



THE ALGORITHM OF GOOD PLACEMENT ON THE SHELF BY CONSIDERING THE WEIGHT AND VOLUME OF THE GOODS TO THE CENTRE OF MASS

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ABSTRACT

This study aims to develop an algorithm for placing goods on warehouse shelves. The process of placing goods in a warehouse is generally placed or arranged in a rack. Placement of goods must be correct to achieve space efficiency and high shelf utilization while maintaining balance on the storage shelf. The placement of items that have various volumes and weights must consider their placement position on the storage rack. Placing goods carelessly and only consider the shelf utilization rate will cause an imbalance. Shelf imbalance will accelerate the damage to storage racks, as well as the risk of collapsing shelves. Best placement of goods, in order to achieve shelf utilization and maintain shelf balance, must consider the weight and volume of goods placed against the total center mass of the rack. The procedure for placing goods on the shelf by considering the total center of mass was developed from research on warehouse layout. The procedure for placing goods in warehouse layout research is carried out on a two-dimensional plane (x-axis and y-axis). Whereas in this study, the placement of goods was carried out by considering the location of the goods in a three-dimensional plane (x, y and z axes). The placement algorithm is designed to place goods with various size (volume and weight) on multi-layer racks (with assumption each layer has same load capacity). This research produces two placing algorithms. The first algorithm focuses on the weight and volume of goods, so the pallets containing with largest volume and weight goods are arranged first and placed on the lowest layer. The second algorithm focuses on the weight of the goods, the pallets containing the heaviest goods will be arranged first on the lowest layer. Both algorithms are simulated using numerical data. The algorithm that focuses on weight (the second algorithm) has a better mass center than the algorithm that focuses on the weight and volume of goods (the first algorithm).

Keywords: placing algorithm, center of mass, layer, shelf, utilization.

Published By:

Fakultas Teknologi Industri
Universitas Muslim Indonesia

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DOI : <http://dx.doi.org/10.33536/jiem.specialedition.776>



I. INTRODUCTION

Every industry, it is common to have a storage area or warehouse. The warehouse is used to store inventories in the form of finished products, raw materials, and any supplies. According to Warman [1], the warehouse is an important part of a company that is used as a storage area for goods. Meanwhile, warehousing is an activity to store goods.

According to Resmana Lim, et al. [2], how to store goods in a warehouse can be done in many ways, which one is by using rack that has multi layers. Appropriate application of multi-layer racks in warehouse can impact to increasing storage utilization. Placing of goods on warehouse shelves without regard to goods characteristics has potential to causes losses. The potential losses include long picking and put away processes, low space utilization, damage to goods, damage to shelves due to imbalance, and work accidents due to falling goods. To minimize losses due to misplaced items, important to heed the location of total center of mass on the shelf

II. PROBLEM STATEMENT

The objective of this study is developing an algorithm for placing goods with multi criteria (multi size, volume, and weight) on multi-layer shelves. The system is modeled by the presence of several items (u) which will be arranged first on a pallet (a), then placed on s -th shelf in k -th layer. Goods placement must take considering weight and volume of goods (u), and limitations from shelves load capacity (y) that using.

There are two algorithms that have been developed in this study. The first algorithm, determining placement location of goods on shelf focuses on the weight and volume of goods loaded on pallets. Meanwhile, the second algorithm focuses on the total weight of goods on a pallet. To evaluate the best goods placement algorithm, used calculation of center of mass from shelf. The best algorithm criteria is that gives location of center of mass on lowest z-axis coordinate (floor direction). The following is the notation used in this paper.

Index:

f = denote the f^{th} location from total location pallet on layer, so $f = 1, 2, \dots, F$

i = denote the i^{th} weight from total variation weight I, so $i = 1, 2, \dots, I$

when placing goods. Zhang et al. [2] have designed shelf structure mechanically to improve shelf balance, but potential for shelf to collapse remains if load placement is not correct.

Molina et al. [4] have also conducted research related to goods placement. Molina developed a system of stacking goods on pallets with the aim that each item can bind (lock) each other. Abdou, et al. [5] designed an algorithm for placing goods on a pallet with performance measurement is level of pallet utility. Larson et al. [6] have designed an algorithm for placing goods in two-dimensional space (x and y axis direction) that optimizes space usage (space utilization level) and minimizes use of material handling in picking and put away processes.

Research about placing goods on the shelf as part of procedure for placing goods in warehouses is still rarely. This study aims to develop a procedure (algorithm) for placing multi-characteristic goods on multi-layer shelves by considering location center of mass of shelf.

j = denote the j^{th} volume from total variation volume J , so $j = 1, 2, \dots, J$

k = denote the k^{th} layer from total layer in one shelf K , so $k = 1, 2, \dots, K$

v = denote the v^{th} shelf from total shelves V , so $v = 1, 2, \dots, V$

q = denote the q^{th} pallet from total pallet Q , so $q = 1, 2, \dots, Q$

m = denote the total mass, where m is member of set of M

Parameter:

H = pallet height

L = pallet length

W = pallet width

CH = denote the height between shelf layers

CP = denote the load capacity of pallets

BP = denote the load on pallets

SL = denote the remaining length of the pallet after placing goods

SW = denote remaining width of the pallet after placing goods

SH = denote remaining high capacity between layer of shelves after placing goods

Variable:

$X_{u,f,k,v}$ = the decision variable (the u -th goods placed on pallet a_f layer y_k and shelf S_v)

b_i = denote the goods with i -th weight variation

r_j = denote the goods with j -th edge variation

u_{ij} = denote the goods with i -th weight variation and j -th edge variation
 a_q = denote the q -th pallet
 a_f = denote the f -th pallet on layer of shelf
 y_k = denote the k -th layer from a number of layers at shelf
 s_ν = denote the ν -th shelves
 x = denotes the location at x coordinate point
 y = denotes the location at y coordinate point
 z = denotes the location at z coordinate point

The following is numerical data that will be used to simulate procedure (algorithm) for placing goods that have been developed. The

shape of the item used is a cube. The goods have three volume variations (v) and three weight variation (b). Total of goods type (specification) is a combination of volume and weight variation. The complete data of goods can be seen in Table 1 and Figure 1. The placement of each type of goods (u) must use a pallet (a). The specifications of the pallet (a) used can be seen in Table 2 and Figure 2. Each pallet has the same size and capacity, assuming an unlimited number of pallets. The shelf (s) used has dimensions of length (p), width (l) and height (h). The rack has four layers (y), length space between layers and load capacity of each layer is same. Illustration of shelf (s) is presented in Figure 3. Total number of good for all type (specification) can be seen in Table 4.

Table 1. Goods Specification

Cubical specification item			
Volume	Edge (cm)	Weights	Massa (kg)
v_1	$r_1 = 60 \times 60 \times 60$	b_1	100
v_2	$r_2 = 40 \times 40 \times 40$	b_2	80
v_3	$r_3 = 20 \times 20 \times 20$	b_3	60

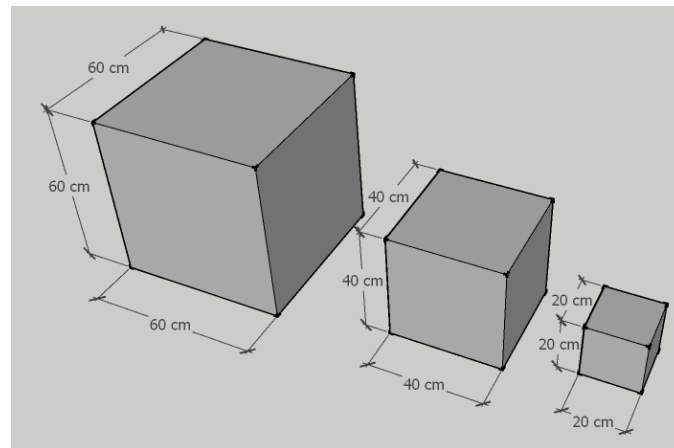


Figure 1. The shape and size of the item (u) to be stored

Table 2. Pallet Specification

dimensions (cm)	Empty weight (kg)	Weight Capacity (kg)
$120 \times 100 \times 15$	10	1000

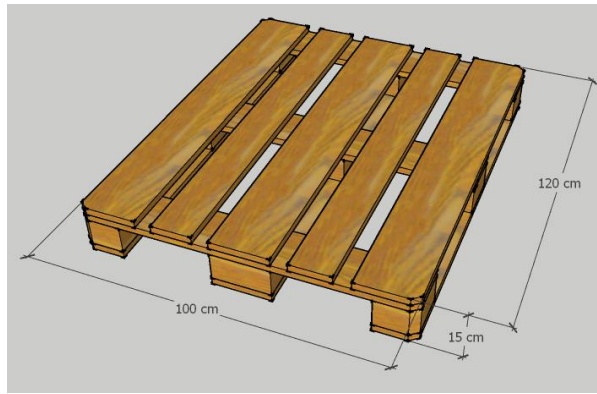


Table 3. Shelf Specification

$Layer$	Mass Capacity (kg)	Length Space between layer (cm)
c_1	3500	160
c_2	3500	160
c_3	3500	160
c_4	3500	160

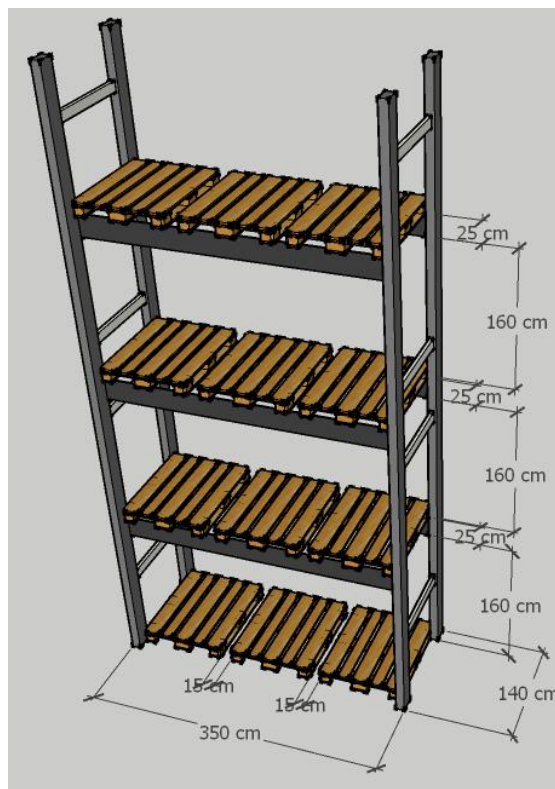


Figure 3. Shelf shape and size used

Table 4. Number of goods for all types

v = volume b = weight	v_1	v_2	v_3
b_1	32	17	24
b_2	15	22	17
b_3	12	21	10

III. MODEL AND ALGORITHM DEVELOPMENT

In this study, two algorithms are proposed to be evaluated. The first algorithm aims to maximize use of a shelf to achieve maximum utility (fully shelf). The first shelf must be fully filled first, then continue filling the next shelves

until it is full again, and so on. The objective function of the first algorithm is to maximize shelf utilization. The second algorithm starts by calculating required number of shelves, then placing the heaviest goods on the lowest layer of a shelf. The second algorithm rule impacts uniformity of shelf utilization measure for each used.

A. The First Algorithm Using Maximization Utility for Criteria Performance

- Step 1 : Input number of weight variation of b_i start from $i = 1$ until $i = I$, sort from heaviest to lightest. Then input number of edge variation r_j , start from $j = 1$ until $j = J$, sort from longest to shortest.
- Step 2 : Using results on the first step, sort the goods (u_{ij}) , starting from $u_{11}, u_{12}, \dots, u_{1J}, u_{21}, \dots$ until u_{IJ}
- Step 3 : In order from step 2, allocate goods u_{ij} on pallet a_q . If all goods u_{ij} have been allocated to pallet a_q , then continue step 5, if not continue step 4.
- Step 4 : Set specify of pallet specifications:
 $SL = L$; (1) ; calculate remaining length of pallet
 $SW = W$; (2) ; calculate remaining width of pallet
 $SH = CH - H$; (3) ; calculate remaining space length of layer
- Step 5 : Place pallet a_q at x, y, z coordinates with the following conditions:
- Step 5a : $x = L - SL$; (4)
 $y = \frac{W - (T \times r_j)}{2}$; (5)
 $z = SH - (CH - H)$; (6)
- Step 6 : Check the length of cube (goods), must meet condition: $r_j \leq SL$; $r_j \leq SW$; $r_j \leq SH$. If one of these conditions is not met, then item u_{ij} must be allocated to next pallets (a_{q+1}). If all these conditions are met, then check total pallet a_q load, must meet this condition: $BP + b_i \leq CP$. Then continue to step 7.
- Step 7 : If pallet load $BP + b_i \leq CP$, then allocate items u_{ij} at coordinate location in step 5a. If $BP + b_i > CP$, then allocate items u_{ij} on next pallet (a_{q+1}).
- Step 8 : Arrange items u_{ij} on next pallets (a_{q+1}) according to step 4 then continue the next step.
- Step 9 : If the entire set of goods $(u_{ij}, \forall I, J)$ has been allocated to the pallet (a_q), then go to step 10. But if not, then looping to step 3.
- Step 10 : The allocation of pallets (a_q) containing goods (u_{ij}) into the shelves (s_v) is carried out sequentially according to the order made in step 2.
- Step 11 : Allocation of pallets (a_q) containing goods (u_{ij}) into racks (s_v), is carried out starting from the first pallet ($a_1, a_2, a_3, \dots, a_f$) on each layer (y_k).
- Step 12 : Allocation of pallets (a_q) containing goods (u_{ij}) into shelves (s_v), is carried out sequentially starting from first layers ($y_1, y_2, y_3, \dots, y_K$) under condition that capacity of each layer reach its maximum (both in terms of space and weight capacity).
- Step 13 : Check whether all pallets (a_q) containing goods (u_{ij}) have been allocated to the shelves (s_v), otherwise the next rack can be opened (s_{v+1}) and the allocation process is carried out according to step 10.
- Step 14 : If all goods (u_{ij}) have been placed on pallets (a_q), and all pallets (a_q) have been allocated to racks (s_v) the process is complete.

B. The Second Algorithm with objective to achieve uniformity of shelves utilization

- Step 1 :* Input number of weight variation of b_i start from $i = 1$ until $i = I$, sort from heaviest to lightest. Then input number of edge variation r_j , start from $j = 1$ until $j = J$, sort from longest to shortest.
- Step 2 :* Sort the goods (u_{ij}), starting from $u_{11}, u_{12}, \dots, u_{1J}, u_{21}, \dots$ until end u_{IJ} .
- Step 3 :* In order from step 2, allocate goods u_{ij} on pallet a_q . If all goods u_{ij} have been allocated to pallet a_q , then continue step 5, if not continue step 4.
- Step 4 :* Set specify of pallet specifications:
 $SL = L$; (1) ; calculate remaining length of pallet
 $SW = W$; (2) ; calculate remaining width of pallet
 $SH = CH - H$; (3) ; calculate remaining space length of layer
- Step 5 :* Place pallet a_q at x, y, z coordinates with the following conditions:
- Step 5a :* $x = L - SL$; (4)
- $$y = \frac{W - (T \times r_j)}{2} ; \dots \dots (5)$$
- $$z = SH - (CH - H) ; \dots \dots (6)$$
- Step 6 :* Check the length of cube (goods), must meet condition: $r_j \leq SL; r_j \leq SW; r_j \leq SH$. If one of these conditions is not met, then item u_{ij} must be allocated to next pallets (a_{q+1}). If all these conditions are met, then check total pallet a_q load, this must meet this condition: $BP + b_i \leq CP$. Then continue to step 7.
- Step 7 :* If pallet load $BP + b_i \leq CP$, then allocate items u_{ij} at coordinate location in step 5a. If $BP + b_i > CP$, then allocate items u_{ij} on next pallet (a_{q+1}).
- Step 8 :* Arrange items u_{ij} on next pallets (a_{q+i}) according to step 4 then continue the next step.
- Step 9 :* If the entire set of goods ($u_{ij}, \forall I, J$) has been allocated to the pallet (a_q), then go to step 10. But if not, then looping to step 3.
- Step 10 :* Count of mass (m) from all pallets (a_q) that carries goods u_{ij}
- Step 11 :* count the number of shelves needed (s_y) use formula :
- $$S_v = \frac{Q}{F \times y_k} ; \dots \dots (7)$$
- Step 12 :* Sort the pallet (a_q) containing goods (u_{ij}), from the largest to the smallest total mass of pallets (m).
- Step 13 :* After knowing the number of shelf requirements (s_v), allocate a pallet (a_q) containing goods (u_{ij}) into the shelf (s_v).
- Step 14 :* Placement of a pallet (a_q) containing goods (u_{ij}) into shelf (s_v) sequentially according to the order in step 12.
- Step 15 :* Placement of a pallet (a_q) containing goods (u_{ij}) into shelf (s_v) is carried start from $(a_1y_1s_1), (a_2y_1s_1), (a_3y_1s_1), (a_1y_1s_2), \dots$, until the lowest layer (y_1) from all shelf (s_y) is filled to the maximum. Then continue to fill the second layer (from the bottom) y_2 start from the fist shelf s_1 to the last shelf $(a_1y_2s_1), (a_2y_2s_1), (a_3y_2s_1), (a_1y_2s_2), \dots$ so on until the entire pallet is placed on shelf.

IV. NUMERIC TEST AND ANALYSIS

A. Process Allocation Goods on Pallets

Numerical testing is done using hypothetical data. The process of goods placement using both algorithms is done manually using Microsoft excel. The following is an example how process the algorithm to fill pallets and placing into shelf. For example, the item to be stored is $(u_{1,i})$ where has length a rib of 60 cm and a weight of 100 kg, thus:

1. Set $(SL = 120)$, $(SW = 100)$, $(SH = 160-15)$. This is done to calculate available capacity of pallets for allocating goods on pallets.
2. Set $(T = 100 / 60 \text{ rounded down})$, then $T = 1$. This is done to determine the number of rows for allocating goods on pallet.
3. Set $x = 120 - 120$, so $x = 0$, this is the start of x coordinate of pallet location for goods location on pallet.

4. Set $y = \frac{100 - (1 \times 60)}{2} = 20$, this is the start of y coordinate of pallet location for goods location on pallet.
5. Set $z = 145 - (160 - 15) = 0$, this is the start of z coordinate of pallet location for goods location on pallet.

Check and calculate if $r_j \leq SL$, so $60 \leq 120$, because the length of edge is smaller than remaining length of pallet, then check if $r_j \leq SW$, so $60 \leq 100$, because the length of edge is smaller than remaining width of pallet, then check if $r_j \leq SH$, so $60 \leq 145$, because the length of edge is smaller than remaining height of pallet, then check load capacity of pallet $(BP + b_i \leq CP)$ is $0 + 100 \leq 1000$, Because pallet load plus the weight of goods is still smaller than pallet load capacity, so goods can be placed on this pallet in accordance with the predetermined x , y , z coordinate points. The result of goods position on pallet is presented in Figure 4.

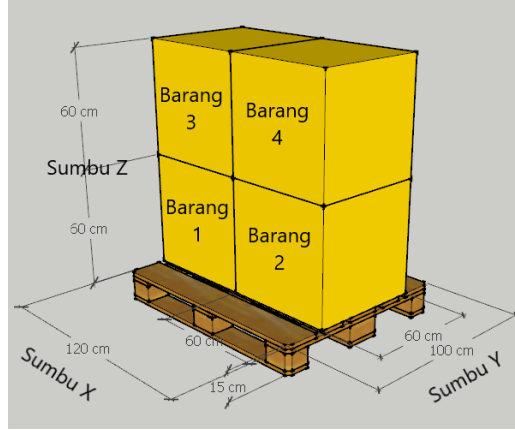


Figure 4. Allocation and position of goods with edge length is 60 cm on pallet

B. Process of Placing Pallets on Shelf

First Algorithm

Pallet placement into rack using algorithm-1 is carried out according to the order made in Step-2. Pallet placement that already fully with goods is carried out sequentially starting from the lowest layer to the fourth layer of the first shelf. After four layers of one shelf are filled, allocate a new shelf until all pallets that fully with goods have been placed on shelf.

Second Algorithm

Calculate the shelf requirement according to step 11 of the second algorithm. sort pallets filled with goods by weight. Pallet placement starting from the heaviest on the lowest layer of the first shelf. When the lowest layer of the first shelf is full proceed to the lowest layer of the second shelf, as so on until the last shelf. If all the lowest layers of the entire shelf are filled, then place the palette on the second layer of each shelf starting from the first shelf.

C. Centre of Mass as Performance Indicator from Both Algorithm

To compare performance of both algorithms, location centre of mass from shelf is used. The formula used to calculate the total centre of mass is the formula for the centre of mass commonly used in physics. Using the formula, the location of the centre of mass on *xyz* coordinate for each layer on the first shelf is:

Layer-1 xyz coordinate (70, 175, 75) with a total load on the layer of 1230 kg.

Layer-2 xyz coordinate (70, 175, 260) with a total load on the layer of 1230 kg.

Layer-3 xyz coordinate (65.5, 212.7, 431.7) with a total load on the layer of 1830 kg.

Layer-4 xyz coordinate (61.1, 186.8, 584) with a total load on the layer of 2730 kg.

Figure 5 shows the illustration of *xyz* coordinate from center of mass in first shelf.



Figure 5. Pallet placement illustration for each layer on the first shelf.

Use the same formula for calculate total centre of mass of the shelves. Location total centre of mass from the first shelf as following.

Total centre of mass on *x* coordinate

$$\bar{X} = \frac{\sum m \cdot \bar{x}}{\sum m} ; \dots \dots \dots (8) \text{ where}$$

$$\bar{X} = \frac{x_1 \cdot m_1 + x_2 \cdot m_2 + \dots + x_n \cdot m_n}{m_1 + m_2 + \dots + m_n}$$

$$\bar{X} = \frac{(70 \cdot 1230) + (70 \cdot 1230) + (65,5 \cdot 1830) + (61,1 \cdot 2730)}{(1230 + 1230 + 1830 + 2730)} ; \dots \dots \dots (10) \text{ where}$$

$$\bar{X} = 65,3$$

Total centre of mass on *y* coordinate

$$\bar{Y} = \frac{\sum m \cdot \bar{y}}{\sum m} ; \dots \dots \dots (9) \text{ where}$$

$$\bar{Y} = \frac{y_1 \cdot m_1 + y_2 \cdot m_2 + \dots + y_n \cdot m_n}{m_1 + m_2 + \dots + m_n}$$

$$\bar{Y} = \frac{(175 \cdot 1230) + (175 \cdot 1230) + (212,7 \cdot 1830) + (186,8 \cdot 2730)}{(1230 + 1230 + 1830 + 2730)}$$

$$\bar{Y} = 189,4$$

Total centre of mass on *z* coordinate

$$\bar{Z} = \frac{\sum m \cdot \bar{z}}{\sum m} ; \dots \dots \dots (10) \text{ where}$$

$$\bar{Z} = \frac{z_1 \cdot m_1 + z_2 \cdot m_2 + \dots + z_n \cdot m_n}{m_1 + m_2 + \dots + m_n}$$

$$\bar{Z} = \frac{(75 \cdot 1230) + (260 \cdot 1230) + (431,7 \cdot 1830) + (584 \cdot 2730)}{(1230 + 1230 + 1830 + 2730)}$$

$$\bar{Z} = 398,3$$

Based on example calculation, the centre of mass first shelf is at point x, y, z (65.3, 189.4, 398.3). Calculation summary centre of mass from the first algorithm can be seen in Table 5 and for the

second algorithm can be seen in Table 6. The placement illustration on all three shelves using first algorithm can be seen in Figure 6 and for the second algorithm in Figure 7.

Table 5. Center of Mass for Each Shelf using First Algorithm

Shelves	Coordinate (X)	Coordinate (Y)	Coordinate (Z)
Shelf 1	65.3	189.4	398.3
Shelf 2	62.8	170.8	310.1
Shelf 3	62.8	152.4	49.7



Figure 6. The location of the center of mass on each shelf using First Algorithm

Table 6. Center of Mass for Each Shelf using Second Algorithm

Shelves	Coordinate (X)	Coordinate (Y)	Coordinate (Z)
Shelf 1	63.9	173.2	164.6
Shelf 2	68	172.9	176.6
Shelf 3	61.9	168.9	174.8



Gambar 7. Location center of mass on each shelf using second algorithm

D. Comparative Analysis of the Centre of Mass from Both Algorithm

For the (x) coordinate, the value closest to half the shelf width is the better coordinate of the center of mass on the x -axis. For the (y) coordinate, the value closest to half the length of the shelf, is the better coordinate of the centre of mass on the y -axis. For the (z) coordinate, lower values are better. Coordinate of centre of mass on z axis is the most important measure because it determines the strength of shelf. Meanwhile, coordinates of centre of mass on x and y axes determine distribution of load balance. When coordinates of the centre of mass on z -axis move away from the floor (or have a high value), potential to the shelf has collapse higher. However, it is different from z -axis which has a big difference.

The first algorithm provides an uneven shelf utilization rate. The first and second shelves are fully occupied with 100% utilization, while the third shelf is only filled at the lowest layer with 25% utilization. The total load on the first shelf is greater than the second shelf, and the second shelf is greater than the third shelf. The distribution of coordinates of centre of mass on x -axis on three shelves is almost same, as is y -axis. Shelf with lowest utilization has a small z -axis coordinate, and shelf with highest total load has a large z -axis coordinate (away from the floor). So, shelves with high utility have a high potential for collapse as well.

The second algorithm provides an equal utility distribution between the three shelves, that is with utility rate under 100%. Apart from having uniformity of utility, the second algorithm provides roughly same mass centre coordinates for three shelves. Each shelf has almost the same load, with the heaviest pallets on the lowest layer. Thus, coordinates of centre of mass on z -axis for the three racks are almost same, so that load balance of the three racks is also same.

V. CONCLUSION

Based on numeric test and analysis that be done, there some conclusion as below:

1. Requirements of total shelf using two developed algorithms are the same.
2. Based on numeric data test, the best algorithm that give location of center of mass is the second algorithm. The second algorithm produces location for placing

pallets with heaviest mass on lowest layer for each shelf, and the pallets with the lighter mass on its top, and so on. So, the average location of the center of mass for each shelf is the same. The procedure for placing goods using this second algorithm also minimizes the potential for shelves to collapse.

3. On the other hand, placing goods using second algorithm results in an uneven load on all filled racks. The results of data testing, the first algorithm result that the first and second racks are fully filled up to the fourth layer, while the last shelf is only filled on the lowest layer. While the result second algorithm show all the shelf filled just until third layer

Future research directions are suggested to develop mathematical model for goods placing case using analytic method for solution computation. In this research, variation of goods is represented by variations in volume and weight. However, the shape of goods is the same is cubical. For further research, a model of goods placements with various shape and characteristics can be developed.

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