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Designing Floor Tile Warehouse Layout Using Heuristic Approach Method to Increase Warehouse Capacity and Reduce Travel Distance

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***Abstract*—** XYZ Company is a distributor focused on distributing floor and wall ceramic tiles. XYZ Company has its own warehouse for storing finished goods with Last In First Out rotation. The XYZ Company Warehouse has an area of 12,312 m^2 with floor stack system. An issue currently risen to the warehouse is that the warehouse is currently overcapacity that urges the company to store some of its SKUs to be stored out of the block or even outside the warehouse. The overcapacity causes some problems including accessibility problem, distribution of storage and retrieval activities, and damaged product. In addition, higher throughput items allocation were not placed near to the input/output point so the material handling went through long travel to do its activities and it caused higher total travel distance. This research is focused on determining the warehouse layout to increase warehouse storage capacity and reduce travel distance. The procedure taken to solve the issue is by redesigning warehouse layout through heuristic approach method. The heuristic approach method is comprised by algorithms that can determine dimensions of storage zone and material assignment needed in designing warehouse layout. It is aimed at having some combinations of lane depths and storage zones to increase the warehouse storage capacity by considering the throughput of each SKU. The next step is allocating the items so it can reduce the monthly travel distance. The proposed design layout, shows that warehouse capacity increases by 35.53% or 5,319 pallet positions and monthly travel distance decreases by 24.58% or 216,032 meters.

***Keywords*—**heuristic approach, travel distance, warehouse layout.

I. INTRODUCTION

This research is conducted at XYZ Company, the only distributor for goods produced by ABC Company. XYZ Company focuses on distributing floor and wall ceramic tiles. XYZ Company has a warehouse that stores-finished goods located in Karawang. This warehouse is in charge for storing finished goods that will be distributed to the company's branches or customers in a certain distribution areas that have been previously determined. XYZ Company has several branch warehouses in Java, Sumatra and Sulawesi. The total number of stock keeping units (SKUs) handled by the company is 106 classified based on size and variant of the product. Fig. 1 shows the existing layout with 5-deep pallet in length and 4 pallets in width for each block, the material handling direction and the allocation of 10 items with the highest throughput. It can be seen that the highest throughput is placed far from the input/output point. Consequently, the material handling should pass through a long travel route for the storage and retrieval activity that causes higher total distance. In the existing condition, the monthly total travel distance is 878,882 meters.

Fig. 2 shows the required number of pallet positions from April to October in 2016 and current warehouse capacity. It can be seen that if the duration of the peak is more than half in a year, the ratio of the peak pallet position requirement to the average requirement should then be less than 1.2 or near the peak pallet position requirement [1]. Thus, with this condition, the warehouse at least has to store 19,843 pallet positions while the current warehouse capacity can only accommodate 14,640 pallet positions.

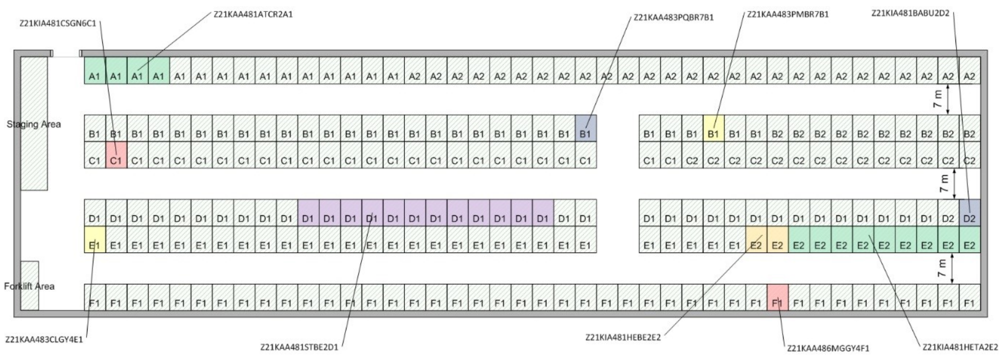

Fig. 1 Existing warehouse layout and item allocation

Fig. 2 Comparison of on-hand inventory and warehouse capacity

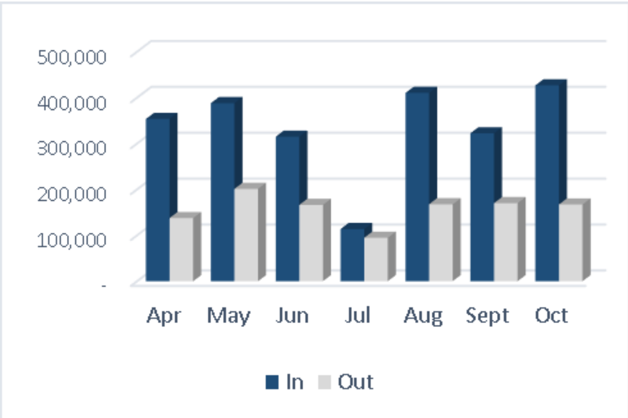

Fig. 3 Comparison of inbound and outbound

Fig. 3 shows the inbound and outbound items of box units in the warehouse for each month. It shows that the inbound of items is higher than the outbound of items and causes the stock accommodated by the warehouse increases. The inventory turnover ratio within this period was 0.75 which means that there was a movement of items in the warehouse. A low inventory turnover ratio indicates excessive inventory level or slow moving inventories [2]. Based on that condition, it can be estimated that the potential for the accumulation of finished goods stored in the warehouse is higher.

The available capacity of item block was not balanced with the required pallet positions and it caused several items should have been placed out of block and several blocks were full of many items. Sometimes, the exceed items were spread out of zone, and stored at functional area, blocked other item ways, and were even being placed outside the warehouse. The selection and storage towards items were disturbed due to the obstruction of the lane by other items. The items that would be delivered were usually placed at staging area before they were delivered to customers but this process should have been passed because there was no space for staging area because the exceed items occupied the area so that the items could not be recorded or checked before. Other exceed items were stacked up and broke the stack policy that had been determined by company and it made the items potentially damaged because the weight of one full pallet was around 750-1000 kilograms so it risked the items in the first level for being damage. The accessibility problem occurred because some items blocked another item entrance.

TABLE 1
WAREHOUSE EXISTING UTILIZATION

Description	Area	Unit	Percentage
Storage Area	7,027	m^2	57.08%
Staging Area	168	m^2	1.36%
Forklift Parking Area	42	m^2	0.34%
Aisle Area	5,070	m^2	41.22%
Warehouse Area	12,312	m^2	

However, Table 1 shows that the functional area~~,~~ in this research including storage area, staging area and forklift area, takes only 58.78% of the warehouse while the aisle is 41.22% which means that the warehouse utilization is only 58.78%. It is still below the maximum warehouse utilization, i.e. 80%-90% [3] so there is no need to expand the warehouse. The existing aisle width is 7 meters while the aisle width requirement for four-wheel counterbalance forklift is only 3.658 meters [4] that causes less storage area. Less storage area means that there is less area provided to store items. Thus, one of the ways to increase warehouse capacity without doing any expansion is by increasing the storage space utilization in the warehouse. However, the other one is by doing the re-layout to minimize the aisle area ~~but~~ that still considers the aisle requirement area [5]. Therefore, it is necessary to add the capacity of the warehouse by re-layouting XYZ Company warehouse in Karawang so that the warehouse capacity increases and travel distance reduces by considering storage requirement and accessibility to do the storage and retrieval activity.

II. LITERATURE REVIEW

Problem solving in warehouse capacity and travel distance through heuristic approach method has been proven and used previously. In his research, [5] designed warehouse layout using class-based storage principles. So that the utility of floor space and warehouse capacity can increase and material handling can decrease. The algorithms designed by Larson are used by [6] to make the maximum inventory position and slot capacity for each SKU balanced and increase floor space utilization using floor stack system. Other study by [7] used heuristic approach method from Larson to increase volumetric warehouse utilization and warehouse capacity so that the average inventory level for each SKU can be accommodated in the warehouse by using racking system.

2.1 Warehouse

Warehouse is any place or buildings to store any kinds of supplies where possible, the supply should meet the demand and as a buffer that facilitates the circulation of goods between the manufacturers and consumers in order to meet the target level of good service with the lowest total cost. Warehouse has to ensure that the product leaving the warehouse is clean and free from damage [8]. Warehouse (noun) is a building that serves to store raw material, semi-finished goods and/or finished goods ready to be marketed. Warehousing (verb) is warehouse management activities include receiving, storage, distribution, inspection, control to ensure the quality of goods [9].

The main function of a warehouse is for storing materials and finished goods. However, warehouse also has other functions that are also important. The functions of a warehouse are as follows [1]:

1. to be a temporary storage area.
2. to keep the supplies needed as a counterbalance and a buffer of variation between production and demand.
3. to be the distributor of a company and customer service center in order to meet the needs of the shortest transport distance and a quick response.
4. to be a place of production and distribution activities.
5. to protect stored goods from theft, fire, flood, and other weather problems with guaranteed safety and security system.

2.2 Warehouse Layout

The proper storage system selection should be taken, i.e. by matching the product characteristics and SKU activity. This is necessary when determining warehouse layout. There are several factors to be considered in determining warehouse layout [1], including:

1. Product characteristic
2. Size and weight of the product
3. Load accessibility
4. Inventory control
5. Warehouse dimensions
6. Material handling

2.3 Heuristic Approach

A heuristic approach is a procedure commonly used to find a good and feasible solution for some alternatives, which cannot lead to an optimum solution for specific problems encountered. There is no guarantee that the solution derived from heuristic approach is the most optimal solution, but the solution can be used with at least nearly optimal conditions. Heuristic methods are often based on relatively simple idea to look for a solution for the problem [10]. Heuristic is used when the number of variables is in thousands that to generate the result using model will take long computational time [11]. Heuristic approach procedure consists of three phases [5], as follows:

1. Determining aisle layout and dimensions thus area of storage zone can be identified by considering the input/output point of the warehouse.
2. Determining storage medium using row depth algorithm.
3. Allocating the storage zone using classification algorithm.

III. Research Methodology

Fig. 4 shows the steps in designing the proposed layout. The first step is the identification stage conducted through field observation, finding the right literature source, determining the problem, determining the limitations of the problem according to the existing condition, and determining the purpose of the research.

The next step is collecting and processing the data. This procedure is based on [5]. The data collected are data related to warehouse, products, and inventory. Data related to the warehouse are warehouse dimensions, material handling dimensions, etc. Data related to the product are product types, product dimensions, product characteristics and packaging of product. The latest data are data related to inventory such as initial stock, inbound and outbound for each SKU in the warehouse from April to October 2016. Furthermore, these data are later processed to generate new data such as average inventory level, stock in the warehouse per month, and throughput. In addition, the data are processed to determine minimum aisle width requirement, slot dimension, and maximum lane depth. The next step is determining the alternative warehouse layout based on the aisle route, i.e. by primarily identifying the aisle route in reference to the current entrance and exit of the warehouse and the material handling used. After the aisle path is determined, the location for the storage area of the product can be determined so that the total number of storage slots of each alternative can be calculated. The next step is determining the optimum lane depth, the number of storage requirements, and the storage zone for each SKU to maximize the utility of each storage location to be placed on the previously selected layout alternatives. Last step is to calculate the travel distance between the location of products with the entrance and exit of the warehouse using rectilinear distance.

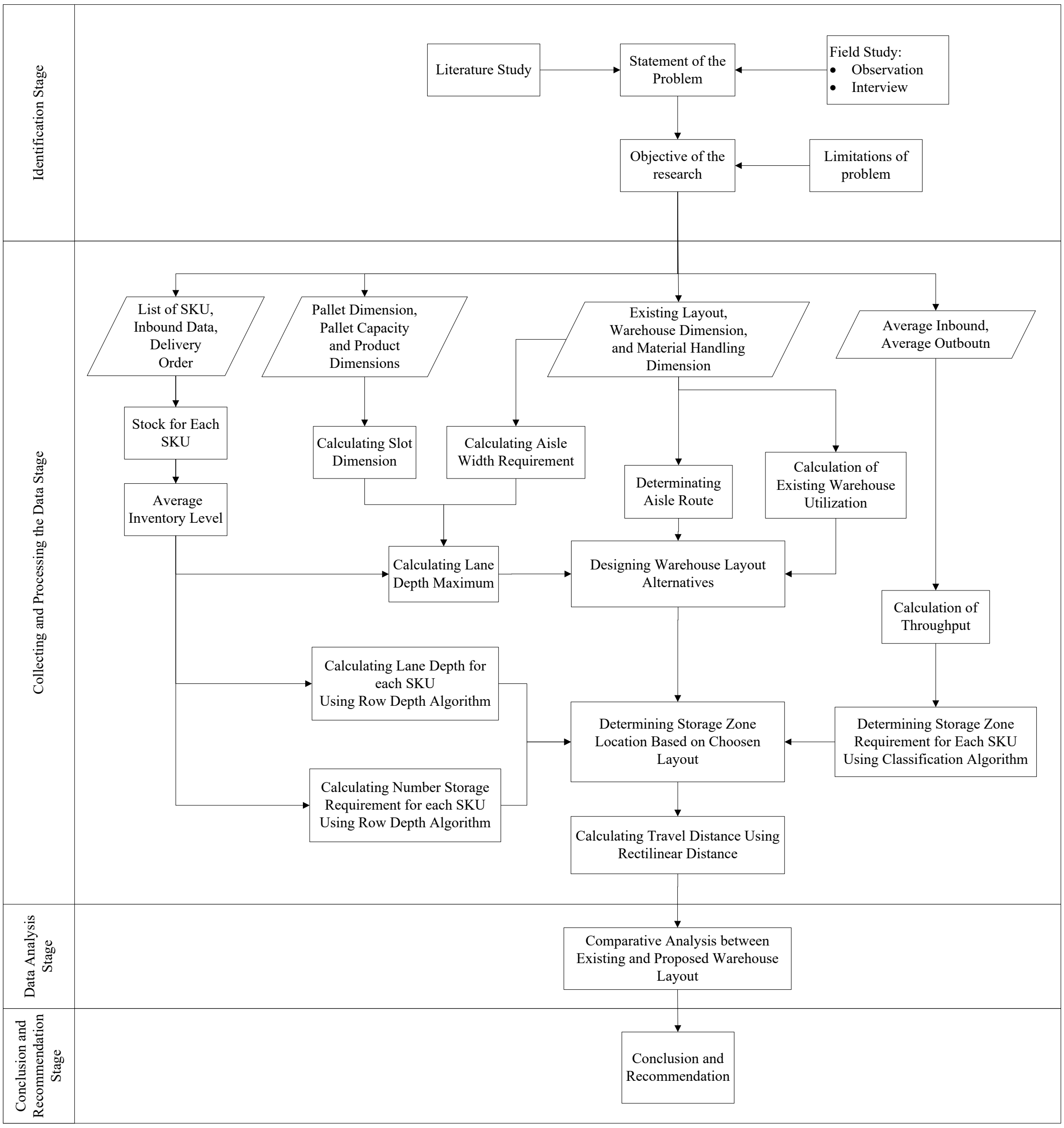

Fig. 4 Problem solving systematic

In analysis stage, there is comparative analysis between the existing conditions and the proposed conditions. The comparison shows capacity and total material handling distance between the existing condition and proposed condition. The last step is the conclusion of the results of the previous analysis.

3.1 Stock Calculation

Data of item stock are used to calculate the number of pallets that will determine the requirement for storage space area for each SKU, as the factors considered in designing the new layout. The formula to calculate stock is:

Stock = Begin Inventory + Inbound – Delivery Order (1)

3.2 Average Inventory Level

Planning the required storage space needs maximum or average inventory level that depends on the assigning material policy. The maximum inventory level will determine the storage space requirement based on fixed storage location. However, it will also determine the average inventory level for random location storage [3]. The formula to calculate average inventory level is:

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$$Average\ Inventory\ Level = \frac{\sum_{i=1}^{T} On\ Hand\ Inventory\ i}{n} \quad (2)$$

3.3 Throughput

Throughput can be measured based on the storage and retrieval activity in warehouse [5]. In this research, forklift is used to do the storage and retrieval activity where each activity can only transport one pallet. The results of this throughput calculation will be used as the input for determining the number of storage requirement for this research.The formula to calculate the throughput is:

$$Throughput = \frac{Average\ Inbound}{Number\ of\ Unitload} + \frac{Average\ Outbound}{Number\ of\ Unitload}$$
(3)

3.4 Warehouse Utilization

The utilization of each functional area, the square footage of the areas, and the total square footage of the warehouse is used to calculate the overall utilization. Warehouse utilization is the percentage of functional area used in the warehouse to total warehouse area. When the warehouse utilization exceeds the maximum warehouse utilization, usually 80% to 90%, additional space is required to store the items [3]. The formula used to determine the warehouse utilities is:

$$Warehouse\ Utilization = \frac{Total\ Used\ Area}{Total\ Warehouse\ Area} x100\% \quad (4)$$

3.5 Slot Dimensionss

Slot dimension is determined by the dimension of the pallet used by the company added with an allowance. Allowance is given to provide the distance between one pallet and another pallet during the storage activity. The allowance that can be given is 6 inches or around 0.15 m [3]. In this research, an allowance of 0.075 m is given for each side of pallet.

3.6 Aisle Width Requirement

The minimum width of aisle can be obtained through the calculation of material handling diagonal using Pythagoras formula, as follows:

$$c = \sqrt{a^2 + b^2} \quad (5)$$

Notation:
a = length of material handling
b = width of material handling
c = diagonal material handling

3.7 Lane Depth Maximum

Calculation of maximum lane depth is used as the maximum depth to be used in designing the proposed layout. The formula is used to reduce honeycombing from storage systems with floor stack system. This formula is designed to reduce the space that is unoccupied but unavailable for storage [12]. The formula to determine lane depth maximum is:

$$dmax = \sqrt{\left(\frac{a}{2}\right)\left(\frac{1}{n}\right)\left(\sum_{i=1}^{n}\frac{q_i}{z_i}\right)} \quad (6)$$

Notation:
dmax = maximum lane depth
a = width of aisle
n = number of product/SKU
qi = quantitys
zi = stackable height

3.8 Lane Depth Maximum and Number of Storage

The row depth algorithm can minimize the number of storage locations required for storing items so the number of aisles will decrease and floor space utilization will increase. The output of this step is the optimal row depth for items and the number of storage locations required for items that will become input to the next step. The row depth algorithm [5] is shown at Fig. 5 below:

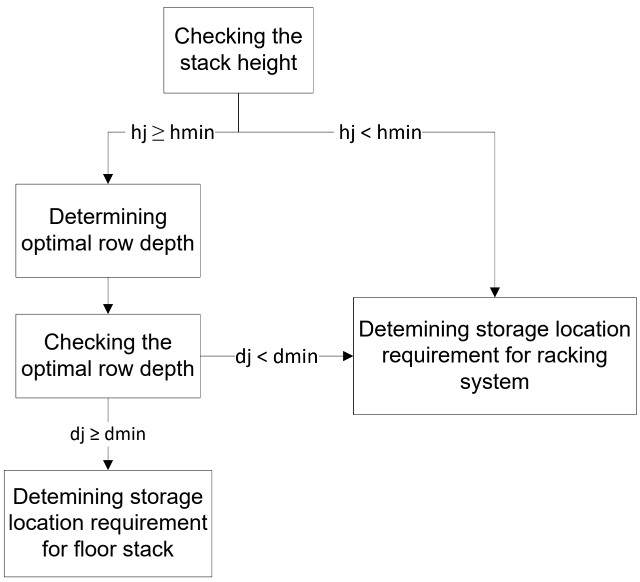

Fig. 5 Row depth algorithm

The process of checking the stack height aims to determine whether the item should use racking system or not by comparing the stack height for item (hj) and minimum stack height for floor stack or (hmin). If some items are going to be assigned for floor stake system, then the next step is determining temporary number of storage locations required (N^*) using this formula:

$$N^* = \left\lceil \frac{(1+\alpha) \times s_j}{d_{max} \times h_j} \right\rceil \quad (7)$$

The α is honeycombing allowance, sj is average inventory level, dmax is maximum row depth for floor stack, and hj is item stack height. Then the optimal row depth for item (dj) will be generated using this formula:

$$dj = \left\lceil \frac{(1+\alpha) \times s_j}{N^* \times h_j} \right\rceil \quad (8)$$

The next step is checking the optimal row depth by comparing dj and minimum row depth for floor stacking (dmin). In determining storage location required for floor stack, the N* will become Nj which refers to the number of storage locations required while in the racking system, Nj will be determined by a function F(sj) that can calculate the number of storage locations required to store sj pallets.

3.8 Storage Zone

The next step is the allocation of each item to store medium based on the number of storage locations and lane depth obtained in the previous phase and the ratio of throughput/storage. This heuristic classification algorithm can lead to a solution similar to the one of knapsack problem. The knapsack problem will accommodate a given weight and then maximize the value of item without the weight. In this heuristic approach, the item value stored is equal to the throughput whereas the weight is equal to the storage space needed [5]. This algorithm assigns the items to storage medium then to class or zone and ensures that each storage zone is not overloaded. The classification–algorithm [5] is shown ~~at~~ in Fig. 6, as follows:

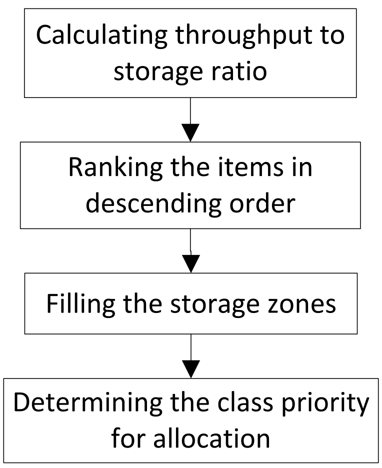

Fig. 6 Classification algorithm

The first process is calculating throughput to storage ratio (Rj) by dividing the throughput (tj) by Nj. The next step is ranking the items based on Rj in descending order

The next step is filling the storage zones or classes for each storage medium. The algorithm of this step is as follows:

For all items fulfilling the criteria of rj = i and dj = l

(a) If Ik + Nj ≤ L
    Then Ck = Ck ∪ j
    Ik = Ik + Nj
    Dk = dj
(b) If Ik + Nj > L
    Then k = k + 1
    Ck = ∅
    Ik = 0
go to (a)

Notation:

rj = Rank of each item
L = Length of storage zone
k = Index for class
Ck = Number of items in the class
Ik = Number of storage locations required of class
Dk = Storage medium of lane depth of class

The final step is to determine the class priority to be allocated in warehouse. The class priority is sorted by the smallest to largest class rank. Here is the step in calculating the average class sequence:

$$R_k^* = \sum_{\forall j \in Ck} \frac{rj}{|Ck|} \quad (9)$$

Notation:

R_k^* = Rank of class
rj = Rank for each SKU (j=1,...,n)
Ck = Number of items in the class

3.9 Distance between Facilities

If there are two workstations or departments i and j where the coordinates are indicated as (xi, yi, zi) and (xj, yj, zj), to calculate the distance between two midpoint dij can be done using the following methods [13]:

1. Rectilinear Distance
2. Euclidean Distance
3. Squared Euclidean Distance

IV. Result and Analysis

Table 2 shows the class summary results on each lane depth. This classification algorithm ensures that one class has the same number of depths, but not all

SKUs with the same number of depths will fit into one class. This algorithm also focuses on throughput so that one class has almost same movement characteristics. The proposed layout requires 12 storage zones for the 12 classes. The zones are named based on the depth of one lane to store the item. The 10-deep floor has multiple class which means that a lot of items need to be stored in 10-lane depth. A letter such as A, B, C and D is added to the zone that has same depth or multiple zones with the same storage medium. The priority indicates the sequence of placing storage zone to warehouse layout. The location of storage zone is determined by minimum total distance calculated using rectilinear distance. Thus, the total area required to store the items is 9580.32 m^2.

The classification algorithm ensures that one class has the same amount of depths, but if the class with the same depth is overload, it will generate another class with the same depth. The capacity can be calculated from each storage medium. Therefore, the total pallet positions conducted in reference to this algorithm is 19,959 pallet position. Table 3 shows the class summary results on each lane depth.

TABLE 2
REQUIRED AREA FOR EACH STORAGE ZONE

Priority	Storage Zone Name	Zone Length	Zone Depth	Total Slot	Total Area (m^2)
1	5-deep floor	1	5	5	7.2
2	10-deep floor A	159	10	1,590	2,289.6
3	9-deep floor	105	9	945	1,360.8
4	6-deep floor	10	6	60	86.4
5	10-deep floor B	160	10	1,600	2304
6	8-deep floor	24	8	192	276.48
7	10-deep floor C	167	10	1,670	2,404.8
8	3-deep floor	3	3	9	12.96
9	10-deep floor D	56	10	560	806.4
10	2-deep floor	3	2	6	8.64
11	7-deep floor	2	7	14	20.16
12	1-deep floor	2	1	2	2.88
	Total			6,653	9,580.32

TABLE 3
STORAGE MEDIUM CAPACITY

Storage Medium	Number of Classes	Number of SKU	Percentage of SKU	Number of Pallet	Percentage of pallet
1-deep floor	1	2	2%	6	0.03%
2-deep floor	1	3	3%	18	0.09%
3-deep floor	1	3	3%	27	0.14%
4-deep floor	0	0	0%	-	0%
5-deep floor	1	1	1%	15	0.08%
6-deep floor	1	7	7%	180	0.90%
7-deep floor	1	1	1%	42	0.21%
8-deep floor	1	9	8%	576	2.89%
9-deep floor	1	21	20%	2,835	14.2%
10-deep floor	4	59	56%	16,260	81.47%
Total	12	106	100%	19,959	100%

TABLE 4
CURRENT AND PROPOSED LAYOUT UTILIZATION

	Initial Layout	Percentage	Proposed Layout	Percentage
Storage Area	7,027	57.08%	9,624	77.81%
Staging Area	168	1.36%	168	1.36%
Forklift Parking Area	42	0.34%	42	0.34%
Aisle Area	5,070	41.22%	2,474	20.48%
Warehouse Area	12,312	100%	12,312	100%

Table 4 shows the comparion comparison between the existing and proposed layout. Based on the calculation of the utility of each area to the existing warehouse area, the storage area utilization of proposed warehouse is 77.81%, staging area is still 1.36%, and forklift parking area is 0.34% so the warehouse utilization is 79.52% where the the warehouse utility of 35.53% is still below the maximum warehouse utility value of 80% to 90% [3]. The proposed layout shows the increase of warehouse utilization by 20.74%. It comes from the reduction of aisle area in the existing warehouse to be the storage area in proposed layout.

TABLE 5
CURRENT AND PROPOSED LAYOUT CAPACITY

	Required Capacity	Existing Layout	Proposed Layout	Percentage
Pallet Position	19,843	14,640	19,959	35.53%

TABLE 6
CURRENT AND PROPOSED LAYOUT TRAVEL DISTANCE OF 10 HIGHEST THROUGHPUT ITEMS

Material	Existing Location	Existing Distance	Proposed Location	Proposed Distance
Z21KIA48 1HETA2E2	E2	106,566.9	10-Deep Floor A	87,978
Z21KIA48 1HEBE2E2	E2	71,482.8	10-Deep Floor B	20,362.8
Z21KAA48 1STBE2D1	D1	46,027.8	10-Deep Floor C	31,800.6
Z21KAA48 3PQBR7B1	B1	41,529.2	10-Deep Floor A	19,288.8
Z21KAA48 6MGGY4F1	F1	45,566.4	10-Deep Floor A	23,760
Z21KIA48 1CSGN6C1	C1	20,950.8	10-Deep Floor A	8,517.6

Material	Existing Location	Existing Distance	Proposed Location	Proposed Distance
Z21KAA48 3CLGY4E1	E1	9,014.7	10-Deep Floor B	23,601.3
Z21KAA48 3PMBR7B1	B1	33,403.6	10-Deep Floor B	18,958.8
Z21KAA48 1ATCR2A1	A1	3,551	10-Deep Floor B	5,909.4
Z21KAA48 3NABR7C1	C1	16,692	10-Deep Floor A	5,184

TABLE 7
CURRENT AND PROPOSED LAYOUT TRAVEL DISTANCE

	Existing Layout	Proposed Layout	Percentage
Total Travel Distance (m)	878,882	662,850	-24.58%

Table 5 shows the comparison between the existing and proposed layout. Along with the increase of warehouse utilization, the warehouse capacity has been increased up to 35.53% or increases by 5,319 pallet positions without exceeding the maximum stacking rules and the the aisle requirement. The capacity also increases because the maximum depth of storage zone increases from 5 in the existing layout to 10 in the proposed layout.

Table 6 shows the comparison of travel distance between the input/output point and the storage location of 10 SKUs with highest throughput. The storage location of items with highest throughput is placed near the input/ouput point so that the meterial handling should not be managed in lengthy distance. The result of the proposed layout allocation shows the material handling distance is lower than that of the existing layout.

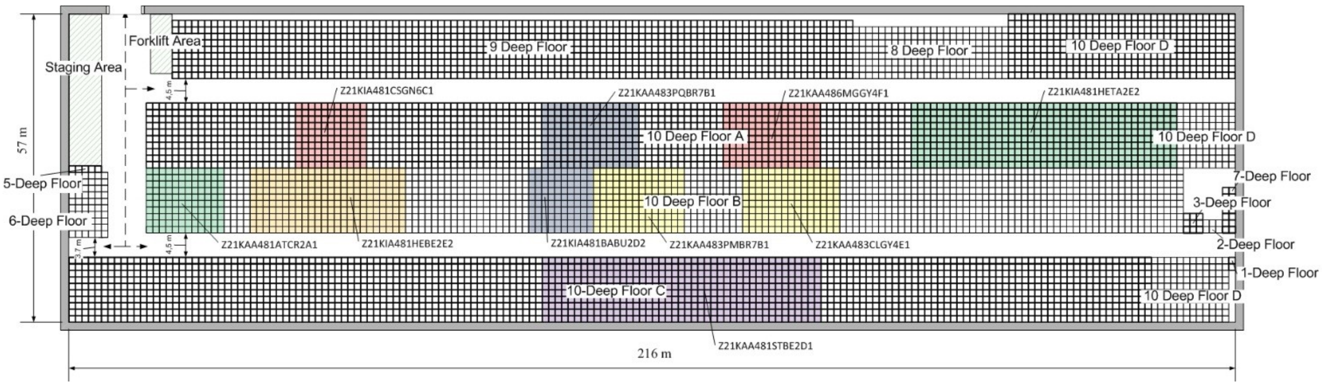

Fig. 7 Proposed warehouse layout

Table 7 shows the comparison of monthly travel distance between the existing and proposed layout. The monthly travel distance of proposed layout has been decreased to 24.58% or by 216,032 meters it is because the allocation considers the priority of class where the same class has similar characteristics and ranking items in reference to the throughput and storage space requirements.

V. CONCLUSION

This paper presents some steps to redesign warehouse layout that can lead to the capacity increase using heuristic approach method. The warehouse used as the object is a warehouse that uses single command pallet storage and retrieval with counterbalance forklift. The warehouse uses floor stacking system to store the item. The three main steps to re-layout the warehouse [5] determining aisle layout and storage zone dimensions, assigning items to a storage medium which is storage zone, and allocating the storage zone to the provided floor space. Row depth algorithm is used for generating optimal row depth while classification algorithm is used to allocate items to storage zone. Then, the proposed layout is compared to the existing layout to be analyzed.

Based on the research objectives set out, it can be concluded that warehouse layout alternative moving the forklift area to the right side of input/output point, as in Fig. 7, is the best proposed layout for floor tile warehouse at XYZ Company. The width of aisle used is appropriate so the exceed space can be turned into storage space. The proposed layout has various lane depth between 1 and10 that is able to increase the storage capacity by 35.53% or 5,319 pallet positions. The item allocation is based on the throughput so the item with high throughput can reduce travel distance by 24.58% or 216,032 meters in month.

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