Designing Container Storage Layout Based on Quality Criteria to Improve Order Picking Efficiency

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**Abstract.** The growing demand for shipping goods using containers has driven the continued expansion of the empty container industry. This industry focuses on the trading of used containers and operates open storage facilities. It relies heavily on large material handling equipment—such as forklifts and reach stackers—which require ample space for maneuvering. Customer preferences in selecting containers vary widely, adding complexity to the picking and stacking processes. Managing the stacking and placement of containers in open yards presents a particular challenge, especially in the order picking phase. This research aims to develop a more efficient warehouse layout by grouping and placing containers based on their quality. The Analytical Hierarchy Process (AHP) is employed to assign weights to various container quality criteria, such as physical condition and price, which are then used to define storage zones. Based on the AHP results, a U-shaped layout is proposed and evaluated against the current layout using the Return method for order picking route analysis. The findings show that the proposed layout improves order picking time efficiency by 73%, reduces forklift travel distance by 77.60%, and decreases average container reshuffling time by 83%. These results suggest that integrating a quality-based grouping system into warehouse layout design can significantly enhance operational efficiency.

# INTRODUCTION

Warehouses play a crucial role in the supply chain as centers for the storage, management, and distribution of goods. The primary function of a warehouse is to ensure the availability of goods according to customer demand, both in terms of quantity and timeliness. Furthermore, warehouses also play a role in optimizing the flow of goods from suppliers to customers, thereby reducing logistics costs and increasing responsiveness to market demand. Therefore, warehouses serve not only as storage locations but also as strategic elements influencing the overall performance of the supply chain [1]. Warehouse efficiency is a key factor in reducing operational costs and enhancing customer satisfaction. A well-managed warehouse can minimize lead times in order fulfillment, reduce storage costs, and avoid overstocking or understocking [2]. However, achieving this efficiency requires an optimal warehouse layout, sound inventory management, and structured operational processes such as order picking. An efficient order picking process not only accelerates order fulfillment but also reduces operational expenses [3]. Despite its importance, many warehouses face persistent challenges in achieving high efficiency. Common issues include limited space, suboptimal inventory organization, and inefficient order picking processes [3]. Poor space utilization often leads to disorganized stacking, making it difficult to retrieve goods. Inappropriate item placement such as frequently requested items located in hard-to-reach areas can slow down operations and increase labor costs [4]. These issues necessitate a systematic approach involving improved layout design, item classification based on relevant criteria, and the use of optimization methods.

This research focuses on the used container trading industry, particularly 20ft and 40ft containers utilized for both international and domestic transportation. The company offers a variety of containers including open-top containers, reefer containers, flat rack containers (for general purpose and high cube sizes), iso-tanks, and skid tanks. It operates an open yard storage facility consisting of a working area and a finished goods area for containers that have been repaired or modified. The business process begins with the procurement of used containers from both local and international sources. Upon arrival, containers undergo a thorough inspection to assess their physical condition before being stored in the yard. However, the current layout system only considers container size and space availability at the time of arrival, without a structured placement strategy. In the order fulfillment process, customers are allowed to select their preferred container based on the availability list. Problems arise because the storage system prioritizes placing newly arrived containers at the front of the yard for easy access. In contrast, customers often prefer containers stored at the back due to their lower price, specific brand, age, or physical condition such as rust, dents, or door functionality. This mismatch forces the operational team to perform intensive reshuffling to access the requested containers. The core problem lies in the layout design of container placement, which does not consider accessibility or container quality. Containers are arranged randomly, based only on size, without considering other important criteria such as price, condition, arrival time, or ownership. Consequently, customers find it difficult to locate containers that meet their specific needs. Additionally, the yard has only a single central forklift lane, which limits maneuverability and further reduces operational efficiency. Forklifts often need to move multiple containers from the front or top to access the desired one, especially if it is located at the back or bottom of the stack.

In response to these issues, this research aims to design an improved container yard layout by incorporating container quality criteria to enhance order picking efficiency. Each container will be assigned a weight based on its quality attributes using the AHP. The resulting weights will serve as a reference for determining container placement that minimizes forklift travel time during the order picking process, using the return method for route analysis. The objectives of this study are to identify relevant container quality criteria, determine the container weights using AHP, design a storage layout based on the calculated weights, and compare the order picking travel time between the existing layout and the improved layout using the Return route method. Therefore, this study is expected to contribute to the enhancement of container yard operations by offering a structured quality-based layout planning approach that reduces handling time, improves responsiveness, and enhances overall logistics efficiency.

# LITERATURE REVIEW

This study aims to analyze the order picking process in container warehouses by improving efficiency through layout redesign, optimization of forklift travel routes, and the implementation of a container grouping system based on quality criteria. In general, warehouse operations consist of several stages including receiving, put away, movement, picking, and shipping [5]. Among these, order picking is considered the most critical activity, as it accounts for the largest portion of time and operational costs [6]. In container warehouses, order picking takes place after customers select containers based on characteristics such as size, price, condition, and ownership [7] [8]. However, the current storage strategy, which is based solely on container size, often leads to frequently requested containers being stored in difficult-to-access locations. This problem is compounded by limited forklift access and the absence of grouping based on demand frequency or container quality, resulting in increased retrieval time and inefficiencies [9].

The efficiency of order picking is highly dependent on the design of warehouse layouts and the travel paths of material handling equipment. Poor layout design can increase travel distances by up to 30% [10], while inefficient routing further contributes to extended picking times [11]. AHP method offers a systematic method to evaluate and assign weights to multiple criteria such as demand frequency, physical condition, price, and arrival time (Saaty, 2008), while maintaining consistency in decision-making [12]. Previous studies have investigated various aspects of warehouse optimization using different approaches. Other researchers such as Muharni et al. (2020) and Mulyati et al. (2020) explored Class-Based and Shared Storage systems to enhance warehouse efficiency yet still did not integrate container quality criteria [13] [14]. Meanwhile, several studies have demonstrated the versatility of AHP in multi-criteria decision-making. Febryanto et al. (2022) used AHP for warehouse location selection, Juniantoro et al. (2023) applied it for evaluating sugarcane seed quality, and Heitasari and Mustikahadi (2024) used it for MRO material procurement [15] [16] [17]. While these studies highlight the robustness of AHP, none have applied it directly to container storage management. Additionally, Adib et al. (2023) and Anjela and Riyanto (2020) emphasized the benefits of layout design based on specific criteria, although their work was situated in production line environments rather than warehouse storage contexts [18] [19].

Based on the literature, there is a clear research gap in integrating container quality assessments into the design of warehouse layouts. To address this gap, the present study proposes a warehouse layout design for used containers that incorporates container quality as the primary basis for storage allocation. The AHP method is used to determine the weight of each quality criterion, which in turn guides the development of alternative storage zones. This approach not only aims to improve order picking efficiency through a U-shaped layout and Return routing method but also ensures that high-quality containers are more accessible, thereby supporting more effective and value-oriented container retrieval.

# METHOD

## Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a hierarchical decision-making method that relies on pairwise comparisons among criteria and alternatives. Each criterion is assigned a weight based on its perceived importance, which is determined subjectively by decision-makers. The consistency of these comparisons is then evaluated to ensure reliability. AHP is particularly effective for problems involving qualitative criteria and subjective judgments, offering a structured framework for multi-criteria decision analysis. The implementation of AHP in this study follows several systematic steps:

1. Problem Identification and Hierarchy Structuring: the first step involves identifying the core problem, determining relevant criteria and alternatives, and structuring these components into a hierarchical model. This hierarchy typically consists of three levels: the overall goal at the top, followed by criteria and sub-criteria in the middle, and the decision alternatives at the bottom.
2. Priority Determination through Pairwise Comparisons: in this step, a pairwise comparison matrix is constructed, where each criterion is compared against others based on its relative importance.
3. Synthesis and Weight Calculation: the pairwise comparison matrix is then normalized to obtain the priority vector, which represents the relative weight (eigenvector) of each criterion. This vector reflects the significance of each criterion in achieving the overall objective.
4. Consistency Measurement: to ensure logical consistency in the pairwise judgments, the maximum eigenvalue (λ\_max) is calculated. The consistency of the matrix is evaluated using the Consistency Index (CI), given by the formula:

( 1)

1. Consistency Ratio (CR) Calculation: the consistency ratio is computed by dividing the consistency index by the random index (IR), as follows:

( 2)

1. Consistency Evaluation: if the calculated CR value is less than 0.1 (10 percent), the pairwise comparisons are considered consistent and acceptable. However, if the CR exceeds 0.1, the judgment matrix should be reviewed and revised to improve consistency.

By following these steps, AHP provides a robust and transparent method to evaluate container quality criteria and determine their relative importance. The resulting weights are then used to classify containers into quality groups, forming the basis for subsequent layout design and storage zoning decisions in the warehouse.

# Container Order Picking and Routing Strategies

In container terminal operations, container reshuffling is one of the key challenges that can significantly impact operational efficiency and productivity. Reshuffling occurs when a target container is blocked by one or more containers stacked above it (Tang et al., 2015). According to Tang et al. (2015), various reshuffling strategies have been proposed, which are generally categorized into two main types: static reshuffling and dynamic reshuffling.

1. Static reshuffling refers to the relocation of obstructing containers within a fixed bay configuration, where no new container arrivals occur during the retrieval process. The focus is on retrieving all containers in a single bay according to a predefined priority sequence, with the primary objective of minimizing the number of reshuffling movements. Since the bay configuration remains unchanged throughout the process, the problem is referred to as “static.”
2. Dynamic reshuffling, on the other hand, takes place in environments where containers are continuously arriving and departing. In this setting, the bay configuration is dynamic and constantly evolving. Every decision related to storage or reshuffling must consider the current state of the bay, making it more complex than the static case. A solution that is optimal under static conditions may not perform well dynamically. The goal is to minimize the average number of reshuffles over time.

To assess the impact of reshuffling on time and operational performance, several studies have introduced quantitative models to estimate the duration required for container movements. One such model was developed by Putri et al. (2023) in the context of Twin Automatic Stacking Cranes (Twin-ASC) in an automated container yard. The time needed to move a container is calculated based on the combination of horizontal and vertical crane movements, referred to as *necessary movement*. The horizontal movement accounts for the maximum distance between the row and bay coordinates, while the vertical movement is based on the initial and final stacking heights of the container. The movement time is calculated using the following formula:

( 3)

where:

= Coordinates of the container's initial () and destination () positions

= Slot width (m)

= Slot length (m)

= Container height (m)

= Horizontal speed of the ASC (m/min)

= Vertical speed of the ASC while carrying a container (m/min)

This formula allows for a systematic estimation of the time required for container reshuffling, providing valuable input for evaluating the impact of reshuffling on overall yard performance. In this research, the Return routing method is applied. Under this method, the picker (e.g., a crane or yard truck) enters and exits each aisle from the same end. Only aisles containing target containers are accessed. While this strategy is simple to implement and easy to manage, it often results in longer travel distances compared to alternative methods. Nevertheless, its straightforwardness makes it suitable for structured environments such as container yards with limited dynamic variability.

# RESULT & DISCUSSION

This research began with a data collection phase aimed at supporting the redesign of the container yard layout, considering container quality and the efficiency of the order picking process. The data collected for this research comprises the following components:":

* Order Data: This dataset contains information on customer container orders along with the storage locations within the yard. The highest demand was recorded on May 9, 2025, and this date was selected as the basis for the order picking simulation.
* Container Quality Evaluation Criteria: The evaluation consists of seven key criteria: price, brand, age, door condition, rust level, dent level, and hole level. Each criterion is classified into three grades (Grade 1 to Grade 3) based on threshold values determined from company records.
* Existing Warehouse Layout: A mapping of the current yard layout was conducted, showing the positions of racks and storage blocks from row R1 to R5. Key reference points such as work areas, forklift lanes, and the outbound gate were documented to support the redesign for improved picking efficiency.
* Picking Time and Activity Data: This includes forklift speed (both loaded and unloaded), lifting capacity, and container dimensions. These details are essential for estimating picking times and calculating maneuvering space requirements for handling equipment.

Once the data was collected, the next phase involved processing it using AHP, a structured and widely recognized multi-criteria decision-making method. This process was used to systematically evaluate and rank the quality of each container based on multiple assessment factors. A hierarchical model was constructed to guide the evaluation, comprising three main components:

* Goal: To determine the overall quality level of each container.
* Criteria: Seven quality attributes—price, brand, age, door condition, rust level, dent level, and hole level—were selected based on their relevance to customer preferences and operational considerations.
* Alternatives: A total of 72 container units were assessed, comprising 70 units of 20-foot containers and 2 units of 40-foot containers.

Pairwise comparison matrices were developed based on expert judgment and supported by structured questionnaires. The results were then normalized to derive the relative weights of each criterion. The price received the highest weight at 0.29, followed by brand (0.21), indicating their stronger influence in assessing container quality. To ensure logical consistency in the pairwise comparison process, the Consistency Ratio (CR) was calculated and yielded a value of 0.004, well below the acceptable threshold of 0.10. This confirms the reliability and validity of the expert judgments used in the AHP process. After determining the weights for each of the seven criteria using the AHP method, the next step was to evaluate the quality of all 72 containers. This evaluation aimed to generate a final quality score for each container, which would later serve as the basis for determining storage priority in the warehouse layout redesign. The scoring process began by performing pairwise comparisons among the containers for each criterion. These comparisons were then normalized to obtain the relative weight (or score) of each container in relation to others for the specific criterion. This process was repeated for all seven criteria: price, brand, age, door condition, corrosion rate, dent severity and perforation severity. Once the alternative weights for each container under each criterion were obtained, the final quality score for each container was calculated using a weighted summation approach. The following formula was used:

( 4)

This formula multiplies the normalized score of a container for each criterion by the respective weight of that criterion (obtained from the AHP analysis) and then sums these products across all seven criteria. For instance, container CNT001 achieved the highest final score of 0.0184, making it the top-ranked container in terms of overall quality. This indicates that CNT001 performed consistently well across the various evaluation criteria and is thus deemed the most suitable for prioritized placement in the warehouse. Each cell in the matrix represents the normalized comparison between containers, while the “Weight” column shows the average row score for each container, indicating its relative performance for the given criterion. The “Score” column is derived by multiplying the weight by the global weight of the hole level criterion from the AHP model (0.06 in this case), contributing to the container’s total quality score. This scoring approach was applied to all 72 containers, resulting in a quantitative and objective ranking that informed the redesign of the warehouse layout, particularly in determining the priority zones for storage.

To support efficient retrieval and storage operations within the container yard, all 72 containers were classified into three distinct priority zones based on their final quality scores. These zones represent the overall condition and suitability of each container, helping to guide their optimal placement in the warehouse. The classification was determined using an interval-based scoring method derived from the total range of quality scores across all containers. The following is the interval calculation used to define the score interval for each zone:

( 5)

( 6)

Based on equation (2), the score intervals for the three zones are determined as follows:

* High Priority: Containers with a score greater than 0.01518
* Medium Priority: Containers with a score between 0.01197 and 0.01518
* Low Priority: Containers with a score less than or equal to 0.01197

Containers in the high priority group are expected to be stored in the most accessible locations within the yard layout, while medium and low priority containers are assigned to less accessible zones, reflecting their relative suitability and demand. After evaluating all 72 container units based on seven quality criteria, 22 containers fell into the High Priority zone, 38 into the Medium Priority zone, and 10 into the Low Priority zone. Additionally, for operational convenience, both 40-foot containers were directly assigned to the High Priority zone to facilitate easier handling and transfer operations due to their larger size. This classification not only supports technical decision-making but also plays a crucial role in improving operational efficiency, informing maintenance planning, and enabling strategic container rotation based on quality and suitability.

**TABLE 1.** Zone Classification Based on Container Quality Scores

| Container | Kriteria | | | | | | | Total | Zone |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Price** | **Brand** | **Age** | **Door Condition** | **Corrosion Rate** | **Dent Severity** | **Perforation Severity** |
| CNT001 | 0.0046 | 0.0041 | 0.0037 | 0.0012 | 0.0017 | 0.0016 | 0.0014 | 0.0184 | High Priority |
| CNT012 | 0.0046 | 0.0041 | 0.0037 | 0.0023 | 0.0017 | 0.0005 | 0.0014 | 0.0183 | High Priority |
| CNT049 | 0.0046 | 0.0041 | 0.0037 | 0.0007 | 0.0017 | 0.0016 | 0.0014 | 0.0178 | High Priority |
| CNT042 | 0.0046 | 0.0041 | 0.0037 | 0.0012 | 0.0017 | 0.0016 | 0.0008 | 0.0178 | High Priority |
| CNT030 | 0.0046 | 0.0041 | 0.0037 | 0.0023 | 0.0005 | 0.0016 | 0.0008 | 0.0176 | High Priority |
| CNT024 | 0.0046 | 0.0041 | 0.0037 | 0.0012 | 0.0017 | 0.0016 | 0.0004 | 0.0174 | High Priority |
| CNT056 | 0.0046 | 0.0041 | 0.0037 | 0.0007 | 0.0017 | 0.0016 | 0.0008 | 0.0172 | High Priority |

The existing layout lacks categorization by container size or quality, resulting in inefficient organization and longer picking times. By visualizing the current layout through zonal classification, the inefficiencies in container grouping become more apparent. The layout modification adopts a U-shaped storage arrangement aligned with the three defined priority zones: High Priority, Medium Priority, and Low Priority. This strategy aims to improve the efficiency of container retrieval and dispatch processes while supporting smooth warehouse operations based on container quality levels. The proposed layout shown in **FIGURE 1** uses a color-coding scheme to indicate priority zones: blue for High Priority, green for Medium Priority, and orange for Low Priority.



**FIGURE 1.** U-Shaped layout with priority zone classification

In the **Error! Reference source not found.**, the labeling system uses R for row, B for bay (column), and T for tier (stack height). For example, T0 indicates the ground level (first tier), T1 represents the second tier, and T2 the third tier. Containers classified as High Priority are strategically positioned in the most accessible zones near the operational area, specifically in bays B13 to B10 and partially in B12. This placement ensures faster retrieval times and minimizes material handling distances, as these containers possess the highest quality and are prioritized for immediate use. Meanwhile, Medium Priority containers are stored in the central area of the warehouse, spanning bays B9 to B4 and occupying most rows R1 to R4. This placement offers a balance between accessibility and operational hierarchy, supporting smooth rotation when shipment demands increase. Containers classified under Low Priority are placed in the least accessible area, particularly in the lower part of the layout from bays B1 to B3. These containers generally exhibit suboptimal quality conditions and are designated for backup usage or pending repairs. However, an exception is made for 40-foot containers, which, despite being in the Low Priority category, are stored in High Priority zones to accommodate their larger size and facilitate easier access. Placing them near the exit gate reduces maneuvering difficulty, as 40-foot containers require wider aisles, and more handling space compared to standard 20-foot containers. Additionally, the application of the U-shaped layout structure streamlines the overall material flow. Forklift movement is optimized through a structured pathway that begins at the processing area, moves through the storage area, and returns to the exit point. This configuration not only enhances operational efficiency but also minimizes reshuffling activities and maximizes the simultaneous operation of two forklifts.

## Order Picking Analysis

After evaluating the quality of 72 container units and determining their storage zones, the next step is to analyze the efficiency of the order picking process. Order picking refers to the process of retrieving containers from warehouse storage locations to fulfill customer requests. Order data is used as a test case to evaluate the effectiveness of the proposed. At this stage, route calculations and analysis of container retrieval by forklifts were conducted based on the warehouse layout and the applied order picking method. The method used is the return method, where each forklift carries only one container per cycle and then returns to the starting point before retrieving the next unit. To optimize the picking sequence, the nearest neighbor algorithm was applied, enabling each forklift to sequentially retrieve the nearest next container until all demands were fulfilled. Two forklifts operated in parallel during this process: Forklift 1 (F1) and Forklift 2 (F2). Each forklift had its own route that did not intersect with the other, as each aisle could only be accessed by one forklift at a time to avoid congestion and enhance operational safety.

The requested containers were located across multiple warehouse blocks (R2–R5) and stacked at various tier levels. This positional information is critical, as containers placed at higher tiers or deeper locations require longer retrieval times and more complex forklift maneuvers. The order picking analysis incorporates the following operational parameters:

* Forklift speed without load: 33.33 meters/minute
* Forklift speed with load: 16.67 meters/minute
* Vertical lifting speed: 30 meters/minute

Container dimensions and aisle widths serve as the basis for lateral and vertical movement planning. Without considering container quality in storage planning, frequently requested containers could end up being stored in less accessible areas, such as the farthest rows or upper tiers, resulting in extended retrieval times, higher energy usage, and increased forklift congestion in narrow aisles. However, after applying the container quality evaluation and implementing a priority zone-based system, the retrieval process becomes more efficient due to the following improvements:

* High-priority containers are stored near the warehouse exit or main operational areas.
* Forklift movement follows a more structured and shorter route.

By strategically placing high-scoring containers in more accessible areas based on the priority zones, the redesigned layout ensures that order picking times are minimized. This planning is further enhanced by adjusting the picking sequence according to both priority and container location, enabling forklifts to follow an optimized route. The return method is adopted as the routing strategy in this redesign. In this approach, forklifts enter and exit an aisle from the same end, and only the aisles containing needed items are accessed. While simple to implement, this method significantly reduces unnecessary travel distance when combined with intelligent zoning. Estimated time simulations reveal that retrieving containers from high-priority zones can reduce travel time by over 30% compared to the original layout. This strategy not only improves warehouse operational efficiency and daily throughput but also reduces customer wait times. In conclusion, the integration of AHP-based quality assessment with targeted order picking analysis provides a comprehensive solution. It not only optimizes storage based on physical and economic attributes of containers but also ensures faster, more accurate retrieval aligned with customer demand.

# CONCLUSION

This study successfully identified and prioritized seven key criteria that influence the physical and economic quality of containers: price, age, brand, door condition, corrosion rate, dent severity, and perforation severity. Using the Analytical Hierarchy Process (AHP), each criterion was assigned a weight based on its relative importance. These weights were used to classify 72 containers into High, Medium, and Low Priority zones. A total of 21 containers, including two 40ft units, were classified as High Priority, 38 as Medium Priority, and 13 as Low Priority. This classification became the foundation for redesigning the warehouse layout, aiming to enhance retrieval efficiency.

To improve operational performance, a U-Shaped warehouse layout was proposed and evaluated against the existing layout. The redesigned layout incorporated separate zones for each priority level, located strategically to minimize travel distances, especially for High Priority containers which were placed near the entrance. The order picking process was optimized using the return method and nearest neighbor algorithm, supported by two forklifts operating on non-overlapping routes. As a result, the average forklift travel distance was reduced by 77.6 percent, from 194.63 meters to 43.38 meters. The new layout also reduced reshuffling activities, leading to faster and more efficient container retrieval.

For future studies, researchers are encouraged to explore alternative warehouse layout models such as fishbone, butterfly, or diagonal configurations to accommodate different space limitations. Dynamic simulation models that reflect fluctuating container priorities over time may also offer deeper insights into real-time operational performance. From a practical perspective, companies are advised to adopt quality-based zoning and structured order picking methods, including the use of parallel forklifts and return routing strategies. Placing high priority containers near the operational area has proven to significantly reduce retrieval time and should be considered the best practice for warehouse layout planning.

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