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A Simulation-based Optimization Approached to Design a Proposed Warehouse Layout on Bicycle Industry

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Abstract: The finished goods must be stored in a warehouse before the items are dispatched. Due to the increasing demand in 2020, there will be an increase in the quantity of items, which will cause the finished goods warehouse at PT X to reach capacity. This issue lengthens the flow through the warehouse and makes it easier for the items to sustain damage. To improve capacity, the firm is building a new finished goods warehouse, and it wants to organize the two warehouses so that the displacement time is as short as possible. This study utilized simulations to calculate the time and dedicated and class-based storage strategies to establish the layout. This study utilized simulations to determine the time and dedicated and class-based storage approaches to establish the layout. According to the findings, the dedicated storage technique has a total displacement distance of 703,952 meters and an average moving duration of 3.37 minutes per pallet. These findings are not as useful as the class-based storage technique, which has 705,961 meters and an average pallet turn time of 3.53 minutes.

Keywords: Facility planning, warehouse, class-based storage, dedicated storage, simulation

Introduction

As one of many logistics processes, the warehouse process currently holds an irreplaceable position in business logistics systems and in supply chain logistics systems. Today, warehouses play a more vital role in company's success (or failure) [1]. The effectiveness of Indonesian supply chain firms' warehouses is increased by proper warehouse design and efficient operations [2]. In general, warehouse activity consists of receiving, put away, storage, picking, and shipping. Among the activities performed within a warehouse, order picking activity costs around 55% of the warehouse operating costs [3].

Particularly in warehouses that handle many large units, workers visit many trips per location to fulfill customer orders in a system called picker-to-part order-picking systems. The efficiency of the warehouse is highly affected by warehouse design and planning in manufacturing [4]. Thus, designing a good warehouse layout is a must-do job for a company to obtain a smooth operational process. A good warehouse layout means the layout needs to be suitable to its warehousing processes.

Several researchers have relaxed one or two of the supposed design rules in traditional warehouse designs and studied aisle designs in unit-load warehouses. These studies, the aisles are angled to reduce travel distance between a pick-up-and-deposit point and a pallet location [5]. Picker-to-part order-picking systems are one type of picking order systems. Pan *et al.*[6] stated that warehouse design and layout have a significant impact on the warehouse's efficiency [6].

To increase storage space and shorten trip times, Sari suggested a layout for a floor tile warehouse utilizing heuristics approach [7]. Furthermore, Gong et al designed a class-based storage Warehouse using a particle swarm optimization algorithm [8].

Bicycle manufacturer PT X sells its products both domestically and abroad. With three different brands and several supply strategies, including make to order and make to stock, currently PT X offers 984 types of bicycles. Since the business has grown in terms of demand quantity, the capacity of warehouse needs to be evaluated as well. The company's completed goods storage is currently at up to two times capacity due to increased bicycle production brought on by high demand.

The company has made some attempts to carry out the warehousing process without any additional space, including placing goods in aisles of shelves, placing in areas near the raw material warehouse, and erecting tents outside the warehouse, when the increase in production size was not as significant as it is today. These efforts, however, are not actually improving the situation. It slows down warehouse

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operations and increases the risk of damage to bicycle crates. Due to expanded capacity, the company has opted to build a new completed goods warehouse. In order to achieve the best average moving time, rearrange the bicycle location in the scheme at the same time.

Methods

The optimal guide between space area and material handling is determined by the warehouse layout system, which aims to minimize overall costs [9]. The issues in this research were resolved using the dedicated storage approach and the class-based storage method. The workflow for the layout method is as follows.

Data Collection

Three techniques could be used to gather data: direct observation of the finished goods warehouse, interviews, and data that belonged to the company, such as data incoming and outgoing of the number of bicycles in warehouses, the location of the warehouse. Interviews were conducted with the finished goods warehouse department and the IT department managers.

Locating the Center of Gravity

The center of gravity can be located by looking at the point where the area's diagonals cross. According to their dimension, objects are divided into three groups; however, the center of gravity used in this study is just two dimensions. Equations 1 provides the formula for computing the center of gravity in two dimensions by determining the building's surface area (A), x-coordinates, and y-coordinates of the building, n is number of facilities in the building [10].

$$X_i = \frac{\sum_{j=1}^{n} A_j x_j}{\sum_{j=1}^{n} A_j} ; Y_i = \frac{\sum_{j=1}^{n} A_j y_j}{\sum_{j=1}^{n} A_j} \quad (1)$$

Calculating Shelf Distance

In warehouse, the distance from the conveyor to the rack and the distance from the rack to the loading dock are determined using the rectilinear distance method. The center points of both sites are found to calculate this approach (0,0). Equation 2 illustrates how to use the findings of the center of gravity determination to calculate rectilinear distance using that method [11].

$$D_{ij} = \{X_i - X_j\} + \{Y_i - Y_j\} \quad (2)$$

Dedicated Storage

After determining the distance between the shelves, the dedicated storage approach is employed as the initial layout strategy. The dedicated storage approach designates a certain spot in the warehouse for each item to be stored in order to maximize efficiency [12]. Because one site for storing products can only be utilized by the goods and cannot be mingled with other goods, this method is often referred to as a fixed lot storage method.

Class Based Storage

The class-based storage method is the second layout technique. In a warehouse that blends random storage with dedicated storage methods, the class-based storage method keeps things organized [13]. The storage area will be divided into several predetermined classes using this manner, and these classes will be used as devoted. Items that have been separated into classes will be randomly put to decide their placement, but they are not permitted to stray outside of their class.

ABC Classification

The ABC classification will be used for class division in the class-based storage approach. A technique for categorizing products and ranking them from highest to lowest value is ABC classification. [14]. This analysis is based on Pareto's law, which argues that although though the value group only accounts for 20% of the total, it has the greatest impact, accounting for 80% of the total.

Space Requirement (S)

Using the storage system and ABC categorization above, it will be necessary to calculate the required space in order to determine the area needed on the shelves for each product. This strategy is essential to ensuring that each type of good stocked in the warehouse has several storage spaces that are in line with the production volume of goods. The formula for calculating space requirements is shown in Equation 3 [15].

$$S = \frac{average\ input\ or\ output}{column\ capacity} \quad (3)$$

Throughput (T)

The number of actions necessary to convey items to the warehouse must be calculated to estimate the throughput value. To gauge a company's degree of production and processing speed, this term is widely

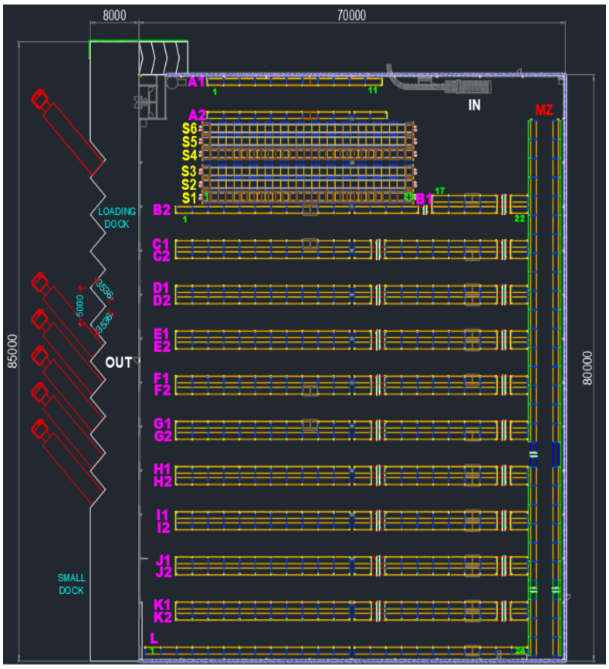

Figure 1. Overhead view of the current warehouse layout

utilized. Equation 4 displays the throughput calculation formula [16].

$$T = \frac{average\ input\ or\ output}{pallet\ capacity} \quad (4)$$

Simulation

After determining the layout of finished goods placement in the warehouse, a simulation is performed to determine the movement time. Using computer technology and certain presumptions, simulation is a technique for scientifically examining a system by imitating the actions or processes that take place in it [13]. The design of this system is an exact replica that is defined based on its actual condition and utilized as a tool for making decisions. There are three types of simulation models: static and dynamic simulations, deterministic and stochastic simulations, and continuous and discrete simulations [14]. The Promodel 7.0 software is used in this study's simulation.

Verification and Validation

The simulation findings are then put through a verification and validation procedure to make sure the model was constructed correctly and that it accurately represented the system's initial condition. A simulation must run a replication test to see whether the number of replications is adequate before completing validation. Equation 5 illustrates the replication test formula by calculating the value of the t-distribution (t_{val}), standard deviation (s), maximum error (α), and average moving time ($\bar{t}$) [15].

$$N' = \left(\frac{t_{val} \times s}{\alpha \times \bar{t}}\right)^2 \quad (5)$$

Results and Discussions

Current Warehouse Layout

The warehouse has a current size of 5600m² (80 x 70). The storage facility has enough for 57,500 bicycles. Selective pallet racking, shuttle racking, and mezzanine racking are the three types of racks that are employed. According to brand, the bicycle placement area is split. Figure 1 displays the layout of the current warehouse.

Warehouse Layout Design

A new completed products warehouse will eventually be built, and as part of the warehouse design idea, chosen pallet racking will take the place of the mezzanine racking. The brand B and C bicycles will be stored in the current warehouse, while the brand A bicycles will be kept in the new warehouse, giving the finished goods warehouse a potential capacity of 122,400 bicycles. The warehouse layout's design is shown in Figure 2.

Calculation of Current Warehouse Mileage

After calculating the distances between the incoming and exiting finished goods, the current total mileage is estimated considering the average bicycle entering and leaving the warehouse, the necessary amount of space, the throughput per space demand, and the mileage.

Average Bicycle Entry and Exit

Data on bicycle entrances and exits were gathered between January 2021 and December 2021. The average number of times the bicycle entered and exited each SKU was calculated after the data had been processed. Examples of average data are shown in Table 1.

Space Requirement (S)

In this computation, the largest value between the average value of bicycles incoming and exiting is considered. This is thus because certain bicycle SKUs lack information on departing or arriving bicycles, while other bicycles have more information on departure than on arriving bicycles. Table 2 provides an illustration of the space needs' outcomes. The needed number of columns is produced after rounding up.

Throughput (T)

The throughput calculation measures the amount of

Figure 2. Overhead view of the warehouse layout design
Description: selective pallet racking (A1-L); shuttle racking (S1-S6); mezzanine racking (MZ)

Table 1. The average incoming and exiting finished goods

SKU	The average of incoming finished goods	The average of exiting finished goods
B1	41	6
B2	26	7

Table 2. The example of the space requirements calculation

SKU	The average value (incoming finished goods)	The average value (exiting finished goods)	The maxi-mum value	S (column)
B1	41	6	41	0.68≈1
B2	26	7	26	0.43≈1

Table 3. The result of the throughput calculation

SKU	Bicycles for each pallet	T input	T output
B1	10	4.1≈5	0.6≈1
B2	10	2.6≈3	0.7≈1

Table 4. The example of T/S calculation

SKU	S	T incoming	T/S incoming	T exiting	T/S exiting
B1	1	5	5	1	1
B2	1	3	3	1	1

Table 5. The Example **of** Current mileage result

SKU	S	T/S incoming	Incoming mileage (m)	T/S exiting	Exiting mileage (m)
B1	1	5	278.25	1	50.35
B2	1	3	166.95	1	50.35

bicycle movement that takes place in the finished goods warehouse. The average number of bicycles incoming and exiting each SKU is used in this computation. The throughput value is rounded up. The Table 3 is an illustration of the computation procedure.

Throughput per Space Requirement (T/S)

Throughput and space needs are calculated to determine how much activity comes from each space requirement. The more activity the SKU requires, the higher the T/S value. The shelf location nearest to the exit will receive priority placement for items with the greatest exit T/S value. The mileage of each SKU will then be calculated using the results of this computation. Table 4 shows an example result of throughput divided by space requirements

Current Mileage

This formula is used to determine the mileage produced by each bicycle SKU. According to the calculations, the total mileage for the arriving trip is 435,986 meters, and the total mileage for the outgoing trip is 257,313 meters. This results in a total distance traveled of 693,300 meters. Therefore, placement nearest to the exit will be given preference to the shelf with the highest T/S value. An illustration of the outcomes of the current mileage computation is shown in Table 5.

Proposed Warehouse Layout Design

The suggested warehouse layout design uses both the class-based storage approach and the dedicated storage method. The warehouse's shelf configuration is

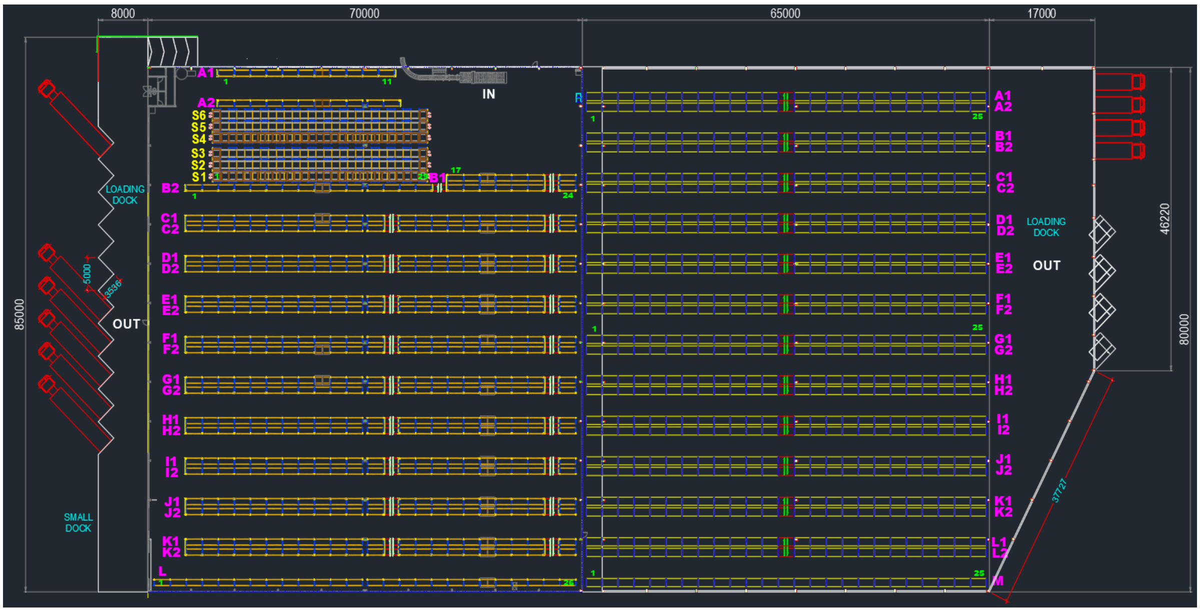

Figure 3. The application of dedicated storage method

Table 6. The results of the dedicated method's mileage

Rack No.	Column	Distance for incoming product (m)	Distance for outgoing product (m)	SKU	S	T/S Input	T/S Output	Mileage for incoming product (m)	Mileage for exiting product (m)
G1	7	78.21	35.60	D1	2	7	9.5	965.37	676.57
D1	7	59.70	35.62						
F1	16	48.01	53.46	D3	4	8.5	8.5	2166.99	1819.13
E1	16	41.84	53.48						
A1	1	43.13	53.53						
L	4	121.96	53.55						

decided using both techniques. The purpose of this proposal is to determine which strategy will result in the ideal changeover time. The class-based storage approach is organized to consider the number of bicycles leaving the warehouse, whereas the dedicated storage method is organized to take into account the average number of bicycles entering and leaving the warehouse.

Dedicated Storage Method

The investigation of the dedicated storage technique goes through the same steps as the current situation. The shelves are held in place by 881 column racks. The application of racks with the dedicated storage mechanism is shown in Figure 3. These findings indicate that the overall mileage of the entry is 477,296 m, and the exit mileage is 226,235 m, for a total mileage of 703,532 m. Table 6 shows an example of the results of calculating mileage using the dedicated method.

Class Based Storage Method

Calculating the average number of bicycles entering and leaving the warehouse, performing an ABC classification analysis, calculating space requirements, calculating throughput, calculating throughput divided by space requirements, determining bicycle rack areas, and calculating mileage are all steps in the analysis process for this class-based storage method.

Table 7. The results of the ABC classification calculation in 2021

SKU	Usage	Percentage of usage	Class
A247	157	10.67%	A
A249	143	9.72%	

The class-based method analysis process follows the same steps as the dedicated method, except that frequency and ABC classification analysis are used for class division. Class A contains 80% of the cumulative value of the percentage, class B contains 15% of the cumulative value of the following percentage, and class C contains 5% of the cumulative value of the remaining percentage. Table 7 shows an example of the ABC classification.

Total Mileage Results Comparison

The mileage comparison findings are shown in Table 8, with the current situation having the least overall

Figure 4. The application of class-based storage method shelves (The colors yellow and orange indicate class A; The colors green and purple indicate class B)

Table 8. The results of the class-based method's mileage

SKU	S (*pallet*)	T/S (Incoming)	T/S (Exiting)	Total distance for incoming product (m)	Total distance for exiting product (m)	Rack No.	Column	Distance (incoming product) (m)	Distance (exiting product) (m)
B200	27	9	4	2,265.75	161.44	E2	1	82.88	12.44
						F1	1	87.52	13.95
						E1	1	81.35	13.97
B206	10	10	3	803	45.07	E2	2	80.30	15.02

distance. This is due to the fact that there is now just one warehouse. Two warehouses are utilized in the proposal's examination of dedicated and class-based techniques. The entry to the two warehouses utilizes the same conveyor as the previous warehouse, but each has its own loading dock for egress. As a result, the transfer time at the time of put away to the new warehouse is longer than under the present circumstances, making it impossible to compare the current circumstances to the proposed technique. A comparison of the overall mileage results is shown in Table 9.

Table 9. Comparison of total mileage

	Total exit mileage (m)	Total entry mileage (m)	Total mileage (m)
Current condition	257,314	435,986	693,300
Class based optimal	253,709	449,150	702,860
Dedicated optimal	226,235	477,296	703,532

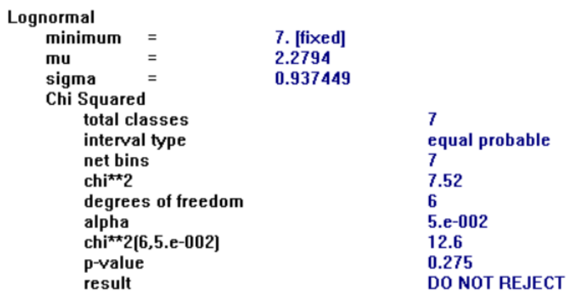

Figure 5. The example of the stat fit test

Data Collection for Inter-Arrival Time

Direct observation is used at the finished good warehouse to get data on the timing of bicycle arrivals on the conveyor. To determine what distribution will be created, the time data is multiplied by 100 and then put into a Promodel's stat fit. Figure 5 shows the bicycle's arrivals are lognormal distributed.

Transfer Time Data Retrieval

Direct observation is used to gather information about the time of movement at the warehouse and determine how quickly materials are handled. In order to later determine the material handling speed from the distance of the rack divided by the duration of movement, the time that has been obtained is then adjusted to the location of the rack as it is moving. The average speed of material handling in the warehouse was 2.17 m/s, according to 40 times of time data gathering. To determine how long it takes to go to and from the rack, this speed is multiplied by the separation between the shelves in and out.

Simulation Process

The following step involves running a simulation to determine the typical pallet transfer time in the completed products warehouse. The simulation is then updated with time data that was gathered in the earlier step. The proposed warehouse layout from the dedicated storage technique and the class-based storage approach will be compared to the average movement time in the current warehouse layout using this simulation.

Promodel software is used throughout the initial model creation phase. The process on the Promodel has several forming elements, including location, entities, resources, arrivals, and variables. Later, the first model will be created using these parts.

Entities are first added one at a time to the conveyor before being moved to a pallet for grouping. The pallet mover will transport the fully loaded pallet to the rack aisle, where the reach truck will then position it in the rack. With the help of a reach truck and a pallet mover, the pallets on the rack will be lowered back onto the rack and transported to the loading dock. If two containers have the same SKU, they will both be fulfilled; otherwise, the first container will be filled first and the second after that. The simulation method is displayed in Figure 6.

Verification Test

During the verification test, the pallet mover underwent a variety of displacement operations. The simulation model may be tested since more transfer activities are allocated to the lengthy wait process when the average wait time is larger, and vice versa. The verification test results are displayed in Table 10.

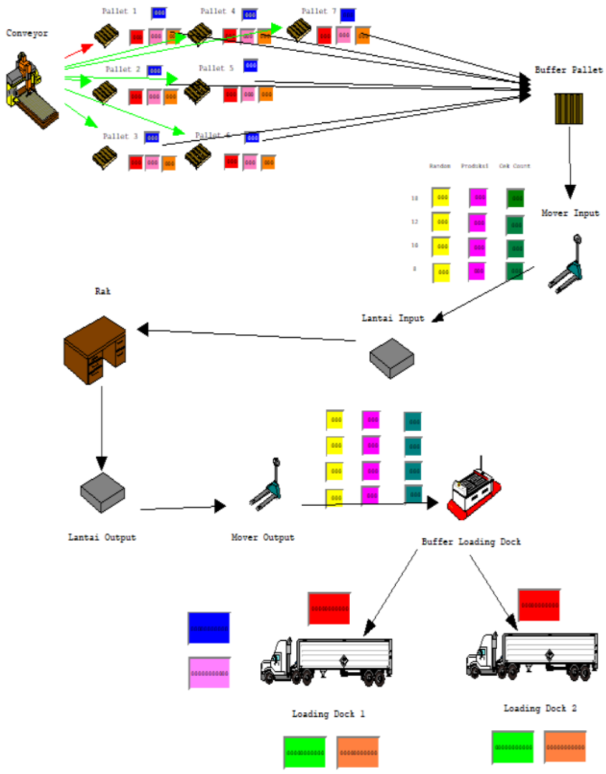

Figure 6. The flow of processes in a finished goods warehouse

Table 10. The result of the verification test

Activity	<	Normal	>
Average time in system	3.32 min	3.37 min	3.43 min

Table 11. The Result of Replication Test

Variable	Value
Average Time	3.222781
Stdev	0.018567
Alpha	5%
t	2.776
N	5
N'	0.319857

Table 12. The result of the simulation output

Method	Current condition	Dedicated	Class based
Average time	3.25 min	3.37 min	3.53 min

Replication Test

The replication test results showed that the simulation's replication was done correctly since the outcome of N' is smaller than the value of N. The replication test's findings are presented in Table 11.

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Two-Sample T-Test and CI: Class, Dedicated

Two-sample T for Class vs Dedicated

           N    Mean   StDev  SE Mean
Class      5  3.5306  0.0244    0.011
Dedicated  5  3.3716  0.0222   0.0099


Difference = mu (Class) - mu (Dedicated)
Estimate for difference:  0.1590
95% CI for difference:  (0.1242, 0.1939)
T-Test of difference = 0 (vs not =): T-Value = 10.78  P-Value = 0.000  DF = 7
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Figure 6. The result of statistical tests

Table 13. The comparison proposed method

	Dedicated storage	Class based storage
Average moving time	3.37 min	3.53 min
Total entry mileage	477,087 m	451,353 m
Total exit mileage	226,865 m	254,608 m
Total mileage	703,952 m	705,961 m
The number of columns used	881	742
Honeycomb loss	A lot because one column cannot be mixed with other SKUs	A little because one column can be mixed with other SKUs

N' is less than the value of N. Table 11 shows the results of the replication test.

Simulation Output

The two proposed techniques are also put through the simulation procedure. The scenario was repeated five times over the course of 384 hours. Conclusion: Compared to the class-based storage technique, the dedicated storage method has an average transfer time per pallet that is 3.37 minutes shorter. The outcomes of the simulation are displayed in Table 12.

Statistic Test

Statistical analyses reveal a considerable difference between the two proposed approaches' average transfer times. This is demonstrated by the T-value findings, which are higher than the T-table (2.365). Results of statistical tests are displayed in Figure 6.

Validation Test

During the validation test, the model and simulation results are presented to the firm. The distance to complete a put away at the current warehouse is unquestionably closer than it was when there was a new warehouse, therefore it can be claimed that the simulation findings are valid.

The Evaluation of Proposed Models

The simulation results of the proposed model are shown in Table 13. For the dedicated storage method, moving a single pallet takes an average of 3.37 minutes, resulting in an average output of 2,753, and for the class-based storage method, it takes an average of 3.53 minutes, resulting in an average output of 2,757. The dedicated storage approach outperforms the class-based approach in terms of average movement time, total outgoing distance, and overall mileage. The number of utilized columns and honeycomb loss, however, are not superior to the class-based solution for the total inbound miles. Additionally, the specialized technique is not appropriate for brand C bicycles since the SKU is not set due to the make-to-order system, but it would be simpler to change the placement arrangement if it were separated into classes.

Conclusion

The dedicated storage and class-based storage approaches, as well as a simulation, were used in this study's analysis to create a layout design and determine the transfer time. According to the findings of the layout calculation, the dedicated storage approach has a lower total mileage than class-based storage, which is 703,952 meters.

The simulation was run for 384 hours and replicated 5 times. There are no process changes in the actual and proposed simulations, it's just that the waiting time or transfer time between the actual and the proposed is different because the rack location for each SKU is different. According to the simulation findings, the dedicated storage approach also has a better transfer time from the put away to picking process, which is 3.37 minutes/pallet, than the class-based storage method.

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