



Optimizing Cold Storage Layout Using ABC Classification to Reduce Worker Exposure Time in the Fishing Industry

Shellen Natasya Suman Ho¹, Chandra Dewi Kurnianingtyas^{2*}, and Twin Yoshua R. Destyanto³

1-Department of Industrial Engineering, Faculty of Industrial Technology, Universitas Atma Jaya Yogyakarta

2-Department of Industrial Engineering, Faculty of Industrial Technology, Universitas Atma Jaya Yogyakarta, chandradewiuajy3@gmail.com

3-Department of Industrial Engineering, Faculty of Industrial Technology, Universitas Atma Jaya Yogyakarta

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ABSTRACT

Cold storage preserves the quality of frozen fishery products, but the low temperatures that protect the products expose warehouse workers to cold stress. Engineering controls that shorten the time workers spend in the cold are preferred over measures that rely on behavioural change, yet layout-based interventions in the cold storage of tropical fishing industries have rarely been examined. This study aimed to reduce workers' exposure time in the cold storage of a fishing company in Central Java, Indonesia, through layout reengineering. Products were classified with ABC analysis based on retrieval frequency, and three layout alternatives were developed under explicit spatial constraints (pallet and hand pallet truck dimensions, minimum aisle clearance, cooling-unit zones, and a required capacity of 108 pallets).

The U-shaped second alternative, with a capacity of 115 pallets compared with 103 in the existing layout, was selected and partially implemented, and storage and retrieval times were compared before and after implementation. Mean storage time decreased by 31.20% (8.53 to 5.87 min) and mean retrieval time by 46.75% (18.26 to 9.73 min; Mann-Whitney U test, $p < 0.001$ for both), and the share of retrieval tasks lasting longer than the 10-min exposure target fell from 100% to 27%. Because no physiological measures were collected after implementation, these results indicate a reduction in time-at-risk per task rather than a demonstrated reduction in cold-related health outcomes. Layout reengineering is therefore a low-cost engineering control that can complement protective clothing, training, and work-warm-up scheduling in cold-stress management.

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1. Introduction

In the fishing industry, product freshness is a primary quality attribute. Cold storage is a facility designed to maintain the temperature of frozen products

at a stable level until they are delivered to consumers [1], [2], [3]. It plays a crucial role as both a freezer and storage facility for seafood products such as fish, shrimp, shellfish, squid, and other varieties. Therefore, an effective cold storage system must maintain a low and

stable temperature while ensuring proper distribution of cold air to preserve the quality of stored products [4], [5]. However, the conditions that preserve the products are hazardous for the workers who enter the cold storage every day. Cold storage operations have been studied extensively from logistics and energy perspectives, [6], but little is known about how the physical arrangement of a cold store determines how long workers remain exposed to cold, particularly in fishing industries in tropical regions, where the thermal contrast between the ambient environment and the cold store is large.

Exposure to low temperatures can trigger both physical [7], [8] and mental fatigue [8], [9], [10]. Extreme cold accelerates the onset of fatigue-related pain in workers' hands [8]. Exposure to extreme cold also significantly impairs workers' short-term memory [8].

Previous findings mentioned that employees exposed to cold temperatures experience complaints such as shivering [11], [12], a runny nose [13], numbness [14], [15], muscle stiffness [14], and other discomforts while working in cold storage. Other studies found that workers in the cold storage sector who are exposed to low temperatures almost daily and continuously are at risk of cold stress [8], [9] and the risk of hypothermia [14], [16]. These effects were identified through interviews, questionnaires, and body temperature measurements [13], [14], [15], [16].

Those risks will indirectly affect the productivity of workers [17]. The increase in rest time and even absenteeism of workers leads to low productivity and turnover. Therefore, managing workers' mobility and discomfort is crucial for productivity in cold storage operations.

From an occupational ergonomics perspective, cold-related risk depends on both the thermal environment and the duration of exposure. ISO 11079 evaluates cold stress through the required clothing insulation (IREQ) and defines a duration-limited exposure (DLE) beyond which body heat balance can no longer be maintained with the clothing worn [18], while ISO 15743 provides a practical model for cold risk assessment and management in cold workplaces [19]. These standards, together with recommended work-warm-up regimes, share a common principle: for a given temperature and clothing ensemble, cold strain accumulates with the continuous time spent in the cold [20], [21]. In this study, this duration is referred to as time-at-risk. Any intervention that shortens the time needed to complete tasks inside a cold store therefore directly reduces the exposure component of cold risk, even when the thermal environment itself cannot be changed because it is dictated by product requirements.

These phenomena indicate a need to balance storage effectiveness and work safety in cold storage environments. Redesigning the workflow and task scheduling by applying shift rotation [22], [23], risk prioritization [24], and job rotation [25], can be an alternative to achieve this goal. The other way to balance the safety and effectiveness of cold storage is by improving the environmental design. Examples include cold-zone partitioning, optimized airflow distribution, and non-slip floors with proper lighting. Operators also need high safety awareness, supported by regular cold

stress training, behavioural measures, emergency preparedness, and first-aid facilities. However, these strategies have limitations: shift rotation can disrupt operations and induce fatigue, job rotation requires long and variable adaptation periods, and changes in operators' safety attitudes and behaviour take a long time to achieve. In the hierarchy of controls, engineering controls that modify the work system are preferred over administrative controls and personal protective equipment because they act at the source and do not depend on sustained worker compliance [26]. Rearranging where products are stored is such a system-level intervention: it shortens the travel and search time of every storage and retrieval task, requires no change in individual protective behaviour, and takes effect immediately once the new layout is in place. Research on human factors in order picking likewise shows that storage assignment and layout decisions shape not only productivity but also the physical load and exposure experienced by workers [27].

One of the potential solutions for this case is reengineering the cold storage layout. Studies related to this layout reengineering apply methods that modify the product organization, such as using data-driven [28], First In First Out (FIFO) [29], [30], and Class-Based Storage [31] methods. The placement of products within the cold storage area significantly impacts the speed at which operators can retrieve items, thereby minimizing prolonged exposure to cold temperatures. The application of this solution may help to regulate the maximum storage duration of products and optimize stock rotation, ensuring that product quality remains well-preserved and supports worker safety. However, these studies evaluated layouts mainly in terms of logistics performance, and none examined cold storage in the fishing industry in tropical regions or framed layout redesign explicitly as a means of reducing workers' cold-exposure time.

Therefore, the objective of this study is to redesign the cold storage layout of a fishing company in Indonesia using ABC classification of retrieval frequency and to quantify the resulting change in the time workers spend inside the cold storage during storage and retrieval tasks. The contribution of this study is threefold: (i) a constraint-based procedure for applying ABC classification to cold storage layout design; (ii) before-after evidence on task time, used as a measure of time-at-risk, from an operating tropical fishing facility; and (iii) a discussion of how layout planning can be integrated into cold-stress management as an engineering control.

2. Material and Methods

2.1. Study site and operational context

The study was conducted in PT XYZ, a fishing company located in Central Java, Indonesia. PT XYZ is a company engaged in livestock, fisheries, agro-complex industries, and green land restoration. This study primarily focuses on the fisheries sector of the company, specifically on the cold storage operations at the PT XYZ manufacturing facility.

Each product in PT XYZ that has undergone the freezing process is stored in the cold storage facility. This aims to maintain optimal frozen conditions and ensure product quality. Products are retrieved from cold storage for two different purposes. First is order fulfillment,

which is when the ordered products are removed from cold storage and transferred to the loading area when shipments to customers are scheduled. The second is inventory checking, which is a routine inventory monitoring that is conducted at the end of each month to verify and recount each Stock Keeping Unit (SKU) stored in cold storage. This process ensures that the actual stock quantity matches the recorded inventory levels. The problem faced by PT XYZ is the inefficient use of worker time during activities in the cold storage, which prolongs workers' exposure to cold.

The cold storage, which PT XYZ rents from a partner company, is operated by two material handling operators who also assist with packing, supervised by the head of field operations. The plant operates six days per week from 07.00 to 15.00 with a one-hour break; between August 2022 and April 2023, the two operators worked about 3 to 16 h of overtime per week. The cold storage is kept between -10°C and -29°C . Assuming an air velocity of about 0.3 m/s (10.8 km/h) from the cooling units [32], -29°C corresponds to a wind-chill temperature of about -38°C , at which exposed skin can freeze within 10–30 min [29], [31]. A maximum stay of 10 min per entry was therefore adopted as the exposure target of the study. The company provides insulated jackets, gloves, and rubber boots, but before the intervention the operators usually did not wear them because the close-fitting jacket and stiff gloves restricted arm and finger movement. Products are stored every working day after packing, whereas retrieval takes place on shipment days (at least once per week), when many pallets are removed in one session. Before the redesign, pallets were placed wherever floor space was free, so that the room was usually full with no aisle, a pallet could contain more than one SKU, and operators had to move blocking pallets out of the room before they could reach the products to be shipped.

During problem identification, the operators reported spending 10–20 min inside the cold storage per session and feeling cold and fatigued, especially during loading and monthly stock taking. Baseline screening showed that their manual handling tasks posed low risk (Manual Handling Assessment Chart scores of 4 for lifting and 3 for carrying), whereas fatigue measured with the 30-item Subjective Self-Rating Test of the Industrial Fatigue Research Committee was moderate for both operators (scores of 61 and 74; moderate range 53–75) [33], [34]. Time spent in the cold storage, rather than manual handling load, was therefore selected as the target of the intervention.

2.2. Layout reengineering method

This study employed a layout reengineering approach using ABC inventory analysis to optimize worker efficiency and minimize exposure time in cold storage [35], [36], [37]. The ABC inventory analysis method classifies stock items based on their frequency of retrieval and overall importance, enabling a more strategic storage layout redesign.

The method was selected considering the conditions of the company's cold storage, where product flow is the dominant driver of worker movement. The frequent movement of products in and out of cold storage, occurring almost daily, requires special handling for both incoming and outgoing products. Due

to the wide variety of product variants entering and exiting cold storage, an organized classification system is necessary. By categorizing products based on retrieval frequency from the most to the least frequently accessed, workers can store and retrieve items in the shortest possible time. The layout alternatives were drawn to scale (1:100) in Microsoft Visio.

The ABC classification followed three steps. First, the retrieval frequency of each SKU was compiled from the company's monthly stock-in and stock-out records (a manual stock book kept by the operational administration staff) for May 2022 to May 2023. Of the 100 SKUs produced since 2021, 30 had no movement in this period and were excluded, leaving 70 SKUs. Because only monthly totals were available, the number of retrievals per SKU and month was calculated as the outbound quantity divided by the maximum load of one pallet (560 kg for box cartons and 1,190 kg for whole and folding cartons), rounded up, since one retrieval moves one pallet. Second, the SKUs were ranked in descending order of retrieval frequency, and the cumulative percentage of retrievals was calculated. Third, SKUs were assigned to class A (the SKUs that together accounted for approximately 80% of retrievals with about 20% of the SKUs), class B (the next 15% of retrievals with about 30% of the SKUs), and class C (the remaining 5% with about 50% of the SKUs), following the Pareto principle [38], [39]. Class A products were assigned to the locations nearest the door and the main aisle, class B to intermediate locations, and class C to the locations farthest from the door, following the class-based storage principle that the most frequently accessed items should require the shortest travel [40], [41].

2.3. Layout design constraints and assumptions

Table 1 summarizes the spatial constraints and assumptions used to develop the layout alternatives. The minimum aisle width was derived from the dimensions of the manually operated hand pallet truck and the pallet it carries. Because the truck moves only forward (push) and backward (pull), no turning radius was required; the longest pallet dimension (1.3 m) plus a clearance of 0.1 m on each side gives a minimum aisle width of 1.5 m. The required storage capacity was calculated by dividing the maximum product inventory (127,606 kg) by the load of one stacked pallet (1,190 kg), giving 107.23, which was rounded up to 108 pallets. No stacking pallets were placed below the three cooling units mounted high on the centre of the left-side wall, which together occupy about 3 m, to avoid obstructing cold-air circulation (Fig. 1). The side clearance of 0.1 m was a design assumption; no specific standard was applied.

Table 1. Layout design constraints and assumptions

Parameter	Value	Basis
Cold storage internal size	16.5 m × 13.0 m (214.5 m ²)	Site measurement
Entrance/exit door	1 door, 1.6 m × 2.0 m (W × H)	Site measurement
Plastic pallet	1.3 m × 1.1 m	Company equipment
Hand pallet truck	1.22 m × 0.685 m	Company equipment
Side clearance	0.1 m each side	Design assumption
Minimum aisle width	1.5 m (1.3 + 0.1 + 0.1)	Calculated
Maximum inventory	127,606 kg	Company records

Parameter	Value	Basis
Load per stacked pallet	1,190 kg	Company records
Required capacity	108 pallets ($127,606 \div 1,190 = 107.23$)	Calculated
Stacking pallet unit	Holds two pallet loads	Proposed equipment
Restricted zone	Below 3 cooling units (left wall, ~3 m)	Cold-air circulation

2.4. Evaluation protocol and data analysis

The selected layout was evaluated with a pre–post field comparison under normal operating conditions. Because the company was giving priority to production-line improvements after an external audit, the layout was implemented in stages. In the after period, the 2 m central aisle and the class-based placement of products were in place, but only five of the planned stacking pallets had been installed (on the left-side wall), floor marking had not yet been applied, and the rear section was still fully occupied by plastic pallets. Several supporting measures were introduced at the same time: storage and retrieval procedures and a cold-hazard poster were posted at the door, a manual stacker was provided for the upper pallet level, and printed carton labels were trialled on some products.

Storage and retrieval times were recorded with a smartphone stopwatch, from the moment the operator began moving a pallet into the cold storage, or began retrieving a pallet, until the task was completed. All storage and retrieval events in two observation windows were timed. Before the redesign (26 June–7 July 2023, 10 working days), 26 storage events and 22 retrieval events (on three shipment days) were recorded; after the start of implementation (28 August–9 September 2023, 12 working days), 36 storage events and 22 retrieval events (on three shipment days) were recorded. The tasks were performed by the same two operators using the same hand pallet truck. Because all time spent inside the cold storage is exposure time, task times were used as direct measures of time-at-risk per task, and the share of tasks exceeding the 10-min target was used as an exposure-threshold indicator. Descriptive statistics (N, mean, and standard deviation) were computed for each condition and for each ABC class, normality was checked with the Shapiro–Wilk test, and before–after differences were tested with the Mann–Whitney U test when normality was violated, with Welch’s t-test reported for comparison ($\alpha = 0.05$). After implementation, a short structured interview (17 open questions) was held with the two operators about ease of work, perceived cold symptoms, PPE use, and remaining difficulties; answers were recorded in writing and summarized descriptively. The three layout alternatives were compared on storage capacity, aisle configuration, and stakeholder assessment; only the selected alternative was implemented and timed.

2.5. Ethical considerations

The study was carried out as an industry-based capstone project with permission from the company management, which also approved the posting of the new procedures and the poster in the cold storage area. It involved observation of routine work, questionnaires, and interviews, and no physiological measurements or intervention on the workers. The company is anonymized, and cost data were not used, to protect internal company information. Participants were recruited through an internal advertisement as

volunteers and the verbal consent was obtained by them.

3. Results and Discussion

3.1. ABC classification results

Of the 70 SKUs, 17 (24.3%) were classified as class A (fast moving), accounting for 79.5% of the 1,637 retrievals in the period; 19 (27.1%) as class B (medium moving), accounting for 17.5%; and 34 (48.6%) as class C (slow moving), accounting for 3.0%, including nine SKUs with no retrieval (Table 2). Class A consisted mainly of whole gilled-gutted fish and fillets, led by Indian mackerel (kembung banjar WGG, 182 retrievals, 11.1% of the total), milkfish (bandeng WGG), dory fillet, tilapia (nila WGG), and pangasius (patin WGG). Based on the maximum monthly inventory of each class, 86, 24, and 7 pallet positions were required for classes A, B, and C (117 in total). Because the selected layout provides 115 positions, the class A allocation was reduced to 84 in agreement with the stakeholders, and occasional overflow of the fastest-moving products is placed near the door. Class A was assigned to the positions nearest the door, class B to the middle section, and class C to the rear.

Table 2. ABC classification of the 70 SKUs (May 2022–May 2023)

Class	SKUs	Retrievals	Positions	Location
A (fast)	17 (24.3%)	1,301 (79.5%)	84	Nearest door
B (medium)	19 (27.1%)	287 (17.5%)	24	Middle
C (slow)	34 (48.6%)	49 (3.0%)	7	Rear
Total	70	1,637	115	

The three layout alternatives described below were developed within the constraints listed in Table 1. The location of the cooling units, below which no stacking pallets may be placed, is shown in Fig. 1.

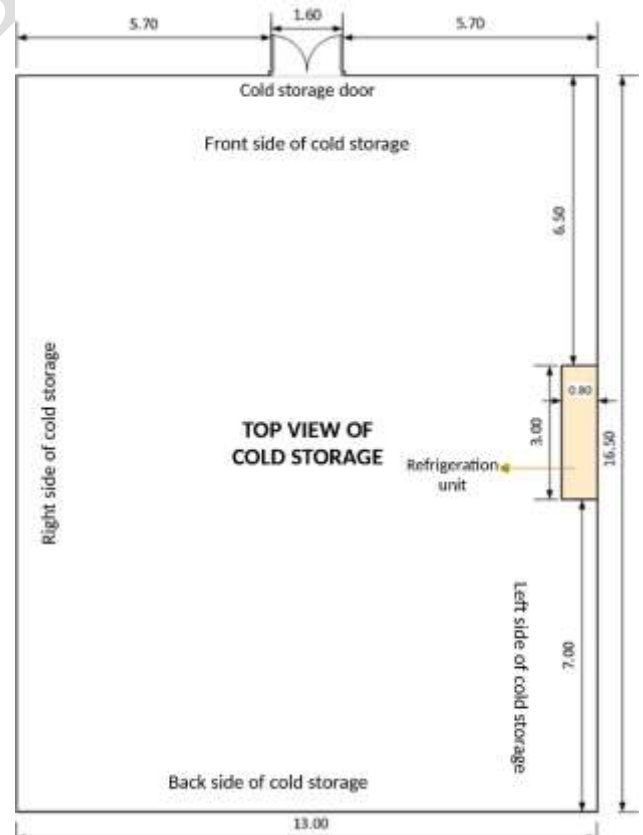


Fig. 1. Location of the refrigeration unit in the cold storage

3.2. First layout alternative

The front section of the cold storage is filled with stacking pallets arranged parallel to the wall. Stacking pallets and plastic pallets are also placed along the left and right walls. In the center of the cold storage, stacking pallets are arranged in parallel rows extending towards the back, with additional plastic pallets to maximize space. Each aisle meets the minimum required width of 1.5 meters. The maximum number of stacking pallets that can be used is 39 units, accommodating up to 78 pallets. Additionally, up to 30 plastic pallets can be placed, bringing the total maximum capacity of this first layout alternative to 108 pallets, which is sufficient to store the required volume. The first layout alternative is illustrated in Fig. 2.

3.3. Second layout alternative

The second layout alternative is designed using a U-shaped concept, where the main aisle runs through the center, extending from the cold storage entrance to the back. Stacking pallets are placed along the left, right, and back walls, while the front sections of the left and right stacking pallets have plastic pallets arranged in four rows forward. A 2-meter-wide aisle is created in a straight path with a slight turn near the cold storage entrance. The maximum number of stacking pallets that can be used is 25 units, accommodating up to 50 pallets. Additionally, up to 65 plastic pallets can be placed, resulting in a total maximum capacity of 115 pallets for this second layout alternative. This alternative therefore meets the required storage capacity (Fig. 3).

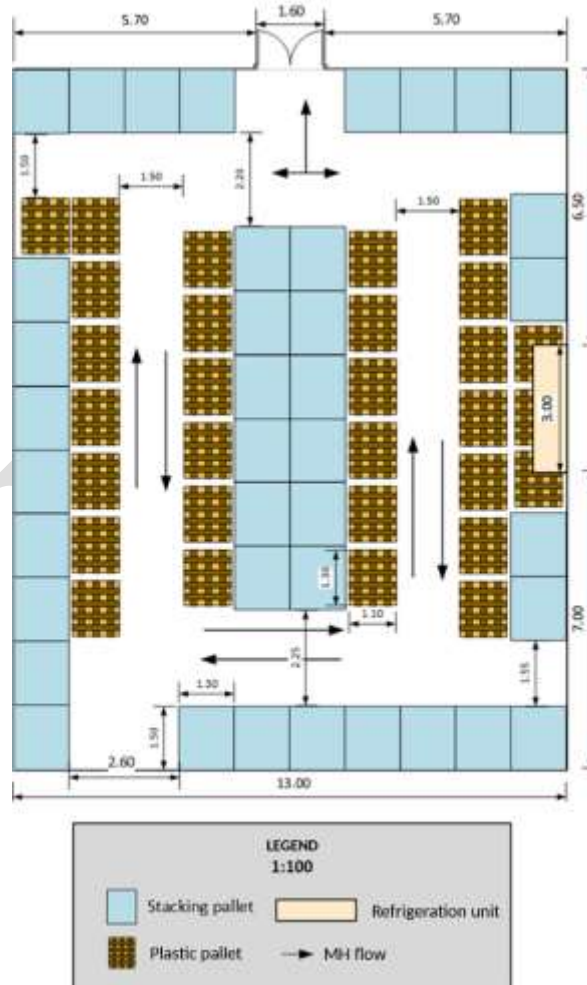


Fig. 2. First layout alternative design

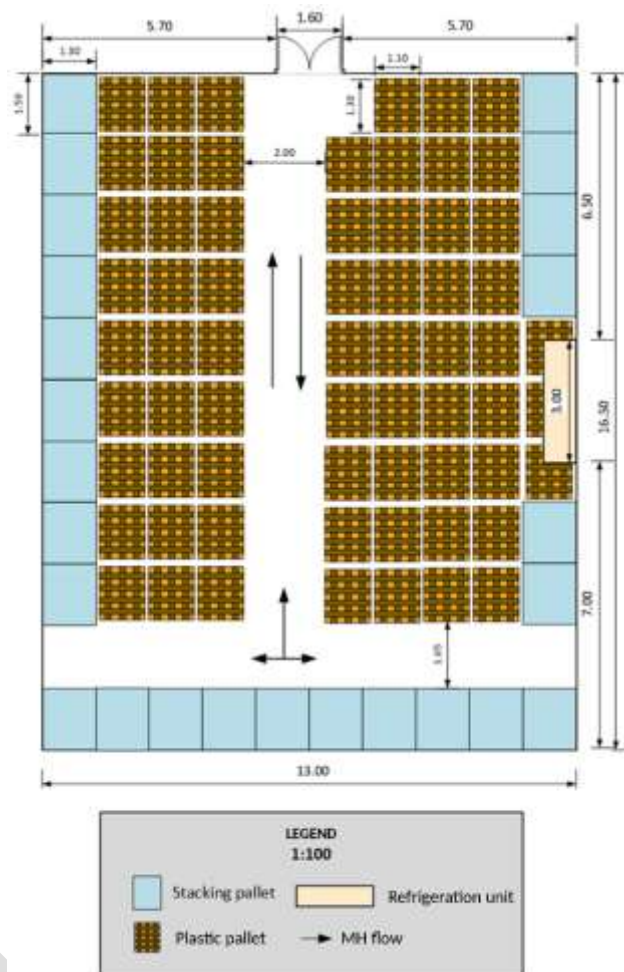
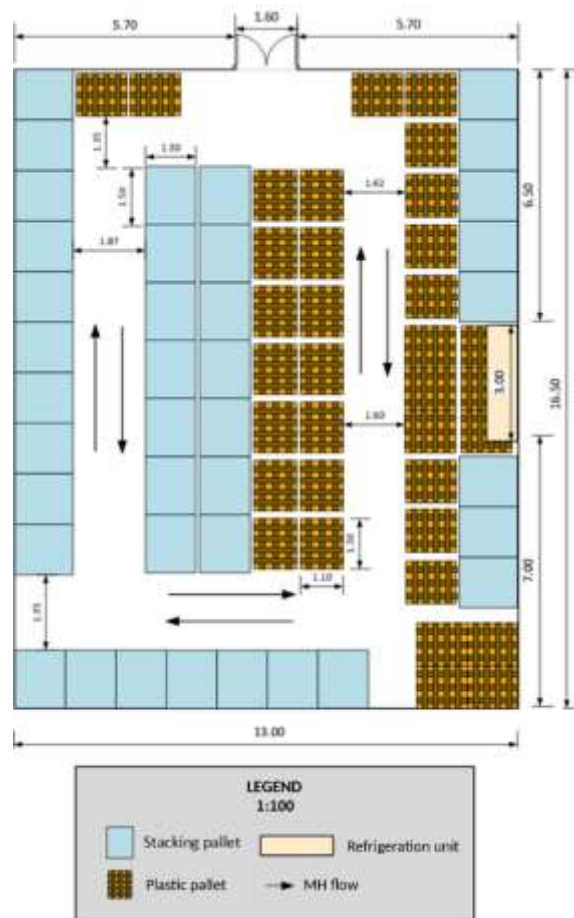


Fig. 3. Second layout alternative design

3.4. Third layout alternative

The third layout alternative is a hybrid design combining elements from both alternative one and alternative two. The most significant difference is that, unlike the alternative one, no stacking pallets are placed at the front of the cold storage. Instead, stacking pallets are positioned along the left, right, and back walls, similar to alternative two. However, the left-back section of the cold storage is left empty, allowing space for up to four plastic pallets. In the center of the cold storage, two rows of stacking pallets and two rows of plastic pallets are arranged, forming two main aisles—one on the right with a width of 1.8 meters and one on the left with a width of 1.6 meters. The maximum number of stacking pallets that can be used is 39, accommodating up to 78 pallets. Additionally, up to 35 plastic pallets can be placed, resulting in a total maximum capacity of 113 pallets for this third layout alternative (Fig. 4).



3.5. Comparison of layout alternatives

Table 3 compares the existing layout with the three alternatives. All three alternatives satisfy the required capacity of 108 pallets and the minimum aisle width of 1.5 m. Alternative 2 was selected because it offered the best compromise between capacity and ease of movement: (i) it provides the highest capacity (115 pallets, seven above the requirement and 12 more than the existing layout); (ii) it has the widest aisle (2.0 m), giving 0.5 m more clearance than the minimum for pushing and pulling the hand pallet truck; and (iii) its single straight main aisle from the door to the back wall creates one unambiguous travel path, so that class A products can be placed along the first section of the aisle near the door. Alternative 1 meets the requirement with no spare capacity and relies on several 1.5 m aisles, whereas Alternative 3 divides traffic between two narrower aisles (1.6 m and 1.8 m). Because only Alternative 2 was implemented, the time performance of Alternatives 1 and 3 was not measured, and their comparison is based on capacity and spatial criteria only. The choice was made together with the head of production, who also noted that Alternative 2 needs the fewest stacking pallets, which lowers purchase, installation, and maintenance costs; that in Alternative 1 the row of stacking pallets directly in front of the door would block the operators' view of the room; and that in Alternative 3 the double row of stacking pallets in the centre would require plastic pallets to be moved first.

Criterion	Existing	Alt. 1	Alt. 2	Alt. 3
Concept	Random	Parallel rows	U-shaped, one	Hybrid of 1

Criterion	Existing	Alt. 1	Alt. 2	Alt. 3
	floor storage		central aisle	and 2
Stacking units (pallet loads)	0	39 (78)	25 (50)	39 (78)
Plastic pallets	103	30	65	35
Total capacity (pallets)	103	108	115	113
Margin vs. 108 required	-5	0	+7	+5
Aisle width (m)	None in practice	1.5 (several aisles)	2.0 (one aisle)	1.6 and 1.8 (two aisles)
Storage / retrieval time	Baseline	Not tested	-31.20% / -46.75%*	Not tested
Selected	-	No	Yes	No

*Measured after partial implementation (Section 2.4).

3.6. Processing Time Comparison Evaluation

Table 4 presents the storage and retrieval times before and after implementation of Alternative 2. The mean storage time decreased by 31.20%, from 8.53 ± 1.20 min ($N = 26$) to 5.87 ± 2.13 min ($N = 36$), and the mean retrieval time decreased by 46.75%, from 18.26 ± 3.76 min ($N = 22$) to 9.73 ± 2.06 min ($N = 22$). Because the after-implementation times were not normally distributed (Shapiro–Wilk $p = 0.010$ and 0.009), the Mann–Whitney U test was used; both reductions were statistically significant (storage: $U = 784$, $p < 0.001$; retrieval: $U = 474$, $p < 0.001$), and Welch’s t-test led to the same conclusion (storage: $t(57.1) = 6.24$; retrieval: $t(32.5) = 9.34$; both $p < 0.001$). Relative to the 10-min exposure target, the share of retrieval tasks exceeding 10 min fell from 100% (22 of 22) to 27.3% (6 of 22), and that of storage tasks from 11.5% (3 of 26) to 2.8% (1 of 36).

By class, retrieval time decreased in all three classes (A: 18.21 to 8.49 min; B: 18.61 to 10.19 min; C: 17.59 to 12.89 min). Storage time decreased for class A (8.44 to 4.46 min) and class B (9.16 to 7.90 min) but increased for class C (6.40 to 9.87 min), which is consistent with class C now being stored at the rear, although this comparison rests on only one and three observations. The reductions are consistent with the removal of searching and of moving blocking pallets out of the room, which the previous random placement required. Because time-at-risk accumulates with every pallet moved, the effect is largest on shipment days: on 26 June 2023, for example, 17 pallets were retrieved, and at the observed mean times the same workload would require about 145 min less time inside the cold storage in total for the two operators.

Task	Phase	N	Mean (min)	SD (min)	>10 min	Change	p*
Storage	Before	26	8.53	1.20	3 (11.5%)	—	<0.001
Storage	After	36	5.87	2.13	1 (2.8%)	-31.20%	
Retrieval	Before	22	18.26	3.76	22 (100%)	—	<0.001
Retrieval	After	22	9.73	2.06	6 (27.3%)	-46.75%	

thermally neutral area; at PT XYZ, the operators spend this time assisting with packing and production outside the cold storage, and they reported having more time to rest after working inside it.

The production manager's objective of maximizing cold storage capacity has been met through the layout improvement based on Alternative Two. The initial cold storage capacity before the redesign was 103 pallets, whereas the improved layout increased capacity to 115 pallets, resulting in a 12-pallet increase. Additionally, the layout redesign has addressed concerns from the field operations manager regarding misplaced products on incorrect pallets. The new product arrangement is now classified into three categories, with standardized procedures established for product placement and retrieval, ensuring a more organized pallet arrangement in line with the designated system.

In the post-implementation interview, the operators reported that the central aisle made it easier to see free locations and to move the hand pallet truck, and that they no longer had to take blocking pallets out of the room. They also reported feeling less cold: whereas they previously began to feel stiff within the first 10 min of a shipment session and shivered on leaving the cold storage, these symptoms now occurred rarely. Remaining difficulties were the unfamiliar manual stacker, the still fully occupied rear section, and inconsistent PPE use, as jackets were worn mainly when many pallets had to be moved. These self-reports were not collected with a validated instrument, but they are consistent with the measured reduction in time-at-risk.

3.7. Ergonomic implications

The results show that layout reengineering can reduce the exposure component of cold risk without altering the thermal environment, which is dictated by product requirements. Within the ISO 11079 framework, a shorter continuous stay in the cold lowers the likelihood that a single entry approaches the duration-limited exposure for the clothing worn [18], [20], and within the ISO 15743 risk management model the redesign is a technical control measure at the level of workplace design and work organization [19]. It complements, rather than replaces, protective clothing, cold stress training, and work-warm-up regimes [21], [42]. Compared with administrative measures such as shift or job rotation [43], [44], the layout change required no behavioural adaptation from workers and became effective immediately after implementation, in line with the prevention-through-design principle [26]. The findings also agree with order-picking studies showing that class-based storage shortens travel time [40], [41], and extend this evidence to the occupational safety context of a tropical cold store.

3.8. Limitations and future research

This study has several limitations. First, no physiological measures (e.g., skin or core temperature) or validated post-implementation questionnaires were collected; fatigue was measured only at baseline, and the post-implementation symptom reports are qualitative. The safety benefit is therefore inferred from reduced time-at-risk and is not demonstrated as a reduction in cold strain, hypothermia, or frostbite. Second, the layout was only partially implemented, and procedures, a

hazard poster, carton labels, and a manual stacker were introduced at the same time, so the measured effect cannot be attributed to the layout alone. Third, the pre-post design without a control group cannot exclude other influences, such as learning, awareness of being observed, or differences in product mix: class A products made up a larger share of the after-period retrievals (14 of 22, compared with 9 of 22 before). Fourth, the observation windows were short (10 and 12 working days, each with only three shipment days), and the study involved a single facility with two operators, which limits generalizability. Fifth, only the selected alternative was timed, so the alternatives were compared on capacity and spatial criteria. Sixth, the ABC classification is based on historical monthly retrieval frequencies and must be updated when the product mix changes.

Future research should combine layout interventions with physiological monitoring (e.g., hand and finger skin temperature), subjective thermal comfort and discomfort questionnaires, and time-motion analysis; use simulation to evaluate layout alternatives before implementation [45]; and test the approach in several facilities with a controlled design.

3.9. Practical implications

For practitioners, the results suggest that storage-location assignment should be treated as part of cold risk management rather than only as a logistics decision. Cold storage operators can include ABC-based slotting and periodic re-slotting in their occupational safety and health procedures, combine them with standard operating procedures for product placement, and use the resulting task times to plan work-warm-up schedules. The approach is transferable to other sectors with frequent manual access to cold rooms, such as frozen-food processing, poultry, dairy, and pharmaceutical cold chains.

4. Conclusion

This study redesigned the cold storage layout of a fishing company in Indonesia using ABC classification of retrieval frequency. Among three alternatives developed under explicit spatial constraints, the U-shaped Alternative 2 provided the highest capacity (115 pallets, 12 more than the existing layout) and the widest aisle, and it was partially implemented. Afterwards, the mean storage time decreased by 31.20% and the mean retrieval time by 46.75% (both $p < 0.001$), and the share of retrieval tasks exceeding the 10-min exposure target fell from 100% to 27%, reducing the time workers spend inside the cold storage per task. These results demonstrate a reduction in time-at-risk, one component of cold exposure; they do not directly demonstrate a reduction in cold strain or in the incidence of hypothermia and frostbite, because no physiological or subjective measures were collected. Layout reengineering is a low-cost, system-level engineering control that requires no behavioural change from workers and can complement protective clothing, training, and work-warm-up regimes. Future studies should verify the safety benefits with physiological and subjective ergonomic measures and controlled designs in multiple facilities.

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