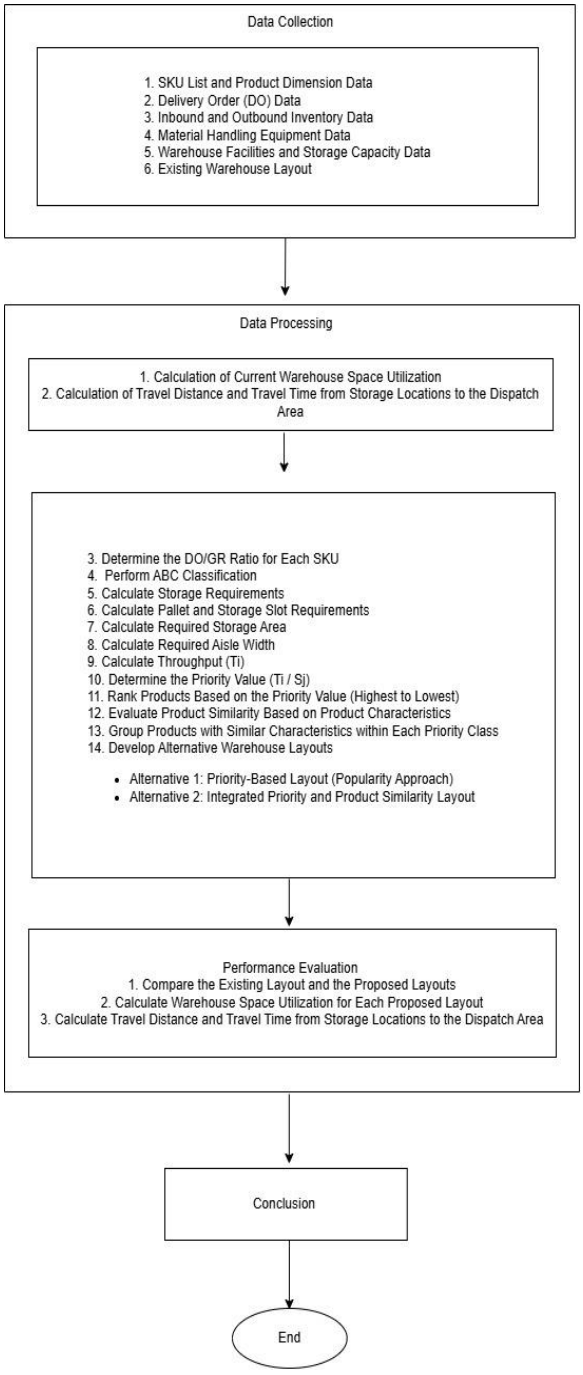


Fig.1. Proposed Decision-Making Framework

2. Processing of Goods Movement Data

Inbound and outbound inventory data were analyzed for each SKU during the study period. Total movement was calculated in units per year to reflect product activity. This value is defined as popularity (P_i), which represents the frequency of product use within the warehouse. Products with a high Pi value are categorized as high-priority products for placement.

3. ABC Classification

Classification is based on cumulative contribution to total goods movement. Products are grouped into Class A (±80%), Class B (±15%), and Class C (±5%) according to the Pareto principle. Class A represents products with the highest activity levels and is the top priority. The classification results are used as the basis for dividing storage zones.

4. Throughput Calculation (T_i)

Throughput is calculated for each SKU as a measure of the intensity of the flow of goods. The throughput value (T_i) is defined as the total product activity over a given period (units/year) using the following equation:

$$T_i = I_i + O_i \quad (2)$$

where:

T_i = Throughput of product i (units/year)
I_i = Quantity of inbound goods (units/year)
O_i = Quantity of outbound goods (units/year)

Throughput is used as the primary parameter for determining the priority of goods placement. The higher the T_i value, the more frequently the product moves within the warehouse system. According to [12] products with high throughput values should be placed closer to input and output areas in order to minimize operational travel distance and improve picking efficiency.

5. Space Requirements Calculation (S_i)

Space requirements (S_i) are calculated based on product dimensions, the number of units, and the capacity of the pallet or storage rack. The S_i value is expressed in square meters (m²). This calculation aims to accurately determine the storage space requirements for each SKU. Additionally, the S_i value is used in calculations of space utilization efficiency.

6. Calculation of Priority Value (T/S Ratio)

To integrate activity aspects and space requirements, a ratio between throughput and space requirements is used. The calculation is performed using the following equation:

$$Priotity\ Index\ (PI_i) = \frac{T}{S} \quad (3)$$

where:

PI_i = Product Priority Value
T_i = Throughput (units/year)
S_i = Space Requirement (m^2)

The PI_i value is used to prioritize the placement of items. Products with a high PI_i value indicate high activity with low space requirements, making them the top priority.

The use of the PI_i value in this study allows for a more objective evaluation of the priority of goods placement. Products with a high PI_i value indicates a significant contribution to system activity with relatively small space requirements, thereby providing greater efficiency in the use of storage space. Conversely, products with low PI_i Values tend to have a small contribution to activity or require a large amount of space, so they are placed in areas with lower priority. Thus, PI_i serves as a key indicator in optimizing the balance between activity and space utilization.

7. Clustering Based on Product Similarity (S_i)

Similarity clustering is performed to identify relationships between products. The similarity parameter (S_i) is determined based on product characteristics, such as item type, product category, and storage requirements. Clustering is performed categorically based on available product data. Products with high similarity are placed in adjacent areas to improve picking efficiency. Research conducted by [16] explains that grouping products with similar characteristics can reduce material handling complexity and improve warehouse organization.

In this study, similarity was determined categorically based on product attributes available in the warehouse data. The parameters used included product type, product category, and storage characteristics such as special handling requirements and product functionality. Products with the same attributes or a high degree of similarity were grouped into the same category. This approach allows for systematic product grouping and is easily implemented in warehouse operations.

8. Proposed Layout Design

The warehouse layout design was carried out using the Class-Based Storage (CBS) method, which is based on the results of the ABC classification and the priority values (PI_i) obtained. The warehouse area is divided into several storage zones: Zones A, B, and C, where Zone A is located closest to the input/output area, followed by Zone B, and Zone C in the farthest area. The area of each zone is determined based on the space requirement (S_i) of each product class, so that storage capacity can be optimally allocated. This zoning aims to minimize the distance goods are moved by placing high-activity products in more strategic locations. In this study, product similarity was operationally defined using a product family classification approach rather than a mathematical similarity metric or clustering algorithm. After the ABC classification and storage priorities had been established, products within each priority class were further grouped according to their product type. Products belonging to the same product family, such as diluents, object glass products, or other identical product categories, were assigned to adjacent storage locations within the same storage zone. This grouping approach facilitates product identification, improves storage organization, and enables warehouse personnel to locate products more efficiently during storage and retrieval activities. The product family classification was based on the company's established product categories and was applied consistently to all Stock Keeping Units (SKUs), thereby reducing subjectivity in the storage grouping process. According to [17], the implementation of the Class-Based Storage approach can minimize material transfer distance and improve warehouse layout efficiency. This zoning approach is widely applied in warehouse layout optimization because it allows high-activity products to be accessed more efficiently during operational activities [18].

Next, products are placed in each zone based on their priority index (PI_i) in descending order. Products with the highest PI_i Values are placed closest to the main aisle and access areas, while products with lower values are placed further inside the zone. In addition to considering priority values, placement also takes into account ease of access for operators and material flow efficiency. This aims to reduce the time spent searching for and retrieving items during operational activities.

Product similarity is integrated by grouping products with similar characteristics into adjacent areas within the same zone. This grouping takes into account product type, product category, and storage characteristics such as

special handling requirements or functional similarities. With this approach, the picking process becomes more structured because products that are frequently picked together or have operational ties are placed in the same area. Additionally, similarity grouping helps reduce the potential for picking errors and improves navigation efficiency within the warehouse.

The layout design also takes into account other technical factors, such as aisle width, rack capacity, and the direction of material flow. Aisle width is determined based on the movement requirements of material handling equipment to prevent obstructions during operations. Additionally, the flow pattern is designed as a one-way flow to avoid the crossing of incoming and outgoing goods. Thus, the proposed layout not only optimizes the placement of goods but also supports the smooth operation of overall activities.

9. Performance Evaluation of the Proposed Layout

A performance evaluation of the proposed layout was conducted to determine the degree of efficiency improvement compared to the existing conditions. The evaluation was carried out using three key indicators: space utilization, total travel distance, and operational time. Space utilization was calculated by comparing the area of storage space in use to the total available warehouse area, expressed as a percentage. This indicator is used to measure the extent to which warehouse capacity is optimally utilized following the layout design

The travel distance is calculated by summing the total distance traveled during put-away and picking activities. The distance is calculated using the rectilinear distance method based on the coordinates of the storage location and the input/output points. Next, the total distance is multiplied by the movement frequency of each SKU to obtain the total movement distance within a single operational period. With this approach, the distance calculation considers not only the position but also the intensity of product activity.

Operational time is calculated based on the total distance traveled and the average speed of the material handling equipment used in the warehouse. Time is calculated in minutes by dividing the total distance by the speed of the operator or equipment. This calculation indicates the time efficiency required for goods retrieval and storage activities. Thus, the time indicator serves as a direct measure of warehouse operational efficiency.

The evaluation results for each layout alternative were then compared with the existing conditions to determine the extent of performance improvement. The comparison was conducted using both absolute values and percentage changes for each indicator. An analysis was performed to identify the alternative that yielded the most significant improvement in operational efficiency. The alternative with the best results was selected as the optimal warehouse layout recommendation and deemed suitable for implementation.

III. Results and Discussion

This section presents the results of a performance evaluation of warehouse layouts based on the existing conditions and two proposed layout alternatives designed using the Class-Based Storage method. The evaluation was conducted using three key indicators: space utilization, total travel distance, and operational time. Additionally, a comparative analysis was performed between the two alternatives to determine the optimal layout. The results obtained are used as the basis for providing recommendations for warehouse layout improvements.

A. Existing Condition of the Warehouse

Based on the data analysis, the existing warehouse has a space utilization rate of 58.11%, a total travel distance of 77,211.94 meters, and a total travel time of 1,457,375.28 seconds. These figures indicate that the current warehouse layout is not yet optimal in supporting operational efficiency. The low space utilization suggests that storage area usage is not yet maximized, while the high movement distance and operational time indicate inefficiencies in material flow within the warehouse.

This situation is caused by a storage system that still uses a shared storage approach without grouping items based on their movement frequency. Unstructured item placement results in high-frequency products not being located in strategic areas. This forces operators to travel longer distances during the picking process. This situation aligns with warehouse layout concepts, which state that placing goods without considering movement frequency can increase travel distances and operational time [1]. A summary of the existing layout's performance is shown in Table 1, and the existing layout is illustrated in Figure 1.

TABLE I. Existing Warehouse Layout Performance

Performance Indicator	Current Layout
Number of Storage Facilities (Units)	36
Total Used Storage Area (m²)	48.00
Space Utilization (%)	58.11
Total Travel Distance (m)	77211.94
Total Travel Time (seconds)	1457375.28

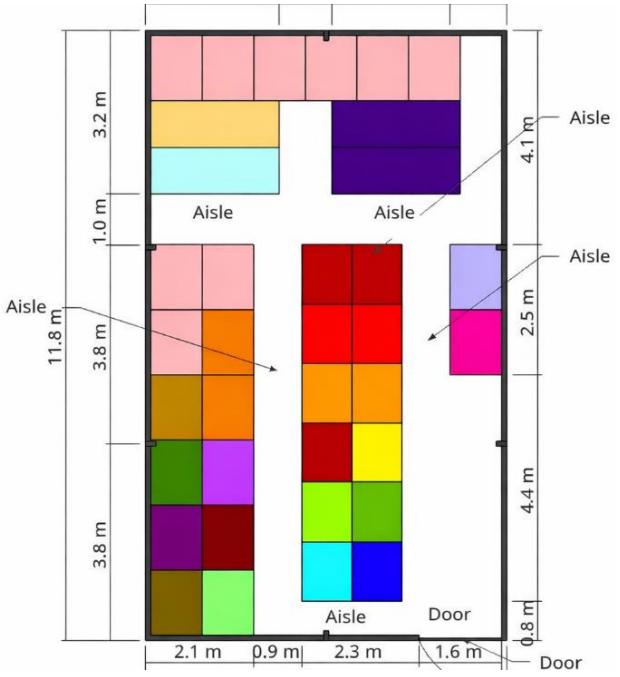


Fig.1. Layout of Existing Conditions

This situation indicates that an unstructured warehouse layout results in inefficient material flow. Storing goods without considering the level of movement activity leads to increased travel distances for operators and longer operational

times. This is consistent with previous research stating that warehouse layout has a significant impact on operational efficiency [15]. Therefore, improvements to the layout are necessary to enhance overall warehouse performance.

B. Alternative Layout 1 Results

The implementation of the Class-Based Storage method in Alternative 1 shows a performance improvement compared to the existing conditions. Space utilization increased to 64.82%, a rise of 11.54%, indicating more optimal use of space. Additionally, the total travel distance decreased to 39,082.31 m, a reduction of 49.38%. This reduction indicates that grouping items based on movement frequency shortens the distance operators must travel during picking activities.

The reduction in travel distance also had a direct impact on operational time, which decreased to 737,678.54 seconds—a 49.38% reduction. Previous studies also demonstrated that warehouse layout reconfiguration using the Class-Based Storage method can significantly reduce travel distance during warehouse operations [17]. This demonstrates that the implementation of the Class-Based Storage method significantly improves the efficiency of material handling processes. These results align with previous studies stating that grouping goods based on movement activity can accelerate the picking process and reduce operational time [7], [9], [14]. The approach used in Alternative 1 is based on the popularity or frequency of goods movement. Product placement was performed by considering throughput value without regard to similarities in product characteristics. Thus, the grouping of goods focused only on movement activity levels, thereby failing to fully optimize the proximity of products with similar characteristics. The performance results of layout alternative 1 are shown in Table II and Figure 2.

TABLE II. ALTERNATIVE 1 LAYOUT PERFORMANCE

Performance Indicator	Proposed Layout Alternative 1
Number of Storage Facilities (Units)	39
Total Used Storage Area (m²)	53.54
Space Utilization (%)	64.82
Total Travel Distance (m)	39082.31
Total Travel Time (seconds)	737678.54

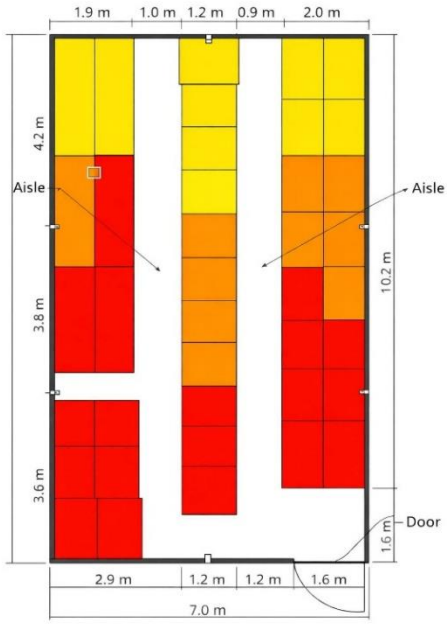


Fig. 2. Alternative Layout 1

Although Alternative 1 demonstrates a significant performance improvement, an approach based solely on popularity still has limitations when it comes to optimizing product relationships. Grouping that does not take product characteristics into account can result in a less structured storage layout. This indicates that similarity factors also need to be considered in warehouse layout design. Therefore, a more comprehensive approach is needed to determine the placement of goods.

This can be further explained through an analysis of product throughput and popularity as the basis for determining item placement priorities. The throughput value (T_i), calculated based on total incoming and outgoing goods, indicates the actual activity level of each SKU in the warehouse. Products with high throughput values have a higher movement frequency and are therefore placed closer to the input/output areas to minimize movement distance. This results in a significant reduction in total movement distance in Alternative 1.

In addition, the popularity value (Pi), calculated based on the proportion of total movement, indicates the distribution of product activity within the warehouse. Products with high Pi values, which generally fall into Class A, contribute the most to total goods movement. By placing these products in more strategic locations, the storage system becomes more efficient in supporting picking operations. This is evidenced by a 49.38% reduction in operational distance and time compared to the existing conditions.

However, an approach based solely on throughput and popularity still has limitations because it does not take into account the relationships between products. Products with similar characteristics may still be scattered across different locations, potentially increasing the complexity of the picking process. This situation indicates that while an activity-based approach is effective in improving efficiency, the integration of other factors—such as similarity—is necessary to produce a more optimal layout.

C. Alternative Layout Results 2

Layout alternative 2 demonstrates better performance compared to alternative 1 and the existing conditions. Space utilization increased to 73.64%, representing a 26.73% increase, indicating more optimal use of space. Additionally, the total travel distance decreased to 33,126.53 m, representing a 57.09% reduction. This reduction indicates that placing goods based on more precise priorities can improve movement efficiency within the warehouse.

Travel time also decreased significantly to 626,040.53 seconds, a reduction of 57.09%. This indicates that the resulting layout is capable of significantly reducing operational time. These reductions in distance and time demonstrate that a zoning arrangement based on priority can improve the efficiency of material handling activities within the warehouse.

Unlike Alternative 1, the approach in Alternative 2 not only considers popularity based on the frequency of goods movement but also takes into account the similarity of product characteristics. This grouping allows products with similar characteristics to be placed in adjacent zones, thereby improving efficiency in the storage and retrieval processes. Additionally, this approach supports more structured

inventory management, particularly for products with special characteristics, such as medical devices that require specific handling.

The improvement of 57.09% in both travel distance and operational time indicates that more than half of the inefficiencies in the existing layout can be eliminated through a structured layout design. This suggests that improper product placement is a major contributor to operational inefficiencies in warehouse systems. With a priority-based arrangement, material flow becomes more organized and systematic.

Furthermore, the significant increase in space utilization indicates that the proposed layout is able to maximize storage capacity without requiring additional physical expansion. This is particularly important for companies operating under space constraints. By optimizing existing space, companies can improve efficiency without incurring additional infrastructure costs.

These findings demonstrate that integrating multiple variables into a single analytical model provides a more accurate representation of warehouse conditions compared to single-factor approaches. Therefore, the proposed model offers a more effective solution for improving warehouse performance. This also highlights the importance of a multi-criteria approach in storage system design. Research conducted by [11] explains that warehouse layout design should consider storage accessibility and operational flow simultaneously in order to achieve optimal warehouse performance.

The combination of popularity and similarity approaches results in a more organized layout compared to an approach based solely on movement frequency. Product placement takes into account not only activity levels but also the relationships between products, thereby reducing potential irregularities in storage. This leads to an improvement in overall operational efficiency. Research conducted by [19] explains that warehouse picking optimization can significantly reduce operational time in logistics systems. According to [20] warehouse operational performance is strongly influenced by material handling efficiency and storage allocation strategies. The performance results for alternative layout 2 are shown in Table III and Figure 3.

TABLE III. ALTERNATIVE 2 LAYOUT PERFORMANCE

Performance Indicator	Proposed Layout Alternative 2
Number of Storage Facilities (Units)	44
Total Used Storage Area (m²)	60.83
Space Utilization (%)	73.64
Total Travel Distance (m)	33133.53
Total Travel Time (seconds)	625395.40

Unlike Alternative 1, the approach in Alternative 2 not only considers popularity based on the frequency of goods movement but also takes into account the similarity of product characteristics. This grouping allows products with similar characteristics to be placed in adjacent zones, thereby improving efficiency in the storage and retrieval processes. Additionally, this approach supports more structured inventory management, particularly for products with special characteristics, such as medical devices that require specific handling.

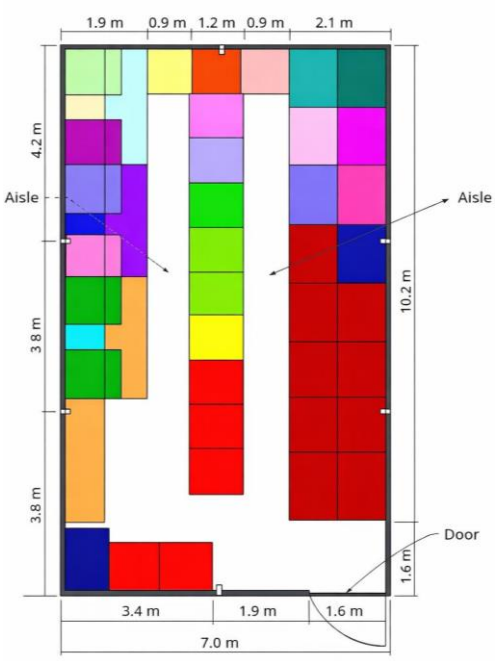


Fig. 3. Alternative Layout 2

The approach in Alternative 2 is also based on the use of a priority index (Pl_i), which is the result of integrating throughput (T_i) and space requirements (S_i). Mathematically, the PIi value is calculated as the ratio of throughput to space requirements, thereby taking into account not only the product's activity level but also the efficiency of storage space utilization. Products with a high Pl_i value indicate a combination of high activity and relatively low space requirements, making them the top priority for placement in strategic locations. This approach allows for a more balanced distribution of goods placement compared to one based solely on throughput.

In addition, the integration of the product similarity factor (S_i) makes a significant contribution to improving warehouse operational efficiency. Products with similar characteristics are grouped in the same zone, thereby reducing the variation in operators' movement paths during the picking process. This results in reduced search times and increased speed in the picking process. Recent studies on warehouse operations also indicate that effective order-picking strategies play an important role in improving warehouse productivity and operational performance [21]. Thus, similarity serves as a factor that reinforces the efficiency previously achieved through a throughput-based approach.

The combination of popularity, throughput, and similarity approaches yields a more organized layout compared to approaches based solely on movement frequency. This is reflected in a 26.73% increase in space utilization and a 57.09% reduction in travel distance and time compared to the existing conditions. These improvements demonstrate that multi-criteria integration can deliver more optimal results in warehouse layout design. Thus, this approach not only enhances operational efficiency but also creates a more structured and easily manageable storage system.

D. Layout Performance Comparison

Based on the comparison results, both proposed layout alternatives demonstrate improved performance compared to the existing conditions. This improvement is evident in the

increased space utilization and the reduction in total distance and time required for goods movement. This indicates that the implementation of the Class-Based Storage method can significantly improve warehouse operational efficiency. According to [22] efficient storage location assignment can significantly improve order-picking performance and reduce operational travel distance in warehouse systems. By grouping goods based on their movement frequency, material flow becomes more structured and directed.

When comparing the two alternatives, Alternative 2 performs better than Alternative 1 across all indicators used. Comparative studies between dedicated storage and Class-Based Storage methods show that Class-Based Storage provides better flexibility and operational efficiency in warehouse management [23]. This is due to the different approaches used in the layout design. Alternative 1 uses only a popularity-based (throughput) approach, so the placement of items focuses on movement frequency. Meanwhile, Alternative 2 combines the popularity approach with product similarity, resulting in a more structured grouping.

The similarity-based approach in Alternative 2 allows products with similar characteristics to be placed in adjacent zones. This not only improves efficiency in the picking process but also simplifies inventory management, particularly for products with specific characteristics such as medical devices. Additionally, this grouping reduces the potential for errors in the picking process. Consequently, the layout becomes more systematic and supports the smooth operation of the warehouse. According to [24] reducing unnecessary travel within warehouse systems can improve picking efficiency and overall warehouse productivity.

Overall, the research results indicate that integrating popularity and similarity factors contributes more significantly to improving warehouse layout performance than an approach based solely on popularity. The increase in space utilization indicates that storage capacity is being utilized more optimally. Meanwhile, the reduction in distance and movement time indicates an increase in efficiency in material handling activities. Thus, Alternative 2 was selected as the best layout recommended for implementation at the PT Tiara Agung Pratama warehouse.

Table IV shows the percentage change in performance of the proposed layout compared to the existing conditions. The percentage values are calculated based on the difference between the alternative values and the existing conditions, which are then compared to the existing values. Positive values indicate a performance improvement, while negative values indicate a decline compared to the initial conditions.

TABLE IV. PERFORMANCE COMPARISON OF PROPOSED LAYOUTS AGAINST EXISTING CONDITIONS

Performance Indicator	Proposed Layout Alternative 1 (%)	Proposed Layout Alternative 2 (%)
Number of Storage Facilities (%)	8.33	22.22
Total Used Storage Area (%)	11.54	26.73
Space Utilization (%)	11.54	26.73
Total Travel Distance (%)	-49.38	-57.09
Total Travel Time (%)	-49.38	-57.09

Remarks: the (+) value indicates an increase, while the value (−) indicates a decrease compared to the existing condition.

Based on the comparison results, both proposed layout alternatives demonstrate improved performance compared to the existing conditions. This improvement is evidenced by increased space utilization and a significant reduction in the total distance and time required for goods movement. This indicates that the implementation of a Class-Based Storage method based on activity analysis can enhance warehouse operational efficiency. The results of this study are consistent with previous research conducted by [12] which states that storage policies and picking strategies significantly affect warehouse operational efficiency. By grouping goods according to their movement frequency, material flow becomes more structured and directed.

When comparing the two alternatives, Alternative 2 delivers better performance than Alternative 1 across all indicators used. This difference in performance stems from differing approaches to determining product placement priorities. Alternative 1 employs a method based on throughput (T_i) and popularity (Pl_i), focusing on the intensity of product activity. Meanwhile, Alternative 2 integrates throughput (T_i), space requirements (S_i), and product similarity (S_i), resulting in a more comprehensive multi-criteria approach.

Analytically, the approach in Alternative 1 tends to maximize efficiency based solely on movement frequency, so that high-activity products are placed in strategic locations without considering inter-product relationships. This leads to potential irregularities in storage, as products with similar characteristics may be scattered across different locations. Conversely, in Alternative 2, the use of priority values ($PI_i = \frac{T_i}{S_i}$) allows for the integration of activity and space requirements into a single parameter. This approach results in a more balanced distribution of goods placement and improves the efficiency of storage space utilization.

In addition, the integration of the product similarity factor (S_i) in Alternative 2 provides an additional contribution to improving operational efficiency. Grouping products based on similar characteristics allows for a reduction in the variation of operator movement paths during the picking process. This not only reduces travel distance and time but also improves the organization of the storage system. Thus, similarity serves as a reinforcing factor that complements the activity-based approach. The integration of throughput and product similarity in this study provides a more comprehensive warehouse layout approach compared to conventional storage assignment methods [10].

From a theoretical perspective, the findings of this study support the concept that warehouse layout design requires the integration of multiple performance indicators simultaneously. Conventional approaches that rely solely on a single parameter, such as movement frequency, are not sufficient to represent the complexity of warehouse systems. Therefore, a more comprehensive approach is required in decision-making. According to [25], warehouse performance evaluation should consider multiple operational indicators simultaneously in order to achieve a more effective layout design.

The integration of throughput, space requirements, and product similarity reflects a more holistic approach to

warehouse layout design. This approach aligns with modern warehouse management principles, which emphasize the balance between operational efficiency and storage organization. As a result, the resulting layout is not only efficient but also more structured.

Therefore, this study contributes to the development of warehouse optimization models by demonstrating the effectiveness of a multi-criteria approach in improving both operational performance and storage structure simultaneously. These findings also confirm that integrating multiple factors is essential to achieve optimal efficiency.

Overall, the research findings indicate that integrating throughput (T), popularity (P), and similarity (S) results in a more comprehensive warehouse layout design model. Throughput and popularity serve as the basis for determining priorities based on activity intensity, while similarity helps optimize the product grouping structure. The combination of these three factors results in a layout that is not only operationally efficient but also more systematically organized.

Overall, the findings demonstrate that integrating throughput, popularity, and product similarity provides a more comprehensive warehouse layout design framework than approaches based solely on product activity. Alternative 2 achieved superior performance because it integrates throughput, space requirements, and product similarity into a unified decision-making framework. These multi-criteria approach not only improves operational efficiency but also creates a more systematic storage structure by considering both product activity and product relationships. Consequently, the proposed framework offers practical advantages for warehouse layout planning, particularly in environments with diverse product characteristics and complex storage requirements.

E. Managerial Implications

The findings of this study offer managerial implications for companies seeking to improve warehouse operational efficiency through the implementation of the Class-Based Storage method. The implementation of this method has proven effective in significantly improving space utilization and reducing the distance and time required for goods movement. Consequently, companies can enhance operator productivity and expedite the distribution of goods to customers. Additionally, a more structured layout helps minimize the potential for errors in the goods retrieval process.

In addition to improving operational efficiency, grouping products based on their turnover rates and characteristics also simplifies the inventory control process within the warehouse. This is particularly important in medical device distribution warehouses, which handle a high number of SKUs and a wide variety of product characteristics. With a more organized storage system, inventory monitoring and control can be carried out more accurately. As a result, the risk of stock surpluses or shortages can be minimized.

Implementing the proposed layout also has a positive impact on the quality of the company's customer service. Order fulfillment times are reduced because the picking process can be carried out more efficiently. This enables the company to improve its responsiveness to market demand and maintain customer satisfaction. Thus, improving the warehouse layout not only enhances internal efficiency but also boosts overall service performance.

Overall, the application of the Class-Based Storage method using the popularity and similarity approaches makes a significant contribution to improving warehouse performance. The combination of these two approaches results in a more systematic and user-friendly layout. These results indicate that the integration of activity factors and product characteristics is crucial in warehouse layout design. Therefore, this method can serve as a reference for developing more optimal warehouse storage systems in the future.

F. Scenario Analysis Under Demand Variation

To further evaluate the robustness of the proposed warehouse layout, a scenario analysis was conducted by considering demand fluctuations of ±10% from the baseline condition. These demand variation scenarios were selected to represent moderate increases and decreases that may occur during warehouse operations. The objective of this analysis was to determine whether changes in demand would affect the storage classification and the feasibility of the proposed warehouse layout.

TABLE V. SUMMARY OF SCENARIO ANALYSIS UNDER ± 10% DEMAND VARIATION

No	Item Code	Product/ Material Name	Existing Class	Impact on Layout
1	CON00006	Cont. Urine non Sterile 50 ml	A	Unchanged
2	ANS00002	Answer HBsAg Device	A	Unchanged
3	BC00001	BC 3000 Diluent	A	Unchanged
4	BC00002	BC 3000 Diluent1	A	Unchanged
5	MIN00012	Mindray CD 80 Detergent	A	Unchanged

Table V summarizes the comparison between the original storage classification and the simulated classification under the demand variation scenarios. The results indicate that the storage class assignment for each product remained unchanged after applying the ±10% demand scenarios. Consequently, the proposed warehouse layout did not require any storage reallocation or modification. This finding demonstrates that the proposed layout is capable of accommodating moderate demand fluctuations while maintaining the established storage configuration. Overall, all evaluated products retained their original storage class after the simulated ±10% demand variations, indicating that the proposed storage classification is stable under the evaluated demand scenarios.

The scenario analysis provides additional evidence of the robustness of the proposed warehouse layout. Since no changes were observed in the storage class assignments following the simulated ±10% demand variations, the proposed layout can accommodate moderate changes in demand without requiring storage reallocation. This indicates that the proposed decision-making framework is sufficiently stable under normal warehouse operating conditions and strengthens the reliability of the proposed warehouse layout model for practical implementation.

G. Comparison Between the Proposed and Conventional Class-Based Storage Approaches

To further highlight the contribution of the proposed

framework, a comparison was conducted between the proposed multi-criteria Class-Based Storage (CBS) model and conventional CBS approaches reported in previous studies. The comparison focuses on methodological characteristics, computational complexity, implementation effort, and practical advantages rather than numerical performance alone. This comparison provides a clearer understanding of the methodological contributions and practical applicability of the proposed warehouse layout design framework.

TABLE VI. COMPARISON BETWEEN CONVENTIONAL CBS AND THE PROPOSED MULTI-CRITERIA CBS MODEL

Aspect	Conventional CBS	Proposed Model
Storage assignment basis	Activity level (ABC/Throughput)	Throughput + Popularity + Product Similarity
Decision criteria	Single criterion	Multi-criteria
Product relationship	Not considered	Considered through product similarity
Storage organization	Activity-oriented	Activity- and relationship-oriented
Computational complexity	Low	Moderate
Implementation effort	Simple	Moderate (requires product similarity classification)
Practical advantages	Improves travel efficiency	Improves travel efficiency while providing a more systematic and organized storage structure

As shown in Table VI, the proposed framework extends the conventional CBS approach by integrating multiple decision criteria into a single storage assignment process. Unlike traditional CBS methods that primarily emphasize product activity, the proposed model simultaneously considers operational activity, storage space requirements, and product similarity. Although the proposed approach requires an additional product similarity classification process, this additional effort enables a more structured storage arrangement and improves warehouse organization. Consequently, the proposed framework offers greater practical value for warehouses with diverse product characteristics and more complex operational requirements.

IV. CONCLUSION

This study aims to design a more efficient warehouse layout using the Class-Based Storage method with an approach that integrates throughput, popularity, and product similarity factors. The results indicate that the existing layout is still suboptimal, characterized by low space utilization and high travel distances and times. The application of an activity-based Class-Based Storage method significantly improves operational efficiency. The improved performance of the proposed layout alternatives demonstrates this. The findings of this study support previous research indicating that warehouse layout optimization can significantly improve operational efficiency and storage organization [12].

Layout Alternative 1 demonstrates that an activity-based storage approach can improve warehouse performance by prioritizing products with higher operational activity. However, this approach does not consider the relationships among products, resulting in storage assignments that are primarily driven by movement frequency. Consequently, although operational efficiency is improved, the storage layout may not yet fully support a structured organization of products with similar characteristics.

In contrast, Layout Alternative 2 demonstrates that integrating throughput, space requirements, and product similarity into a unified decision-making framework provides a more comprehensive warehouse layout design. By simultaneously considering operational activity and product characteristics, the proposed model achieves a more systematic storage arrangement that supports warehouse efficiency while improving product organization. These findings indicate that the proposed multi-criteria approach offers a practical and adaptable solution for warehouse layout planning in environments with diverse product characteristics and operational requirements [11].

Overall, this study demonstrates that integrating throughput, popularity, and similarity into the Class-Based Storage method yields a more comprehensive warehouse layout design model. This approach not only improves operational efficiency but also results in a more organized and easily manageable storage system. According to modern warehouse management concepts, structured product grouping and efficient storage allocation are essential for improving warehouse operational performance [24]. Therefore, the proposed model can serve as an alternative solution for designing more optimal warehouse layouts.

Although this study was conducted using a single warehouse case study, the proposed framework is based on widely applicable warehouse management principles, including ABC classification, throughput analysis, priority-based storage allocation, and product family grouping. Therefore, the proposed approach has the potential to be adapted to warehouses with different layouts, product characteristics, storage policies, and operational scales, provided that the classification criteria and operational parameters are adjusted according to the specific characteristics of each warehouse. Accordingly, the proposed framework should be regarded as a transferable decision-making approach rather than a warehouse-specific solution. Nevertheless, the quantitative performance improvements may vary across different warehouse environments depending on their operational characteristics and storage conditions.

The performance evaluation in this study was intentionally limited to three operational indicators, namely space utilization, travel distance, and travel time, because these indicators directly reflect the effectiveness of warehouse layout optimization and storage allocation. Other important warehouse performance indicators, such as picking accuracy, labor productivity, order fulfillment rate, and operational cost, were not included, as they are influenced by additional operational factors beyond warehouse layout, including workforce performance, inventory management policies, and organizational procedures. Therefore, the findings of this study should be interpreted within the scope of warehouse layout optimization rather than overall warehouse operational performance.

Future research is recommended to incorporate additional factors such as implementation cost, labor productivity, and the use of automated material handling

systems. Furthermore, the integration of real-time data and digital warehouse systems may enhance the adaptability of the proposed model in dynamic operational environments.

Further studies can also explore the application of this model in different types of warehouses, such as e-commerce distribution centers and cold storage facilities, to evaluate its generalizability and scalability. Thus, the model can be further developed to become more adaptive and applicable across various industrial conditions.

REFERENCES

[1] J. J. Bartholdi and S. T. Hackman, *Warehouse and Distribution Science*, The Supply Chain and Logistics Institute, School of Industrial and Systems Engineering, Georgia Institute of Technology, 2008. [Online]. Available: https://books.google.co.id/books?id=9tlZAQAACAAJ

[2] J. A. Tompkins, J. A. White, Y. A. Bozer, and J. M. A. Tanchoco, *Facilities planning*. John Wiley & Sons, 2010.

[3] J. Gu, M. Goetschalckx, and L. F. McGinnis, "Research on warehouse operation: A comprehensive review," *Eur. J. Oper. Res.*, vol. 177, no. 1, pp. 1–21, Feb. 2007, doi: 10.1016/j.ejor.2006.02.025.

[4] D. Sri Rezeki, E. Girsang, M. Silaen, and S. R. Nasution, "Evaluation of drug storage using FIFO/FEFO methods in Royal Prima Medan Hospital pharmacy installation," *Int. J. Health Pharmaceutical (IJHP)*, vol. 2, no. 1, pp. 9–17, Feb. 2022, doi: 10.51601/ijhp.v2i1.8.

[5] 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, e378, Dec. 2023, doi: 10.1007/s42452-023-05608-0.

[6] V. Tiupysheva, N. Reznik, and A. Zahorodnia, "Modern condition and direct development of warehouse logistics," *Int. J. Innov. Technol. Econ.*, vol. 1, no. 41, Feb. 2023, doi: 10.31435/rsglobal_ijite/30032023/7938.

[7] N. Choernelia and A. Yohanes, "Usulan perbaikan tata letak pada gudang bahan jadi menggunakan metode class based storage (Studi kasus di PT. Garudafood Putra Putri Jaya Pati)," SITEKIN: Jurnal Sains, Teknologi dan Industri, vol. 20, no. 1, 2022, doi: 10.24014/sitekin.v20i1.18405.

[8] R. de Koster, T. Le-Duc, and K. J. Roodbergen, "Design and control of warehouse order picking: A literature review," *Eur. J. Operational Res.*, vol. 182, no. 2, pp. 481-501, 2007, doi: 10.1016/j.ejor.2006.07.009.

[9] J. I. A. Sutrisno and T. Octavia, "Implementasi sistem manajemen pergudangan dengan pendekatan class based storage dan metode ABC classification pada perusahaan farmasi," Teknoin, vol. 29, no. 1, pp. 25–31, 2024.

[10] S. S. Heragu, L. Du, R. J. Mantel, and P. C. Schuur, "Mathematical model for warehouse design and product allocation," *Int. J. Prod. Res.*, vol. 43, no. 2, pp. 327-338, 2005, doi: 10.1080/00207540412331285841.

[11] S. Sharma, "Revisiting the shelf life constrained multi-product manufacturing problem," *Eur. J. Oper. Res.*, vol. 193, no. 1, pp. 129–139, Feb. 2009, doi: 10.1016/j.ejor.2007.10.045.

[12] C. G. Petersen and G. Aase, "A comparison of picking, storage, and routing policies in manual order picking," *Int. J. Prod. Econ.*, vol. 92, no. 1, pp. 11–19, Nov. 2004, doi: 10.1016/j.ijpe.2003.09.006.

[13] K. J. Roodbergen and I. F. A. Vis, "A survey of literature on automated storage and retrieval systems," *Eur. J. Oper. Res.*, vol. 194, no. 2, pp. 343–362, Apr. 2009, doi: 10.1016/j.ejor.2008.01.038.

[14] E. A. Rahayu and R. Y. H. Silitonga, "Perbaikan tata letak gudang PT PYT dengan memperhatikan jarak, waktu handling, dan utilitas ruang penyimpanan," *J. Integrated System*, vol. 7, no. 1, pp. 31–51, Jun. 2024, doi: 10.28932/jis.v7i1.8678.

[15] J. Gu, M. Goetschalckx, and L. F. McGinnis, "Research on warehouse operation: A comprehensive review," *Eur. J. Oper. Res.*, vol. 177, no. 1, pp. 1–21, Feb. 2007, doi: 10.1016/j.ejor.2006.02.025.

[16] V. R. Muppani & G. K. Adil, "Efficient formation of storage classes for warehouse storage location assignment" *Omega*, vol. 36, no. 4, pp. 609-618, 2008, doi: 10.1016/j.omega.2007.01.006.

[17] K. Muhammad, B. P. Wicaksana, and A. A. Sibarani, "Warehouse layout design with class-based storage approach to minimize material transfer distance," *AIP Conf. Proc.*, vol. 2482, e090017, 2023, doi: 10.1063/5.0113824.

[18] M. Ragni, M. Perini, A. Setti, and P. Bosetti, "ARTool Zero: Programming trajectory of touching probes using augmented reality," *Comput. Ind. Eng.*, vol. 124, pp. 462–473, Oct. 2018, doi: 10.1016/j.cie.2018.07.026.

[19] D. Ueno and E. Hirata, "The optimization of picking in logistics warehouses in the event of sudden picking order changes and picking route blockages," *Math.*, vol. 12, no. 16, e2580, Aug. 2024, doi: 10.3390/math12162580.

[20] E. H. Frazelle, *World-Class Warehousing and Material Handling*, NY: McGraw-Hill Education, 2002.

[21] G. Casella, A. Volpi, R. Montanari, L. Tebaldi, and E. Bottani, "Trends in order picking: A 2007–2022 review of the literature," *Prod. Manuf. Res.*, vol. 11, no. 1, e2191115, Dec. 2023, doi: 10.1080/21693277.2023.2191115.

[22] M. Wang, R.-Q. Zhang, and K. Fan, "Improving order-picking operation through efficient storage location assignment in warehouses," *Comput. Industr. Eng.*, vol. 139, e106186, 2020, doi: 10.1016/j.cie.2019.106186.

[23] M. M. Pratama and S. S. Dahda, "Designing steel warehouse layouts: A comparative study of dedicated storage and class-based storage methods at PT. BSB," *Adv. Sustain. Sci. Eng. Technol.*, vol. 6, no. 3, May 2024, doi: 10.26877/asset.v6i3.737.

[24] G. Richards, *Warehouse Management: A Complete Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse*, Kogan Page, 2011.

[25] J. Gu, M. Goetschalckx, and L. F. McGinnis, "Research on warehouse design and performance evaluation: A comprehensive review," *Eur. J. Oper. Res.*, vol. 203, no. 3, pp. 539–549, Jun. 2010, doi: 10.1016/j.ejor.2009.07.031.



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