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Optimization of Warehouse Performance through Class-Based Storage based FSN Analysis for Travel Efficiency and Cost Reduction

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ABSTRACT

This study aims to optimize operational efficiency at PT XYZ's raw material warehouse by mitigating high material handling costs (MHC) and inefficient forklift travel caused by random storage and LIFO stacking constraints. The research proposes a warehouse layout redesign applying a Class-Based Storage (CBS) strategy zoned via FSN (Fast, Slow, Non-moving) analysis. The methodological approach involves material flow analysis of 31 SKUs, priority classification based on Turnover Ratio (TOR), and simulation of rectilinear distances and travel times using a standard speed of 1.4 m/s. Through comparative evaluation, the study found that the strategic relocation of 14 Fast-category items to zones closest to the Inbound/Outbound point successfully reduced monthly travel distance from 11,261.3 m to 9,557.3 m. This directly impacted operational time, reducing it by 0.34 hours, and lowered total MHC by 15.13%, equivalent to a monthly saving of IDR 1,610,231. The results conclude that FSN-activity-based zoning not only quantitatively reduces logistical costs but also qualitatively minimises aisle congestion and non-value-added backtracking movements, thereby enhancing overall warehouse productivity.

Keywords: *Material Handling Cost (MHC), Class-Based Storage (CBS), FSN Analysis, Warehouse Layout, Travel Distance, Travel Time.*

Introduction

In the competitive landscape of modern manufacturing, material handling efficiency is not merely a support function but a critical determinant of operational margins. Material handling activities typically account for 30–50% of total warehouse operational costs. [1]. However, in developing economies where manual forklift operations dominate, this cost is frequently inflated by suboptimal storage policies. The efficiency of a warehouse is strictly governed by how effectively it manages the flow of goods, where every unnecessary meter traveled translates directly into wasted labor hours and increased fuel consumption. Therefore, layout optimization is a fundamental requirement for minimizing operational overhead. Among the various performance metrics, travel distance serves as the primary driver of Material Handling Cost (MHC).

Excessive travel distance directly correlates with prolonged cycle times, thereby reducing the warehouse's overall throughput rate. In conventional layouts without velocity-based zoning, long retrieval paths lead to compounded time losses. [2], [3]. This is particularly critical in forklift-dependent environments, where fuel and maintenance costs are linear functions of distance travelled. When high-velocity items are stored deep within the facility, the "cost per pick" increases significantly due to "dead-heading"—the phenomenon of travelling empty or unnecessary distances to retrieve stock. Consequently, reducing travel distance is the most direct method to lower the aggregate MHC.

A specific operational bottleneck is evident at PT XYZ's raw material warehouse, which operates under Last-In, First-Out (LIFO) constraints within a single-aisle layout. Currently, the Random Storage policy causes severe backtracking and "dead-heading" (travelling without a load), as operators frequently travel to deep zones to retrieve fast-moving items [4]. This creates a physical inefficiency where operators spend a significant portion of their shift in non-productive travel, extending order fulfilment time unnecessarily.

Despite the prevalence of layout optimization studies, a critical research gap exists regarding the specific application of storage classification in LIFO environments. Previous studies [5] S. Sinambala *et al.* and [6] D. Azhis *et al.,* successfully utilized Class-Based Storage to enhance picking efficiency. However, these studies primarily relied on ABC Analysis (value-based) or general frequency without accounting for the physical stacking constraints of LIFO systems. In raw-material warehouses, high-value items (Class A) are not necessarily high-velocity. Consequently, standard ABC optimizations often fail to eliminate the specific non-value-added unstacking movements required to access buried stock in LIFO configurations.

This study introduces a novel approach by integrating FSN (Fast, Slow, Non-moving) to provide a holistic evaluation by triangulating travel distance, operational time, and financial metrics. The Analysis is specifically designed to eliminate backtracking bottlenecks in LIFO-constrained warehouses. [7] N. S. Isnaeni, who focused solely on distance evaluation, or Juliani et al [8], who limited their scope to time reduction, this research contributes a detailed financial model. This model converts specific reductions in forklift manoeuvres directly into defined monetary savings (MHC per meter), providing a tangible financial justification for layout reconfiguration that previous distance-centric studies lacked.

Based on the identified problems and gaps, the primary objectives of this study are to diagnose the baseline inefficiency caused by the value-velocity mismatch in the current random layout, design an optimal Class-Based Storage (CBS) layout strictly governed by FSN zoning to simultaneously minimize travel distance and operational time, and quantify the precise reduction in monthly Material Handling Cost (MHC) achieved by the proposed design.

Research Methods

Data acquisition was executed from March to May 2025 at PT XYZ, focusing on two streams. Primary data involved direct measurement of warehouse dimensions ($50\ \text{m} \times 27\ \text{m}$),Applying LIFO constraints, and validation of forklift operational speeds (1.4 m/s). Secondary data was retrieved from logistical records, encompassing 3-month inbound/outbound volumes for 31 SKUs, stock levels, and cost components (fuel and labour). The systematic progression of this research is visualized in the research flowchart below.

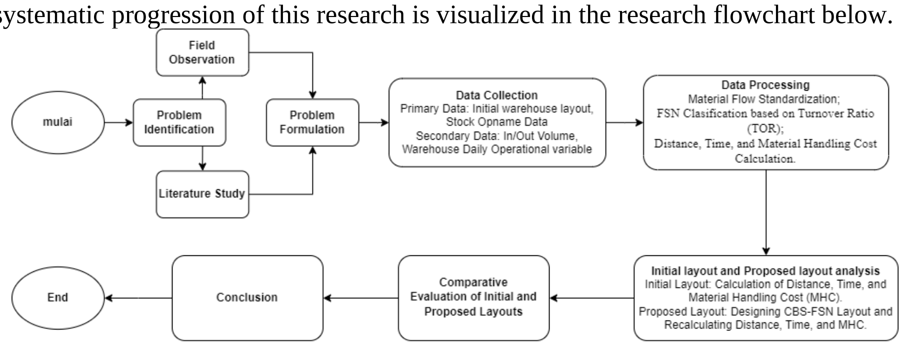

Figure 1 Research Flowchart

Data Processing procedure

The data analysis was structured into four sequential processing stages to transform raw logistical data into actionable efficiency metrics, which are as follows.

1. Material Flow Standardization.
   The first stage involved processing raw data from the three months to normalize disparate units into a standardized metric. To ensure calculations reflected actual handling cycles, all material volumes were converted from cubic meters (m³) into pallet units using a standard average forklift load of 1.55 m³/pallet [9]. Movement frequency was calculated using Equation (1):

$$Freq = \frac{Inventory\ volume}{average\ forklift\ load} \tag{1}$$

   This standardization reveals the actual handling intensity for each item, serving as the quantitative foundation for the subsequent velocity analysis.
2. FSN Classification based on Turnover Ratio (TOR).
   To ensure zoning precision, SKU classification into Fast, Slow, and Non-moving (FSN) categories is determined exclusively by the Turnover Ratio (TOR). This ratio acts as the sole metric for assigning storage priority in the Class-Based Storage (CBS) system, ensuring that high-velocity items are mathematically prioritized for the most accessible locations [10], [11]. The TOR is derived through the following calculation sequence (Equations 2–6):

$$Ending\ Inventory = Initial\ item + Item\ in - Item\ out \tag{2}$$

$$Average\ inventory = \frac{Initial\ inventory + ending\ Inventory}{2} \tag{3}$$

$$Turnover\ Ratio\ Period = \frac{freq\ out}{Average\ Inventory} \tag{4}$$

$$nventory\ Period = \frac{Number\ days\ of\ period\ observated}{TORp} \tag{5}$$

$$Turnover\ Ratio = \frac{Number\ days\ of\ per\ year}{Inventory\ Period} \tag{6}$$

The classification results produced a total of TOR>3, which are Fast-Moving SKUs, should be placed in a nearer I/O gate, TOR 1-3 are Slow-moving SKUs, and TOR <1 are Non-moving SKUs, which can be placed with less accessibility. This directly formed the basis for proximity zoning in the proposed layout.

3. Distance, Time, and Material Handling Cost Calculation.

To quantify operational efficiency, this study employs a unified calculation model that translates physical movement into time and financial metrics. The evaluation begins with Travel Distance, modeled using the Rectilinear geometry approach (Manhattan distance), standard for single-aisle layouts [12]. The distance from the zero-reference point (Gate Z) to the storage centroid (A) is calculated using coordinates (x, y) in Equation (7):

$$Distance\ (m) = |x1 - x2| + |y1 - y2| \tag{7}$$

Subsequently, Travel Time is simulated assuming a constant forklift velocity of 1.4 m/s (validated for indoor operations with <3% deviation [5]), as shown in Equation (8):

$$travel\ time = \frac{distance}{forklift\ speed\ Avg.(1.4m/s)} \tag{8}$$

Finally, to establish a standardized financial metric, the Material Handling Cost per Meter (MHC/m) is calculated. This value is derived by dividing the total daily operational expenses (fuel and labor) by the accumulated daily travel distance [14][15]. Using the established operational parameters (Fuel: 2.2 L/h @ IDR 6,800/L; Labor: 2 operators @ IDR 4,200,000/month), the calculation is performed using Equations (9) and (10):

$$\text{Daily Distance} = \frac{\sum\left(\text{Distance per Item} \times (\text{Freq In} + \text{Freq Out})\right)}{25} \tag{9}$$

$$\text{MHC/m} = \frac{(\text{Fuel Cost/Day}) + (\text{Labor Cost/Day})}{\text{Daily Distance}} \tag{10}$$

The final evaluation was conducted by benchmarking the initial layout (Random Storage) against the proposed layout (Proposed CBS Layout) using three Key Performance Indicators (KPIs): Total Monthly Distance, Total Monthly Time, and Total Monthly MHC [16],[17]. These KPIs were calculated for each SKU and aggregated using Equations (11) through (13):

$$Monthly\ travel\ time = Travel\ time \times Freq\ I/O\ total\ per\ month \tag{11}$$

$$Monthly\ Distance = Distance \times Freq\ I/O\ total\ per\ month \tag{12}$$

$$Monthly\ MHC = MHC\ per\ m \times Freq\ I/O\ total\ per\ month \tag{13}$$

Results and Discussion

To bridge analytical results with operational findings, each subsection below begins with a contextual connector that links computed metrics (frequency, distance, and time) with managerial implications before discussing technical insights.

Initial Layout Raw Material Warehouse Analysis

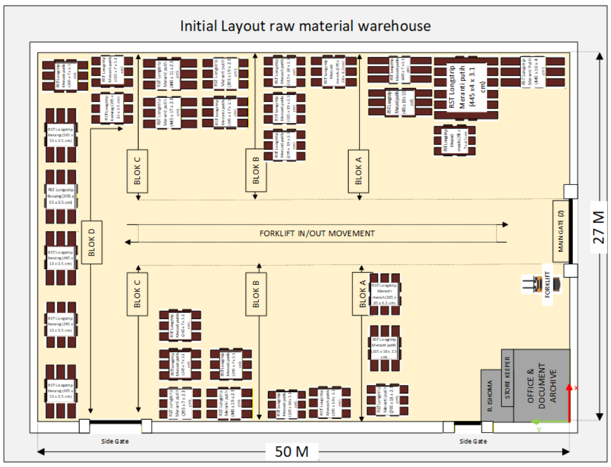

Figure 2 Initial Layout Raw Material Warehouse

In the initial layout, there are 8 SKUs stored in Block A, 6 SKUs stored in Blocks B, 9 SKUs stored in Block C, and 10 slow-moving SKUs stored in Block D. The storage arrangement applies a stacked configuration using a LIFO (Last-In, First-Out) system. To retrieve items located at the deepest position in the stack (earlier inbound stock), the forklift operator must unload all obstructing stacks.

All material handling activities rely on a single main aisle for both inbound and outbound operations, reflected in three measurable impacts: higher monthly travel distance (m), longer travel time (hours), and increased monthly MHC (IDR)—all of which the proposed layout seeks to reduce through proximity-based zoning [18], [19].

Frequency Movement calculation

The analysis begins by quantifying the material handling intensity for each Stock Keeping Unit (SKU). By processing the inbound and outbound volume data through Equation (1), the specific handling frequency for all 31 SKUs was established (Table 1). The results reveal a significant disparity in movement activity, identifying which items dominate the forklift workload. This quantitative baseline of handling frequency serves as the critical input data for the subsequent velocity analysis.

Table 1 Frequency Calculation Summary

No	Name Item	Inventory Volume (M^3)			Average Forklift Load (1.55 M^3/Pallet)	Freq (Pallet)		
		Initial	In	Out		Initial	In	Out
1	RST Longstrip Meranti Putih (445 x 10 x 4 cm)	3.97	7.45	3.40	1.55	3	5	3
2	RST Longstrip Meranti putih (445 x4 x 3.1 cm)	3.89	10.33	5.17	1.55	3	7	4
:	:	:	:	:	:	:	:	:
31	RST Longstrip Keruing (445 x 13 x 3.5 cm)	5.87	5.99	1.76	1.55	4	4	2

Class based storage Fsn Analysis Based On TOR result

Following frequency computation, the SKU demand distribution demonstrates a Paretotype imbalance where a minority of items generate the majority of travel workload. Building directly upon the frequency data established above, the analysis proceeds to the segmentation of inventory using the Turnover Ratio (TOR) logic defined in Equations (2–6) and frequency movement result (Table 2). This step transforms raw frequency counts into a velocity-based classification essential for zoning.

Table 2 Class Based Storage Based On TOR Result

No	Item Name	Ending Inventory (EI)	Average Inventory (AI)	Turnover Ratio period (TOrRp)	inventory period	Turnover Ratio (TOR)	Category
1	RST Longstrip Meranti Putih (445 x 10 x 4 cm)	5	4	0.75	120.00	3.04	F
2	RST Longstrip Meranti putih (445 x4 x 3.1 cm)	6	4.5	0.89	101.25	3.60	F
3	RST Longstrip Meranti merah (295 x 7 x 4.2 cm)	5	4	0.75	120.00	3.04	F
4	RST Longstrip Meranti putih (445 x 7 x 3.1 cm)	7	4.5	0.22	405.00	0.90	N
5	RST Longstrip Meranti putih (445 x 10 x 3.5 cm)	6	5	0.80	112.50	3.24	F
6	RST Longstrip Meranti putih (295 x 18 x 2.3 cm)	9	6	0.17	540.00	0.68	N
7	RST Longstrip Meranti putih (315 x 18 x 2.3 cm)	6	4.5	0.22	405.00	0.90	N
8	RST Longstrip Meranti merah (265 x 20 x 4.2 cm)	5	4.5	0.67	135.00	2.70	S
9	RST Longstrip Meranti merah (295 x 20 x 4.2 cm)	4	3	0.67	135.00	2.70	S
10	RST Longstrip Meranti putih (315 x 20 x 2.3 cm)	6	5	0.80	112.50	3.24	F

11	RST Longstrip Meranti putih (315 x 19 x 2.3 cm)	6	5	0.60	150.00	2.43	S
12	RST Longstrip Meranti putih (295 x 19 x 2.3 cm)	5	3.5	0.57	157.50	2.32	S
13	RST Longstrip Meranti putih (295 x 10 x 3.1 cm)	6	4.5	5.11	17.61	20.73	F
14	RST Longstrip Meranti putih (265 x 10 x 3.1 cm)	6	4.5	0.22	405.00	0.90	N
15	RST Longstrip Meranti putih (445 x 17 x 2.3 cm)	5	5	1.40	64.29	5.68	F
16	RST Longstrip Meranti putih (395 x 17 x 2.3 cm)	3	2.5	1.60	56.25	6.49	F
17	RST Longstrip Meranti putih (445 x 11 x 2.3 cm)	6	4.5	0.22	405.00	0.90	N
18	RST Longstrip Meranti putih (395 x 19 x 2.3 cm)	4	3	0.67	135.00	2.70	S
19	RST Longstrip Meranti putih (445 x 19 x 2.3 cm)	6	4.5	0.89	101.25	3.60	F
20	RST Longstrip Meranti putih (295 x 7 x 2.3 cm)	8	5.5	1.27	70.71	5.16	F
21	RST Longstrip Meranti putih (295 x 7 x 3.1 cm)	7	5	0.20	450.00	0.81	N
22	RST Longstrip Meranti putih (245 x 7 x 3.1 cm)	4	3.5	1.14	78.75	4.63	F
23	RST Longstrip Meranti putih (265 x 7 x 3.1 cm)	7	5.5	0.18	495.00	0.74	N
24	RST Longstrip Meranti putih (315 x 7 x 3.1 cm)	6	4.5	0.44	202.50	1.80	S
25	RST Longstrip Meranti putih (265 x 7 x 2.3 cm)	6	4.5	0.44	202.50	1.80	S
26	RST Longstrip Keruing (395 x 13 x 3.5 cm)	8	6	0.17	540.00	0.68	N
27	RST Longstrip Keruing (545 x 13 x 3.5 cm)	7	5.5	0.91	99.00	3.69	F
28	RST Longstrip Keruing (395 x 15 x 3.5 cm)	5	4	0.50	180.00	2.03	S
29	RST Longstrip Keruing (495 x 13 x 3.5 cm)	6	5	0.80	112.50	3.24	F
30	RST Longstrip Keruing (295 x 13 x 3.5 cm)	3	2.5	1.60	56.25	6.49	F
31	RST Longstrip Keruing (445 x 13 x 3.5 cm)	6	5	0.40	225.00	1.62	S

The classification results indicate a Pareto-like distribution where a minority of items drive the majority of movements. Specifically, 14 SKUs were identified as Fast-Moving (Category F) with high TOR values (e.g., RST Longstrip Meranti putih (295 x 10 x 3.1 cm) with TOR > 20), necessitating priority placement. Conversely, 8 items were classified as Slow-Moving (S) and 9 as Non-Moving (N).

This validation of velocity-based segmentation confirms that random storage policies are suboptimal for this inventory profile [18].

Calculation of Total Distance, Time, and Material Handling Cost in the Initial Layout

The baseline evaluation begins with Table 3, which details the granular rectilinear distance and travel time for a single trip of each SKU, calculated using Equations (7–8). This itemized breakdown highlights that deep storage positions for high-frequency items (like RST Longstrip Keruing at 59.6 m) create significant per-trip latency (42.9 seconds).

Table 3 Distance and Travel Time Calculation Summary

No	Item Name	From /To	X1	Y1	X2	Y2	Distance (m)	forklift speed Av.g (1.4 m/s)	Travel time (s)
1	RST Longstrip Meranti Putih (445 x 10 x 4 cm)	Z/A	13.5	0	25.7	2.2	14.4	1.4	10,4
2	RST Longstrip Meranti putih (445 x4 x 3.1 cm)	Z/A	13.5	0	22.6	7.0	16.1	1.4	11.6
:	:	:	:	:	:	:	:	:	:
1	RST Longstrip Keruing (445 x 13 x 3.5 cm)	Z/A	13.5	0	3.8	49.9	59.6	1.4	42.9

Material Handling Cost Analysis: Material handling expenses, comprising fixed and variable components (labor and fuel) [14][20]. These parameters serve as the primary variables for determining the Daily Distance (Equation 9) and Daily Operational Costs (Equation 10), resulting in the following unit valuation:

1. A total of 25 working days per month is considered effective.
2. Average forklift operating time is 6 hours per day.
3. Fuel price is IDR 6,800 per litre, and fuel consumption is 2.2 litres per hour.
4. The warehouse employs two forklift operators. The monthly salary per operator is IDR 4,200,000.
5. Material movement distance per day.
$$\frac{\sum(Each\ item\ distance\ \times\ (each\ item\ Freq\ in\ +\ each\ item\ Freq\ out)}{25} = \frac{11262}{25} = 451\ m \quad (14)$$
6. Fuel Consumption Cost of Forklift per day.
$$Operational\ Hours \times Fuel\ Consumption\ Rate \times Fuel\ Price = 6\ hours \times 2.2\ liters/hour \times IDR\ 6{,}800\ /liter = IDR\ 89{,}760\ /day \quad (15)$$
7. Labor Cost per day.
$$Labor\ Cost/month = 2 \times 4{,}200{,}000 = IDR\ 8{,}400{,}000$$
$$Labor\ Cost/day = \frac{8{,}400{,}000}{25} = IDR\ 336{,}000/day \quad (16)$$
8. Forklit cost per meter.
$$\frac{Fuel\ consumption\ per\ day}{\text{Material movement distance per day}} = \frac{IDR\ 89{,}760}{451\ m} = IDR\ 199/ \quad (17)$$
9. Labor cost per meter.
$$\frac{labor\ cost\ per\ day}{\text{Material movement distance per day}} = \frac{IDR\ 336{,}000}{451\ m} = IDR\ 746/m \quad (18)$$
10. Material handling Cost per meter.
$$Forklift\ cost\ per\ meter\ +\ Labor\ cost\ per\ meter = IDR\ 746 + IDR\ 199\ =\ IDR\ 945/\text{m} \quad (19)$$

Standardization of Material Handling Cost (MHC) To quantify the financial impact of spatial inefficiencies, to evaluate the efficiency of the current facility layout, the distances, travel times, and material handling costs in the existing layout were calculated. This analysis aims to understand how optimal the material movement is within the raw material warehouse and to identify potential improvements in the layout arrangement, a comparison can be made regarding the material handling cost between the initial and the improved layouts [16], [17]. The Spatial Cost Constant (MHC) To ensure methodological robustness in the financial evaluation, this study establishes a Fixed-Rate Spatial Benchmark. Unlike dynamic costing—which can obscure efficiency gains by redistributing fixed costs over reduced output—this approach isolates the geometric variable by treating the initial cost per meter as a constant 'Shadow Price' of internal transport . Following calculation which is aggregated using Equations (11) through (13), as follows.

Table 4 Calculation of Monthly Distance, Time, and Material Handling Cost in the Initial Layout Result.

no	Item Name	**From/To**	Travel time	Distance (m)	Freq I/O total per month	MHC per m (IDR)	Monthly travel time (s)	Monthly Distance (m)	Monthly MHC (IDR)
1	RST Longstrip Meranti Putih (445 x 10 x 4 cm)	Z/A	10.4	14.4	8	945	83	115.4	109053
2	RST Longstrip Meranti putih (445 x4 x 3.1 cm)	Z/A	11.6	16.1	11	945	127	177.1	167380
3	RST Longstrip Meranti merah (295 x 7 x 4.2 cm)	Z/A	11.9	16.5	8	945	95	132.0	124755
4	RST Longstrip Meranti putih (445 x 7 x 3.1 cm)	Z/A	17.2	24.0	7	945	121	167.7	158429
5	RST Longstrip Meranti putih (445 x 10 x 3.5 cm)	Z/A	15.2	21.2	10	945	152	211.9	200198
6	RST Longstrip Meranti putih (295 x 18 x 2.3 cm)	Z/A	14.0	19.4	8	945	112	155.4	146891
7	RST Longstrip Meranti putih (315 x 18 x 2.3 cm)	Z/A	12.6	17.5	5	945	63	87.6	82782
8	RST Longstrip Meranti merah (265 x 20 x 4.2 cm)	Z/A	10.3	14.4	7	945	72	100.5	94991
9	RST Longstrip Meranti merah (295 x 20 x 4.2 cm)	Z/A	23.4	32.5	6	945	140	194.9	184133
10	RST Longstrip Meranti putih (315 x 20 x 2.3 cm)	Z/A	25.3	35.1	10	945	253	351.3	331931
11	RST Longstrip Meranti putih (315 x 19 x 2.3 cm)	Z/A	23.4	32.5	8	945	187	260.3	246002
12	RST Longstrip Meranti putih (295 x 19 x 2.3 cm)	Z/A	21.8	30.3	7	945	153	212.0	200368
13	RST Longstrip Meranti putih (295 x 10 x 3.1 cm)	Z/A	23.0	32.0	49	945	1127	1566.8	1480602
14	RST Longstrip Meranti putih (265 x 10 x 3.1 cm)	Z/A	25.1	34.9	5	945	125	174.4	164784
15	RST Longstrip Meranti putih (445 x 17 x 2.3 cm)	Z/A	34.2	47.5	14	945	478	664.7	628094
16	RST Longstrip Meranti putih (395 x 17 x 2.3 cm)	Z/A	32.5	45.2	9	945	293	407.0	384639
17	RST Longstrip Meranti putih (445 x 11 x 2.3 cm)	Z/A	30.9	42.9	5	945	154	214.6	202821
18	RST Longstrip Meranti putih (395 x 19 x 2.3 cm)	Z/A	29.6	41.2	6	945	178	247.1	233462
19	RST Longstrip Meranti putih (445 x 19 x 2.3 cm)	Z/A	31.2	43.4	11	945	344	477.7	451403
20	RST Longstrip Meranti putih (295 x 7 x 2.3 cm)	Z/A	34.0	47.2	19	945	646	897.3	847925
21	RST Longstrip Meranti putih (295 x 7 x 3.1 cm)	Z/A	29.8	41.4	6	945	179	248.3	234625
22	RST Longstrip Meranti putih (245 x 7 x 3.1 cm)	Z/A	31.8	44.2	9	945	286	397.6	375751
23	RST Longstrip Meranti putih (265 x 7 x 3.1 cm)	Z/A	28.8	40.0	5	945	144	199.9	188858
24	RST Longstrip Meranti putih (315 x 7 x 3.1 cm)	Z/A	41.6	57.9	7	945	291	405.0	382744
25	RST Longstrip Meranti putih (265 x 7 x 2.3 cm)	Z/A	41.6	57.8	7	945	291	404.5	382281
26	RST Longstrip Keruing (395 x 13 x 3.5 cm)	Z/A	40.9	56.8	6	945	245	340.7	321999

27	RST Longstrip Keruing (545 x 13 x 3.5 cm)	Z/A	40.0	55.7	13	945	521	723.6	683783
28	RST Longstrip Keruing (395 x 15 x 3.5 cm)	Z/A	36.4	50.6	6	945	218	303.5	286760
29	RST Longstrip Keruing (495 x 13 x 3.5 cm)	Z/A	39.8	55.3	10	945	398	552.9	522443
30	RST Longstrip Keruing (295 x 13 x 3.5 cm)	Z/A	40.9	56.9	9	945	368	512.2	484020
31	RST Longstrip Keruing (445 x 13 x 3.5 cm)	Z/A	42.9	59.6	6	945	257	357.7	337989
Total Monthly Travel Time (s)							**8102**		
Total Monthly Distance (m)								**11261.3**	
Total monthly MHC/m									**Rp 10,641,898**

The calculations (Table 4) culminate in the total monthly key performance indicators for the initial layout. The Total Monthly Distance travelled is 11,261.3 meters, requiring a Total Monthly Travel Time of 8,102 seconds. This level of activity, combined with non-segmented LIFO stacking, results in a Total Monthly MHC (Material Handling Cost) of IDR 10,641,898. This high cost and time expenditure condition directly influences monthly MHC accumulation, the suboptimal positioning of high-frequency items far from the main gate—which significantly inflates total travel distance—and repeated unstacking operations, conditions commonly found in non-segmented LIFO storage environments.

Proposed Layout Analysis

To improve accessibility and reduce handling effort within the warehouse, storage locations are prioritized based on proximity to the inbound/outbound point. The classification results produced a total of TOR>3, 14 Fast-Moving SKUs should be placed in a nearer I/O gate, TOR 1-3 are 8 Slow-moving SKUs, and TOR <1 are 9 Non-moving SKUs, which can be placed with less accessibility. This directly formed the basis for proximity zoning in the proposed layout. This zoning strategy is supported by FSN classification results (Table 2).

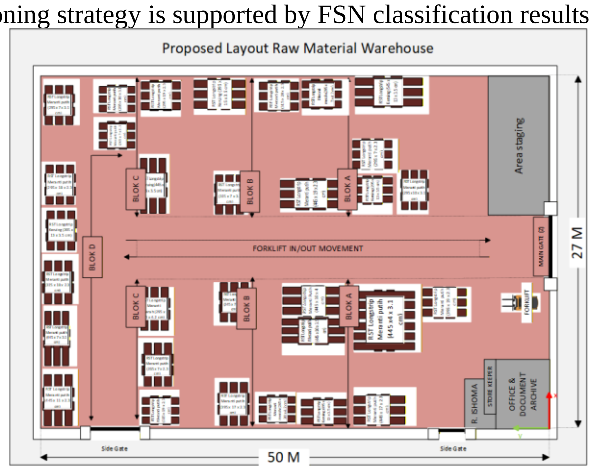

Figure 3 Proposed Layout of Raw Material Warehouse

Description :

1. Fast-moving items will be prioritized in Blocks A and B
2. Medium-moving items will be stored in Blocks C.
3. Slow-moving items can be placed in Blocks D.
4. A vacant space in Block A is repurposed as a staging area.
5. Clear labels are applied to each block to facilitate item retrieval.

Calculation of Total Distance, Time, and Material Handling Cost in the Proposed Layout.

Based on the FSN classification results presented in Table 2, the storage assignment in the proposed layout was determined by sorting the items in descending order of their Turnover Ratio (TOR). This prioritization logic ensures that SKUs with the highest velocity are allocated to the most accessible zones (Blocks A and B), while lower TOR items are shifted to further locations. Following this strategic placement, the total travel distance, operational time, and Material Handling Cost were recalculated using the standardized cost baseline of IDR 945/m established in the initial layout analysis [21].

Fixing this rate at IDR 945/m for both layouts is critical. If the rate were recalculated for the proposed design, the fixed labor costs would be distributed over a shorter distance, mathematically inflating the cost-per-meter and distorting the comparison. By locking the rate, it serves as a pure measure of layout efficiency independent of accounting variances [16]. The result of the calculation of the Total Distance, time, and material handling monthly in the proposed layout is as follows.

Table 5 Calculation of monthly distance, time, and material handling cost in the proposed layout result.

no	Item Name	**From/ To**	Travel time	Distance (m)	Freq I/O total per month	MHC per m (IDR)	Monthly travel time (s)	Monthly Distance (m)	monthly MHC (IDR)
1	RST Longstrip Meranti putih (295 x 10 x 3.1 cm)	Z/A	12.6	17.5	49	945	616	856.3	809180
2	RST Longstrip Meranti putih (445 x 17 x 2.3 cm)	Z/A	12.6	17.5	14	945	176	244.7	231194
3	RST Longstrip Meranti putih (445 x4 x 3.1 cm)	Z/A	14.6	20.2	11	945	160	222.5	210239
4	RST Longstrip Meranti putih (395 x 19 x 2.3 cm)	Z/A	16.4	22.8	6	945	98	136.7	129134
5	RST Longstrip Keruing (445 x 13 x 3.5 cm)	Z/A	11.3	15.7	6	945	68	94.0	88821
6	RST Longstrip Meranti putih (295 x 7 x 2.3 cm)	Z/A	13.3	18.5	19	945	253	351.8	332437
7	RST Longstrip Meranti putih (245 x 7 x 3.1 cm)	Z/A	10.6	14.8	9	945	96	132.9	125619
8	RST Longstrip Meranti putih (315 x 20 x 2.3 cm)	Z/A	18.8	26.1	10	945	188	261.2	246834
9	RST Longstrip Meranti putih (315 x 19 x 2.3 cm)	Z/A	18.6	25.8	8	945	149	206.6	195237
10	RST Longstrip Meranti putih (295 x 7 x 3.1 cm)	Z/A	16.1	22.4	6	945	97	134.3	126866
11	RST Longstrip Meranti merah (265 x 20 x 4.2 cm)	Z/A	16.1	22.4	7	945	113	156.5	147911
12	RST Longstrip Meranti putih (295 x 19 x 2.3 cm)	Z/A	13.9	19.4	7	945	98	135.6	128166
13	RST Longstrip Keruing (545 x 13 x 3.5 cm)	Z/A	23.2	32.3	13	945	302	419.6	396498
14	RST Longstrip Meranti Putih (445 x 10 x 4 cm)	Z/A	26.0	36.2	8	945	208	289.4	273483
15	RST Longstrip Meranti putih (445 x 10 x 3.5 cm)	Z/A	33.8	46.9	10	945	338	469.3	443489
16	RST Longstrip Meranti putih (445 x 19 x 2.3 cm)	Z/A	25.7	35.8	11	945	283	393.5	371881
17	RST Longstrip Meranti putih (315 x 7 x 3.1 cm)	Z/A	35.2	48.9	7	945	246	342.6	323738
18	RST Longstrip Meranti putih (395 x 17 x 2.3 cm)	Z/A	34.9	48.5	9	945	314	436.7	412705
19	RST Longstrip Meranti putih (265 x 7 x 3.1 cm)	Z/A	25.8	35.9	5	945	129	179.5	169628
20	RST Longstrip Keruing (395 x 15 x 3.5 cm)	Z/A	33.2	46.2	6	945	199	277.2	261954
21	RST Longstrip Meranti putih (445 x 7 x 3.1 cm)	Z/A	25.5	35.4	7	945	178	247.7	234105
22	RST Longstrip Meranti putih (295 x 18 x 2.3 cm)	Z/A	26.7	37.2	8	945	214	297.4	281043
23	RST Longstrip Meranti putih (265 x 7 x 2.3 cm)	Z/A	30.2	42.0	7	945	212	294.1	277896

24	RST Longstrip Keruing (495 x 13 x 3.5 cm)	Z/A	39.7	55.2	10	945	397	551.9	521546
25	RST Longstrip Meranti merah (295 x 7 x 4.2 cm)	Z/A	39.3	54.6	8	945	314	436.5	412511
26	RST Longstrip Meranti putih (315 x 18 x 2.3 cm)	Z/A	39.2	54.5	5	945	196	272.4	257442
27	RST Longstrip Meranti merah (295 x 20 x 4.2 cm)	Z/A	37.1	51.5	6	945	222	309.3	292260
28	RST Longstrip Meranti putih (265 x 10 x 3.1 cm)	Z/A	36.4	50.6	5	945	182	252.9	238967
29	RST Longstrip Meranti putih (445 x 11 x 2.3 cm)	Z/A	39.8	55.3	5	945	199	276.4	261222
30	RST Longstrip Keruing (395 x 13 x 3.5 cm)	Z/A	40.9	56.9	6	945	246	341.5	322680
31	RST Longstrip Keruing (295 x 13 x 3.5 cm)	Z/A	42.9	59.6	9	945	386	536.5	506983
Total Monthly Travel Time (s)							**6876**		
Total Monthly Distance (m)								**9557.3**	
Total monthly MHC/m									**Rp 9,031,667**

Table 5 shows the totals for the proposed layout, which implemented FSN-based zoning. The Total Monthly Distance is reduced to 9,557.3 meters, equating to a Total Monthly Travel Time of 6,876 seconds, or 1.91 hours of pure movement. As a direct result of these operational efficiencies (a 1,704 m reduction in travel), the Total Monthly MHC is lowered to IDR 9,031,667.

This demonstrates an apparent reduction in all key metrics. By prioritizing fast-moving (FSN) items in Blocks A and B, their travel paths are minimized, which directly lowers the aggregated monthly MHC. This outcome aligns with findings where FSN-based slotting policies have demonstrated direct cost reductions in material handling operations[22].

Comparative Evaluation of Initial and Proposed Layouts

The comparative evaluation between the Initial and proposed layouts at PT XYZ is carried out by analyzing three key performance aspects: material handling distance, travel time, and material handling cost. Analized from the initial state are benchmarked against the proposed state. [23]. The result which is as.

Table 6 Comparative Evaluation Of Existing And Proposed Layout Result

No	Evaluation Aspect	Initial Layout	Proposed Layout	Difference	Reduction
1	Total Monthly Distance (m)	11,261.30	9,557.30	1,704.00	15.13%
2	Total Monthly Travel Time (Hours)	2.25	1.91	0.34	15.11%
3	Total Monthly MHC (IDR)	10,641,898	9,031,667	1,610,231	15.13%

Implementing the FSN-based Class-Based Storage (CBS) layout yields significant improvements across all metrics. The 15.13% reduction in travel distance directly translates to a 15.11% reduction in pure travel time (a saving of 0.34 hours/month) and, most critically, a 15.13% reduction in monthly material handling costs, saving IDR 1,610,231 per month. To demonstrate the significance of the efficiency improvements achieved, the performance comparison between the Initial Layout and Proposed Layout is visualized in the following bar charts. These figures highlight reductions in distance, travel time, and material-handling costs.

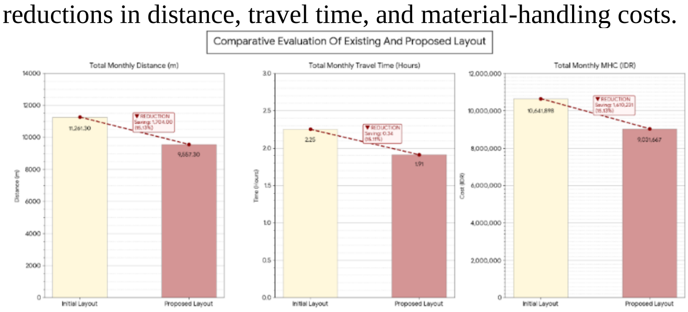

Figure 4 Comparative Evaluation of Existing and Proposed layout Chart

This magnitude of layout optimization reduced material handling distances by approximately 10-20%, validating the effectiveness of the CBS method in the Indonesian manufacturing context. [24]. Moreover, the reduction in backtracking suggests improved workflow fluidity, which is often cited as a key factor in reducing operational bottlenecks[25] .

Conclusion

This study redesigned the raw-materials warehouse layout at PT XYZ using a Class-Based Storage (CBS) policy informed by FSN analysis. The objective was to reduce operational inefficiencies and the high material-handling costs associated with the initial layout. The comparative evaluation demonstrates the effectiveness of the proposed design. By zoning SKUs by turnover rate, storage locations are prioritised by proximity to the inbound/outbound point. The classification results identified 14 Fast-Moving SKUs that should be placed in Blocks A and B, which are closer to the I/O point. 8 Slow-moving SKUs will be stored in Block C, and 9 Non-moving SKUs can be placed in Block D, which has less accessibility. The new layout achieved a 15.13% reduction in total monthly travel distance (1,704.0 m) and a 15.11% reduction in monthly travel time (0.34 hours). This optimization directly translates to significant financial savings, cutting the Total Monthly Material Handling Cost (MHC) by IDR 1,610,231, a 15.13% reduction. The results confirm that applying FSN classification to warehouse zoning is a highly effective strategy for minimizing forklift travel, reducing costs, and improving overall handling efficiency.

Beyond cost and distance reduction, organised layouts based on velocity zoning improve order-picking efficiency and reduce retrieval times by ensuring high-turnover items are continuously monitored and readily accessible. Furthermore, the streamlined flow supports faster order fulfilment rates by ensuring high-demand items are retrieved with minimal travel, thereby maximising throughput in peak periods. Despite these significant improvements, this study acknowledges certain limitations. Which is :

1. The distance calculation relies on a rectilinear model with a constant forklift velocity, which simplifies actual manoeuvring dynamics and acceleration phases.
2. Furthermore, the FSN classification is based on static historical data, potentially limiting responsiveness to sudden seasonal demand shifts.

Future research could address these gaps by employing Discrete Event Simulation (DES) to model real-time traffic congestion and variable speeds. Additionally, integrating dynamic slotting algorithms that update storage assignments automatically based on rolling forecasts would further enhance system adaptability and long-term operational resilience.

References

[1] G. Richards, *Warehouse Management: The Definitive Guide To Improving Efficiency And Minimizing Costs In The Modern Warehouse (4th Edition)*. London: Kogan Page, 2022.

[2] S. Primisari Putri *Et Al.*, “Penentuan Ongkos Material Handling Di Pt Xyz Menggunakan Metode Computerized Relative Allocation Of Facilities Technique (Craft),” *Jurnal Ilmiah Teknik Dan Manajemen Industri Jurnal Taguchi*, Vol. 4, No. 2, Pp. 457–468, 2024, Doi: 10.46306/Tgc.V4i2.

[3] R. Chen, J. Yang, And Y. Yu, “Integrated Scattered Storage And Picker Routing In Picker-To-Parts Warehouses,” *Eur J Oper Res*, Aug. 2025, Doi: 10.1016/J.Ejor.2025.08.018.

[4] A. R. Ardysti And D. Ernawati, “Identifikasi Pemborosan Dengan Pendekatan Lean Warehouse Pada Gudang Oli Di Pt Abc,” *Briliant: Jurnal Riset Dan Konseptual*, Vol. 10, No. 3, Pp. 736–749, Aug. 2025, Doi: 10.28926/Briliant.V10i3.1915.

[5] Sahat Sinambela, Argi Thaufani, Muhammad Irvan, And M. Manik, “Perancangan Tata Letak Gudang Dengan Menggunakan Metode Class Based Storage Pada Pt. Xyz,” *Jenius : Jurnal Terapan Teknik Industri*, Vol. 5, No. 2, Pp. 264–277, Nov. 2024, Doi: 10.37373/Jenius.V5i2.1392.

[6] Dhani Azis And Resista Vikaliana, “Usulan Perbaikan Tata Letak Gudang Dengan Menggunakan Metode Class Based Storage Di Pt. Maju Kaya Rejeki,” *Ikra-Ith Teknologi Jurnal Sains Dan Teknologi*, Vol. 7, No. 3, Pp. 57–66, Nov. 2023, Doi: 10.37817/Ikraith-Teknologi.V7i3.3234.

[7] N. Safira Isnaeni And N. Susanto, “Penerapan Metode Class Based Storage Untuk Perbaikan Tata Letak Gudang Barang Jadi (Studi Kasus Gudang Barang Jadi K Pt Hartono Istana Teknologi).”

[8] K. P. Juliani, T. Herawaty, And R. M. A. Hakim, “Evaluasi Dan Perancangan Ulang Tata Letak Gudang Pt X Dengan Metode Class Based Storage,” *Jurnal Terapan Manajemen Dan Bisnis*, Vol. 11, No. 1, Pp. 59–74, Jul. 2025, Doi: 10.26737/Jtmb.V11i2.7582.

[9] 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, Feb. 2023, Doi: 10.1063/5.0113824.

[10] E. Fatmawati And N. Rahmawati, "Layout Planning Of Finished Goods Warehouse Using Class-Based Storage Method Based On Turnover Ratio In Pt Xyz," *Jati Emas (Jurnal Aplikasi Teknik Dan Pengabdian Masyarakat)*, Vol. 9, No. 1, Pp. 199–208, Feb. 2025, Doi: 10.12345/Je.V9i1.263.

[11] M. D. N. Nasution, "Perancangan Sistem Klasifikasi Persediaan Suku Cadang Menggunakan Analisis Fsn-Tor (Turn Over Ratio) Dan Class-Based Storage Untuk Mengurangi Waktu Picking Pada Gudang Suku Cadang Tunas Toyota Cimindi - Dalam Bentuk Buku Karya Ilmiah," 2025, Https://Openlibrary.Telkomuniversity.Ac.Id.

[12] S. Tiwari, "Smart Warehouse: A Bibliometric Analysis And Future Research Direction," *Sustainable Manufacturing And Service Economics*, Vol. 2, P. 100014, Apr. 2023, Doi: 10.1016/J.Smse.2023.100014.

[13] R. Yusuf, M. A. Fais, And A. Chusaini, "Identifikasi Beban Kerja Mental Operator Forklift Pt. Ndis Menggunakan Metode Nasa-Task Load Index," *Jurnal Teknik Industri Terintegrasi*, Vol. 8, No. 1, Pp. 485–491, Jan. 2025, Doi: 10.31004/Jutin.V8i1.35759.

[14] N. Choernelia, A. Yohanes, S. V Jl Kendeng, B. Ngisor, K. Gajahmungkur Kota Semarang, And J. Tengah, "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, Pp. 108–115, Nov. 2022, Doi: 10.24014/Sitekin.V20i1.18405.

[15] S. Primisari Putri *Et Al.*, "Penentuan Ongkos Material Handling Di Pt Xyz Menggunakan Metode Computerized Relative Allocation Of Facilities Technique (Craft)," *Jurnal Ilmiah Teknik Dan Manajemen Industri Jurnal Taguchi*, Vol. 4, No. 2, Pp. 457–468, 2024, Doi: 10.46306/Tgc.V4i2.

[16] N. Sari, "Perencanaan Dan Pengendalian Persediaan Barang Dalam Upaya Meningkatkan Efektivitas Gudang," *Jurnal Bisnis, Logistik Dan Supply Chain (Blogchain)*, Vol. 2, No. 2, Pp. 85–91, Nov. 2022, Doi: 10.55122/Blogchain.V2i2.542.

[17] E. Kusrini, F. Novendri, And V. N. Helia, "Determining Key Performance Indicators For Warehouse Performance Measurement - A Case Study In Construction Materials Warehouse," *Matec Web Of Conferences*, Vol. 154, Feb. 2018, Doi: 10.1051/Matecconf/201815401058.

[18] Y. Nursyanti *Et Al.*, "Usulan Tata Letak Penyimpanan Barang Jadi Pada Industri Manufaktur Menggunakan Metode Class Based Storage," *Jurnal Teknologi Dan Manajemen Industri Terapan*, Vol. 3, No. I, Pp. 27–39, Mar. 2024, Doi: 10.55826/Tmit.V3ii.272.

[19] A. Andriyanto And X. F. Rivan, "Analisis Perancangan Tata Letak Gudang Menggunakan Metode Class Based Storage Di Cv Permata Hitam Permai," *Jurnal Logistik Bisnis*, Vol. 14, No. 2, Pp. 18–26, 2024, Doi: 10.46369/Logistik.V14i2.3971.

[20] A. Setiawan, "Analisis Dan Estimasi Biaya Logistik," 2021, Accessed: Nov. 27, 2025. [Online]. Available: Www.Freepik.Com

[21] 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, Feb. 2023, Doi: 10.1063/5.0113824.

[22] R. Alfatiyah, S. Bastuti, And R. Effendi, "Model Tata Letak Gudang Penyimpanan Menggunakan Metode Class-Based Storage," *Suara Teknik : Jurnal Ilmiah*, Vol. 12, No. 2, P. 21, Nov. 2021, Doi: 10.29406/Stek.V12i2.3121.

[23] F. Yener And H. R. Yazgan, "Optimal Warehouse Design: Literature Review And Case Study Application," *Comput Ind Eng*, Vol. 129, Pp. 1–13, Mar. 2019, Doi: 10.1016/J.Cie.2019.01.006.

[24] J. Karasek, "An Overview Of Warehouse Optimization," *International Journal Of Advances In Telecommunications, Electrotechnics, Signals And Systems*, Vol. 2, No. 3, Nov. 2013, Doi: 10.11601/Ijates.V2i3.61.

[25] S. S. Heragu, *Facilities Design (5th Edition)*. Crc Press, 2011.