Improving Raw Materials Warehouse Utilization and Efficiency in a Haircare Manufacturer

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การปรับปรุงการใช้ประโยชน์และประสิทธิภาพของคลังสินค้าวัตถุดิบสำหรับผู้ผลิตผลิตภัณฑ์ดูแลเส้นผม

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ในงานวิจัยนี้มีวัตถุประสงค์เพื่อเพิ่มพื้นที่ใช้สอยในคลังสินค้า รวมถึงการปรับปรุงประสิทธิภาพและการใช้ประโยชน์ของคลังสินค้าวัตถุดิบสำหรับผู้ผลิตผลิตภัณฑ์ดูแลเส้นผมแห่งหนึ่งในประเทศไทย ในขณะเดียวกันก็มีเป้าหมายที่จะลดต้นทุนการจัดเก็บผลิตภัณฑ์สำเร็จรูปที่คลังสินค้าสาธารณะภายนอกโดยการจัดเก็บผลิตภัณฑ์สำเร็จรูปบางส่วนที่คลังสินค้าวัตถุดิบภายในแทน วิธีการหลักที่ใช้ในการปรับปรุงคลังสินค้าวัตถุดิบภายในได้แก่ การนำวัตถุดิบล้าสมัยที่ไม่ได้ใช้งานแล้วออกจากคลังสินค้า การจัดกลุ่มวัตถุดิบใหม่ตามประเภท ขนาด และอัตราการหมุนเวียนของวัตถุดิบ การจัดสรรพื้นที่สำหรับแต่ละกลุ่มวัตถุดิบใหม่ การพิจารณาปรับความสูงของชั้นจัดเก็บให้เหมาะสมกับขนาดของวัตถุดิบ และการมอบหมายพื้นที่ที่เหมาะสมให้สำหรับแต่ละกลุ่มของวัตถุดิบ ผลการวิจัยพบว่าหลังจากการใช้วิธีการดังกล่าวสามารถทำให้พื้นที่ใช้สอยในคลังสินค้าเพิ่มขึ้น 12.65% ระยะการหยิบสินค้าลดลง 52% เมื่อเทียบกับสถานการณ์ปัจจุบันและการใช้ประโยชน์มีความสมดุลมากขึ้นทั่วทั้งคลังสินค้า นอกจากนี้ยังมีพื้นที่เหลือในคลังสินค้าวัตถุดิบ 324 ตำแหน่ง ซึ่งสามารถใช้ในการจัดเก็บผลิตภัณฑ์สำเร็จรูปบางส่วนที่คลังสินค้าวัตถุดิบได้ ผลประโยชน์สุทธิที่ได้จากการจัดเก็บผลิตภัณฑ์สำเร็จรูปบางส่วนที่คลังสินค้าวัตถุดิบคือ 264,000 บาทต่อปี โดยงานวิจัยนี้ได้มีการจัดทำแผนการดำเนินงานและส่งมอบเครื่องมือสำหรับการวิเคราะห์ข้อมูลให้กับบริษัทกรณีศึกษาไว้ใช้ในการลงมือปฏิบัติเพื่อเพิ่มประสิทธิภาพของคลังสินค้าวัตถุดิบต่อไป

สาขาวิชา	วิศวกรรมอุตสาหการ	ลายมือชื่อนิสิต	
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Chariya Paveenchana : Improving Raw Materials Warehouse Utilization and Efficiency in a Haircare Manufacturer. Advisor: Asst. Prof. NARAGAIN PHUMCHUSRI, Ph.D.

This study aims to improve the capacity, efficiency, and utilization of raw materials warehouse in a case study of haircare manufacturer in Thailand. At the same time, it is our goal to save the storage cost of finished products at the external public warehouse by locating some of the finished products at this internal raw materials warehouse. The key methodologies used to improve the current raw materials warehouse are removing obsolete materials from the warehouse, regrouping materials according to types, sizes, and turnover rates, reallocating space for each group of materials, considering beam height adjustment, and reassigning the location for each group of materials. The results show that after these methodologies were applied, the capacity of the raw materials warehouse can be increased by 12.65%, picking distance can be reduced by 52% compared to the current situation and the utilization is more balanced throughout the warehouse. Furthermore, 324 locations are available for storing some finished products at the raw materials warehouse which can help to save cost at the external warehouse by 264,000 THB per year. In addition, implementation plans and analysis tools are created in order to navigate the case study company on how to turn improving plans as recommended in this research to actual implementation so that efficiency of warehouse can be increased.

Field of Study: Industrial Engineering   Student's Signature ....
Academic Year: 2018   Advisor's Signature ....

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In addition, I would like to thank the case study company for providing me an opportunity to access data and understand the company’s processes. It is my pleasure for being a part to improve the warehousing performance of the company.

Last but not least, I would like to express my appreciation for the support given me by my family and friends. I would not be able to go through the difficulties during my work on this thesis without them cheering me up in my weak moments.

Chariya Paveenchana

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1.1. Company Background

The manufacturing plant of the case study company is used to produce color, care, developer, perm, and neutralizer products. Currently, the warehouse under study at this manufacturing plant is used to store raw materials and pack materials. The case study company uses mixed strategy between fixed location and random location to store those products. The space in the warehouse is divided into several areas for general raw materials, combustible raw materials, bulk materials, high pack materials, and low pack materials. Each type of materials is assigned to be stored in a specific area (fixed storage) but they can be stored in any locations within the assigned area (random storage).

For finished products, they are currently shipped from the manufacturing plant to be stored at an external public warehouse before delivering to customers. The external warehouse is a public warehouse rented by the case study company for storing finished products. All the operations at the external warehouse and transportations between the manufacturing plant and the external warehouse are managed by a third-party company. The contract to rent the external warehouse covers 4,000 pallet locations per month with an additional 10% or 400 pallets buffering per month. In case that the case study company would like to ask for more space at the external warehouse, the warehouse manager has to inform the third-party company two months in advance. Cost components that the third-party company charges the case study company include transportation cost, reserved racking cost, and movement of pallets within warehouse cost.

1.2. Products and Production Processes Overview

Finished products produced by the case study company include color, developer, perm, neutralizer, and care products. All products are accounted for 2,389 SKUs. Those products are sold in tube, bottle, jar, and kit packaging. There are 299 SKUs of raw materials, 1,774 SKUs of pack materials, and 1,075 SKUs of bulk materials used for producing finished products as summarized in Table 1.

Table 1. Number of SKUs under each product category

Categories	Number of SKUs
Finished Goods	2,389
Pack Materials	1,774
Raw Materials	299
Bulk Produced in House	1,039
Imported Bulk	36

At the first process of producing finished products, raw materials received from suppliers are processed to make bulk products in the making production area. Then, bulk products from making department and pack materials received from suppliers are transferred to the packing production area to make finished products by filling bulk products into packaging materials. For some finished products, bulk products are not made in-house but are imported from another plant (Hunfeld plant, Germany). However, the filling processes to obtain finished goods are the same. After that, finished products from the production area are moved to dock area (FL2) prior to moving to be stored at the external public warehouse and shipping to customers.

1.3. Warehouse Overview

The warehouse under study in this thesis is the raw materials warehouse. Raw materials warehouse is used for storing 1,774 SKUs of pack materials, 299 SKUs of raw materials, and 36 SKUs of imported bulk products. The size of the raw materials warehouse is 11 (Height)* 40.5 (Depth)*101 (Width) cubic meters with 4,254 storage locations in total. There are two types of storage used within this warehouse namely single selective rack and drive in rack. For drive in rack, there is only one size of storage bin which is 200 cm (height) × 315 cm (depth) × 120 cm (width). However, there are five sizes of storage bin for the single selective rack. Dimension and number of bins for each storage type are summarized in Table 2.

Table 2. Dimension and number of bins for each storage type

Storage Bin Types	**Storage Types**	**Dimension in cm3 (Height × Depth × Width)**	**Number of Bins**
R1	Single Selective Rack	65 × 120 × 120	522
R2	Single Selective Rack	90 × 120 × 120	184
R3	Single Selective Rack	120 × 120 × 120	1,126
R4	Single Selective Rack	140 × 120 × 120	737
R5	Single Selective Rack	190 × 120 × 120	1,285
JT	Drive-In-Rack	200 × 315 × 120	400
Total			**4,254**

The majority of racks in the warehouse are single deep selective rack, except racks in DIR area that are drive in rack (accounted for 10% of total racks). Drive in rack or DIR is designed to be used for storing common pack materials that are ordered in huge volume from suppliers and have high demand such as bottles for developer products and aluminum tubes for color products.

To recognize the locations for the single selective rack, they are named by two alphabets per row, by number per column (starting from 1 for every row), and by level (L) plus number for each level. The layout of raw materials warehouse with the name for each row, the number for each column, and the number of levels for each rack is shown in Figure 1.

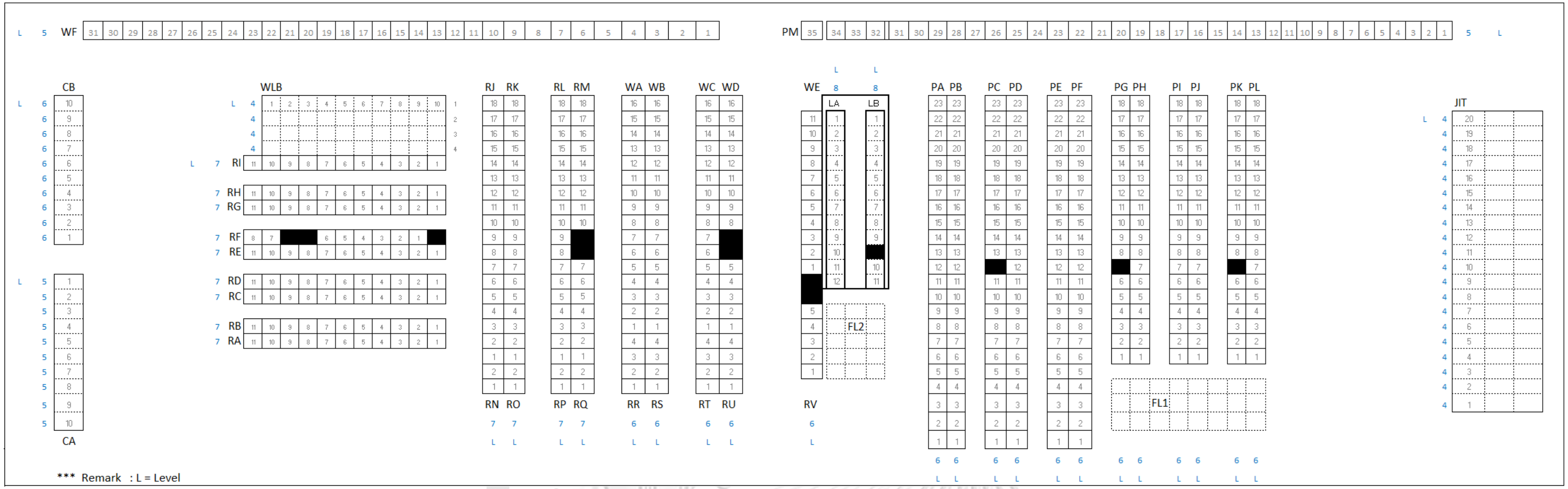


Figure 1. Layout of raw materials warehouse

To indicate a specific location in the raw materials warehouse, each location is named by row plus level plus column number. For example, CA11 represents racking row CA, level 1, and column 1. RH611 indicates row RH, level 6, and column 11. So, the first two alphabets always indicate the row of racking, the first digit number after the alphabets indicates the level of racking, and the rest of the numbers indicate the column of racking.

Based on current warehouse's layout, areas in the warehouse are divided into seven storage areas for combustible raw materials, general raw materials, bulk materials, low pack materials, high pack materials, pack materials with huge volume (drive-in-rack materials), and label pack materials.

This study covers six storage areas, leaving the label area out of the scope since labels are kept in a separate cold storage area. Therefore, storage bin type R2 for the label room is also out of scope. The remaining number of bins after exempting storage type R2 are 4,070 locations. The total number of bins available and rack types in each storage area are shown in Figure 2.

	General raw materials
	Combustible raw materials
	Bulk materials
	Low pack materials
	High pack materials
	Drive-in-rack materials
	Label pack materials

Location	Rack Type									Number of BIN								
	L0	L1	L2	L3	L4	L5	L6	L7	L8	L0	L1	L2	L3	L4	L5	L6	L7	L8
CA		R3	R3	R3	R3	R3					10	10	10	10	10			
CB		R3	R3	R3	R3	R3	R5				10	10	10	10	10	10		
WLB		R5	R5	R5	R5						40	40	40	40				
JIT		R5	R5	R5	R5						60	60	60	60				
RA		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RB		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RC		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RD		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RE		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RF		R3	R3	R3	R3	R3	R3	R5			8	8	8	8	8	8	8	
RG		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RH		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RI		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RJ	R1	R1	R3	R3	R3	R3	R3	R5		18	18	18	18	18	18	18	18	
RK		R3	R3	R3	R3	R3	R3	R5			18	18	18	18	18	18	18	
RL		R3	R3	R3	R3	R3	R3	R5			18	18	18	18	18	18	18	
RM		R3	R3	R3	R3	R3	R3	R5			16	16	16	16	16	16	16	
WA		R4	R4	R4	R4	R4	R5				16	16	16	16	16	16		
WB		R4	R4	R4	R4	R4	R5				16	16	16	16	16	16		
WC		R4	R4	R4	R4	R4	R5				16	16	16	16	16	16		
WD		R4	R4	R4	R4	R4	R5				14	14	14	14	14	14		
WE		R4	R4	R4	R4	R4	R5				11	11	11	11	11	11		
WF		R4	R4	R4	R4	R4					24	28	31	31	31			
PA		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PB		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PC		R1	R1	R5	R5	R5	R5				22	22	22	22	22	22		
PD		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PE		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PF		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PG		R1	R1	R5	R5	R5	R5				17	17	17	17	17	17		
PH		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PI		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PJ		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PK		R1	R1	R5	R5	R5	R5				17	17	17	17	17	17		
PL		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PM		R4	R4	R4	R4	R5					24	28	35	35	35			
LA		R2	R2	R2	R2	R2	R2	R2	R2		12	12	12	12	12	12	12	12
LB		R2	R2	R2	R2	R2	R2	R2	R2		11	11	11	11	11	11	11	11
RN		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RO		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RP		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RQ		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RR		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RS		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RT		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RU		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RV		R4	R4	R4	R4	R4	R5				5	5	5	5	5	5		

Figure 2. Total number of bins available and rack types in each storage area

As each type of pack materials has different size, received pack materials are divided into two categories which are low-height pack material and high-height pack materials in order to be easily matched with types of storage bin. Low-height pack materials are pack materials with a height lower than 1.8 meters and high-height pack materials are pack materials with a height greater than 1.8 meters.

Each type of materials is assigned to one storage area. Within the same storage area, materials can be stored in a random pattern and there is no fixed location for individual SKUs. However, materials can be stored across the storage area by the manual bin-to-bin process (instead of using auto recommendation for available locations) in cases that storage locations assigned for that materials are full.

For the current space allocation in the warehouse, general and combustible raw materials are assigned closer to making production area, bulk materials are assigned to the first level of the warehouse due to weight constraint, and drive-in-rack materials are assigned in drive-in-rack areas. For color pack materials and perm pack materials, they are randomly located throughout the warehouse, with the only constraint that material heights have to match the rack heights. Class-based storage according to material turnover rate is not applied in this raw materials warehouse.

1.3.1. Flow of Materials and Warehouse System

In this part, the flow of materials and warehouse system used in the raw materials warehouse are discussed. The overall flow of materials in the raw materials warehouse is shown in Figure 3.

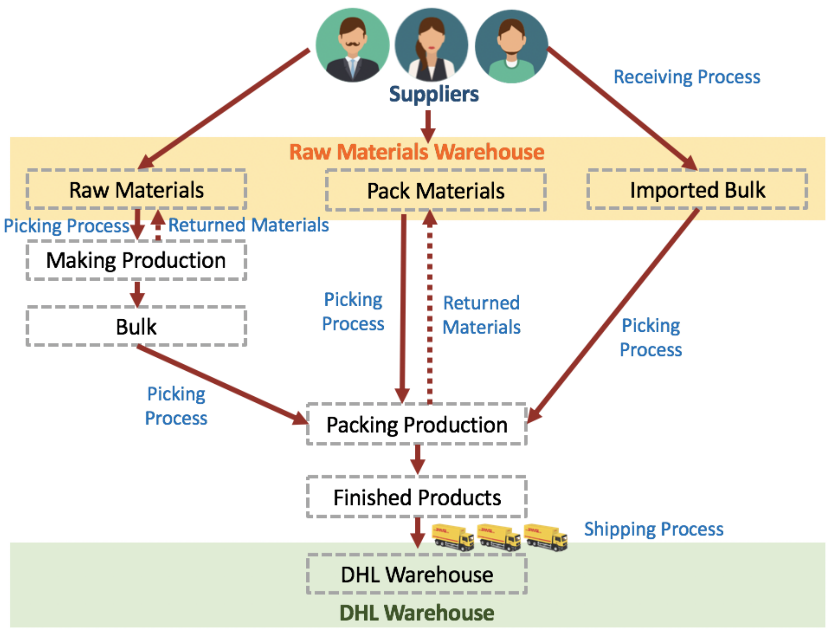


Figure 3. Flow of materials in raw materials warehouse

After the suppliers of raw materials and pack materials deliver their products at the loading area, warehouse operators will transfer the products to the dock area (area FL1 for raw materials and pack materials) in order to check the quality and quantity according to the invoices before moving the products to rack locations. For the put-away process, the SAP system will auto-recommend available storage location for operators. Then operators will use reach truck to move materials from the dock area to store at the recommended storage location. In case that recommended location by the SAP system does not match the physical materials due to wrong material master data such as the height of storage bin is lower than a physical product, warehouse operators will use the manual bin-to-bin process to relocate materials to the suitable storage location. These are parts of receiving, put-away, and storing processes.

Once there is an order triggered by operation, warehouse operators will look at a storage location in the SAP system and use a forklift to pick products at the storage location to serve at the operation area which is a part of the picking process. In case that a required material presents in more than one location, the SAP system will trigger material according to priorities set in the SAP system which are materials in their original location followed by materials located across the location. For example, if operation requests SKU of pack material in drive-in-rack areas, the SAP system will search that SKU in drive-in-rack areas first. If there is no material in drive-in-rack areas, the SAP will change to search at high pack material locations. In addition, materials within the same area will be triggered according to the expiry date.

After finishing the packing process, finished products will be transferred to the dock area or FL2 area in order to prepare for loading to containers which is part of the shipping process to the external warehouse. During the shipping process, finished products are typically in the on-hold status because the testing process by QA department spends time for three days. In case that products are off-quality, they can be recalled and have to be transported back to the manufacturing plant for inspecting and reworking which incur additional costs.

Most of the exported products are shipped according to demand forecasting while there is a minority of products that are shipped according to customer's orders. All finished products are directly transported from the external warehouse to the seaport.

1.4. Problem Statement

Due to growing in demand from customers, the current space at the external public warehouse is not sufficient for keeping the projected finished good's inventory as shown in Figure 4. To extend, the case studied company currently reserves space at the external warehouse for 4,400 rack locations, whereas the projected finished good's inventory is over 4,400 locations in every month. Actually, the company can ask for more space at the external public warehouse but it will come with higher operating cost for the company. Hence, the warehouse manager is looking for an opportunity to store some finished products at the internal raw materials warehouse in order to reduce the cost incurred by using the external public warehouse.

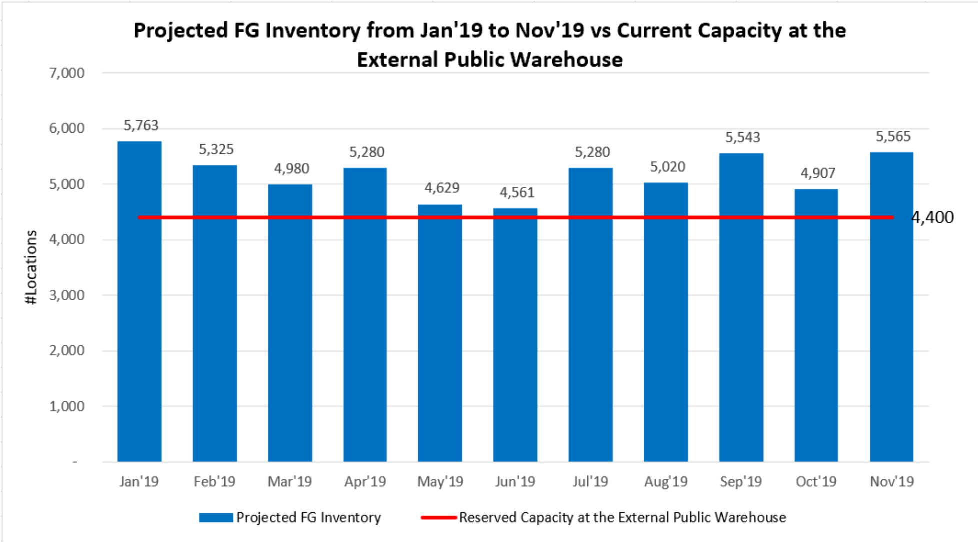


Figure 4. Projection of FG inventory from January to November 2019 versus current capacity at the external public warehouse

In order to store finished products at the internal raw materials warehouse, the warehouse manager has to reallocate areas within the raw materials warehouse and check the feasibility of storing finished products at the raw materials warehouse. In addition, the warehouse manager would like to use this opportunity to improve the capacity, efficiency, and space utilization at the raw materials warehouse. The warehouse manager has observed the following issues at raw materials warehouse and foreseen that these issues will continue in the future if there is no improvement.

1) Unsuitable allocation of space for each type of materials resulting in huge work effort to carry out manual adjustment by workers and larger picking distance as shown in Figure 5.

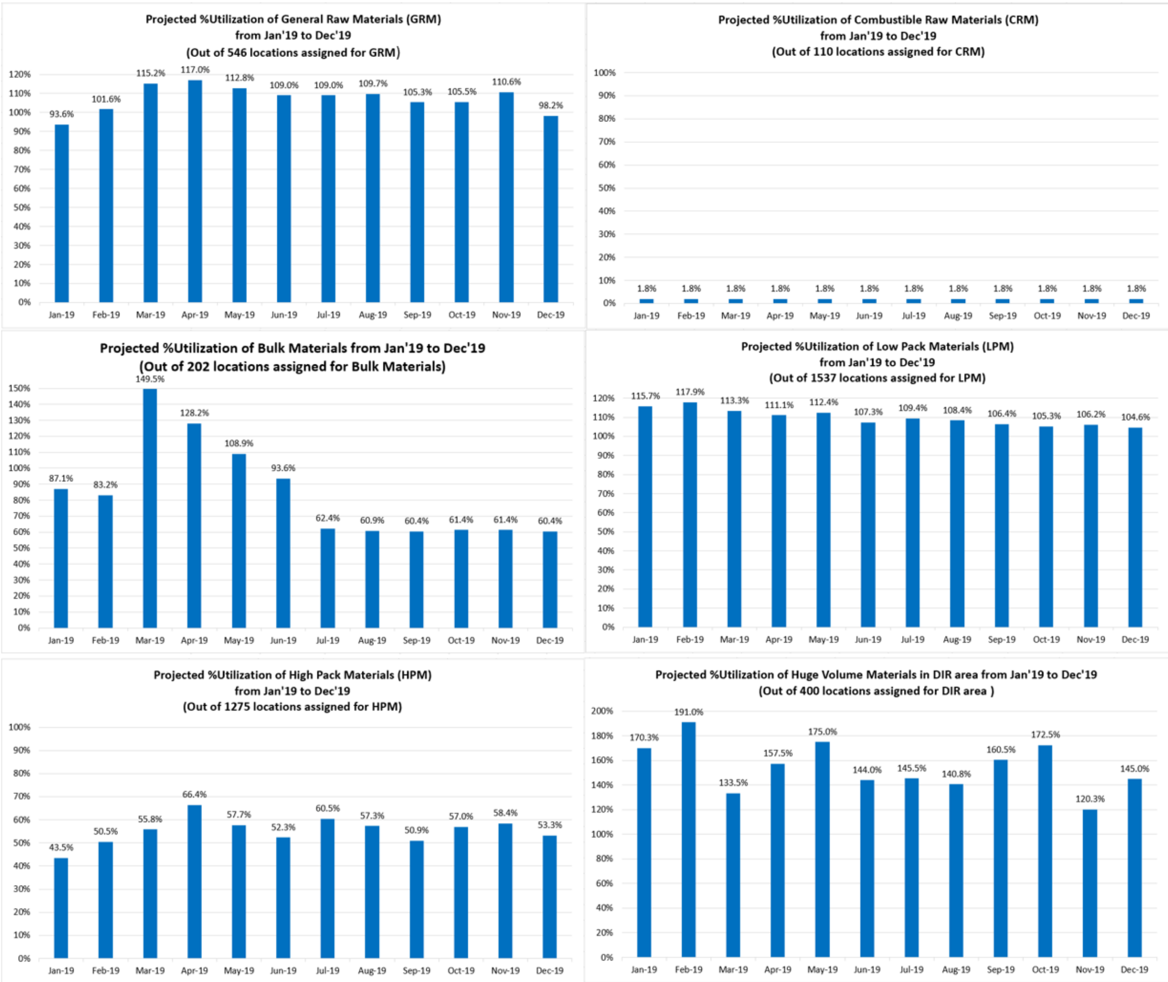


Figure 5. Projected percentage of utilization of each type of materials from January to December 2019 based on current space allocation

Figure 5 clearly shows that the space allocated for each type of materials is not appropriate. Some materials are assigned too much space resulting in very low utilization (< 80%) while some materials are assigned too little space resulting in very high utilization (> 100%). In case that utilization is over 100%, workers have to manually assign a location for materials in other areas which increase the quality risk that materials may not be triggered based on first in, first out (FIFO). In addition, materials may be located in farther locations from usage area causing longer travel distance during the picking process. Figure 6 represents the situation that some areas have available locations while at the same time some areas face material's overflow and operators have to put materials on the floor.

Figure 6. Inappropriate space allocation for each group of materials

2) Some products are assigned into wrong product's group due to outdated master data and outdated grouping as evidenced by the following:

- Many SKUs of pack materials are assigned in drive in rack (DIR) area despite they are slow-moving materials and have low inventory level. On the other hand, some pack materials that are fast-moving materials with huge volume are not assigned in DIR location. Table 3 shows an example of materials that have low inventory level, low demand and low supply but are assigned into DIR locations.

Table 3. Example of materials that are assigned to wrong grouping

GCAS	Material Description	Unit	Current Inventory (in pallet)	Average Demand (in	Average Supply (in	Assigned Location
90858043	BDEC CLAPROF COLIN CRMDEV 12PC 60ML ANZ	PCE	3	0	0	DIR
90858050	BDEC CLAPROF COLIN CRMDEV 9PC 60ML ANZ	PCE	3	0	0	DIR
91009178	DECBO CLPRO COLD STD NEU 90ML ANZ ADO	PCE	3	0	0	DIR
91319775	DECBO CLPRO COLD PRM MED 90ML ANZ ADO	PCE	2	0	0	DIR
91319776	DECBO CLPRO COLD PRM MILD 90ML ANZ ADO	PCE	3	0	0	DIR
91319777	DECBO CLPRO COLD PRM STRONG 90ML ANZ ADC	PCE	4	0	0	DIR
92195190	BO WELAPR BRILL CON CRS 1000ML AAI JK CN	PCE	4	0	0	DIR
97106842	BO WP 250ML PURPLE AAI JK IN CN ANZ	PCE	2	0	0	DIR
97125099	BO WP MULTI 250ML RED AAI JK IN CN ANZ	PCE	1	0	0	DIR
97577272	DECBO CLPRO NEU 90ML ADO ANZ	PCE	1	0	0	DIR
97577275	DECBO CLPRO COLD PRM MED 90 ML ADO ANZ	PCE	1	0	0	DIR
99938652	BO MULTI BRAND 100ML XX 38X55XH99.5-PURP	PCE	2	0	0	DIR
99938654	BO MULTI BRAND 100ML XX 55X38X99,5 OVAL	PCE	2	0	0	DIR
99260007559	BDEC WELLOXON DEV 6% 60ML ASIA	PCE	2	0	0	DIR
99260007561	BDEC WELLOXON DEV 12% 60ML ASIA	PCE	2	0	0	DIR
99260007562	BDEC WELLOXON DEV 9% 60ML ASIA	PCE	1	0	0	DIR

- During the put-away process, operators found that some materials are assigned into wrong storage height.

3) Product groups that are obsolete are not written-off and are still located in the warehouse. Table 4 represents an example of materials that should be removed from the warehouse due to no demand triggering in the future.

Table 4. Example of materials that have no demand in the next 12 months

GCAS	Material Description	Unit	Current Inventory (in PCE or KG or G)	Sum Demand in the next 12 months
90588532	FOCA KLSTNP COLCRM 8_47 80G JP	PCE	8,082.00	-
90588595	FOCA KLSTNP COLCRM 6_47 80G JP	PCE	4,900.00	-
90622669	LBWR WP ENR FINE SHAM250ML ANZ IN CN ADO	PCE	7,732.00	-
90672777	FOCA CLAPROF PCOLCR 6_56 60G ANZ	PCE	2,980.00	-
90723266	FOCA CF YELLOW GOLD 33 150G JP KR	PCE	950.00	-
90747505	LBWR WP RES STR SHAM250ML ANZ IN CN ADO	PCE	6,430.00	-
90759781	FOCA KLSTNP COLCRM 6_17 80G JP	PCE	3,220.00	-
90766802	FOCA WELLATN 2PLUS1 PCOLCM 7PB 60G JP	PCE	2.00	-
90767570	SHPR NNE RTU PCOL DG 11 G 12EA AU NZ	PCE	26.00	-
90769813	FOCA NNE PCOL 98 60ML AU NZ	PCE	8,190.00	-
90769880	FOCA NNE PCOL 112 60ML AU NZ	PCE	6,320.00	-
90769971	FOCA NNE PCOL 115A 60ML AU NZ	PCE	1,580.00	-
90769973	FOCA NNE PCOL 116A 60ML AU NZ	PCE	19,900.00	-
90770063	FOCA NNE PCOL 124 60ML AU NZ	PCE	6,730.00	-
90770064	FOCA NNE PCOL 131 60ML AU NZ	PCE	6,725.00	-
90770065	FOCA NNE PCOL 132 60ML AU NZ	PCE	6,716.00	-
90789121	FOCA KLSTNP COLCRM 8_33 80G JP	PCE	480.00	-

1.5. Objective

The objective of this research is to improve the utilization and efficiency of the raw material warehouse of a haircare manufacturer so that the space utilization is more balanced throughout the warehouse and the overall picking travel distance is decreased.

1.6. Scopes

1) Raw materials warehouse is currently used to store raw materials and pack materials. To improve capacity, space utilization and efficiency at raw materials warehouse, the following scopes are included:

- Updating material master data (material types, pallet heights, and turnover rates)
- Reviewing inventory, supply, and demand data in order to identify obsolete products to be written-off from storage locations to increase space available in the warehouse
- Adjusting beam height to match the actual size of materials and adding storage locations to current storage racking in a warehouse
- Regrouping materials according to an updated master data
- Reallocating space and reassigning location for each material group to balance the utilization and reduce work effort in operating
- Considering the suitable finished products to be stored at the raw materials warehouse

2) The capacity improvement in the raw materials warehouse results from the increasing of vacant locations after clearing obsolete materials from the raw materials warehouse and the increasing of rack locations after adjusting beam

height to match with actual size of raw materials. The utilization improvement is measured in terms of the balance of utilization throughout the warehouse. The more balance of the utilization in the warehouse means the less deviation of actual usage space from the allocated space. The efficiency improvement is quantified by the travel distance reduction during the picking process.

3) This research considers all materials currently stored at the raw materials warehouse which includes 299 SKUs of raw materials, 1,774 SKUs of pack materials, and 36 SKUs of imported bulk products. In addition, this thesis also studies the possibility to store some of 2,389 SKUs of finished products at the raw materials warehouse.

4) Raw materials warehouse has size of 11 (Height)* 40.5 (Depth)*101 (Width) cubic meters. There are two storage types used in this warehouse which are single selective rack and drive in rack. However, there are five types of the single selective rack which have different dimensions but only four types are included in this research (racking type R2 is excluded from this study). Numbers of bins for each type of racks are shown in table 2 (part 1.3).

5) Finished products will be considered to be stored at the raw materials warehouse in case there is available space after reallocating space to raw materials, pack materials, and imported bulk products according to procedures as stated in (1).

6) This research does not consider inventory level improvement. On the other hand, the analysis in this study based on forecasted inventory, supply, and demand data from January 1 to December 31, 2019, provided by the company on January 1, 2019.

7) Implementation plan and tools are developed and delivered to the company.

8) Assumptions used for this study are stated as the following:

- Forecasts on inventory, demand, and supply for the next 12 months (January to December 2019) are available and can be extracted from the SAP system currently used by the company. This forecast data is assumed to be reliable and can be used to analyze the improvement at the raw materials warehouse
- There is no conflict occurring during put-away and picking processes as they are handled by different teams and timing
- The company has resources to reallocate warehouse layout once a year

1.7. Outcome of this thesis

1) Providing methodology for improving utilization and efficiency at raw material warehouse
2) Delivering implementation plans for a case study company
3) Creating tools for helping the company to assign locations for each group of materials in the future

1.8. Benefits of this thesis

1) The company can benefit from capacity, efficiency, and space utilization improvement
2) The company can save cost by storing some finished products at the raw materials warehouse instead of storing them at the external warehouse.
3) The company can apply regrouping, reallocating, and reassigning method to improve warehouses in the future.

1.9. Research Timeline

The total periods for studying this research are 12 months starting from June 2018 to May 2019. Activities involved in this research and timeline are presented in Figure 7.

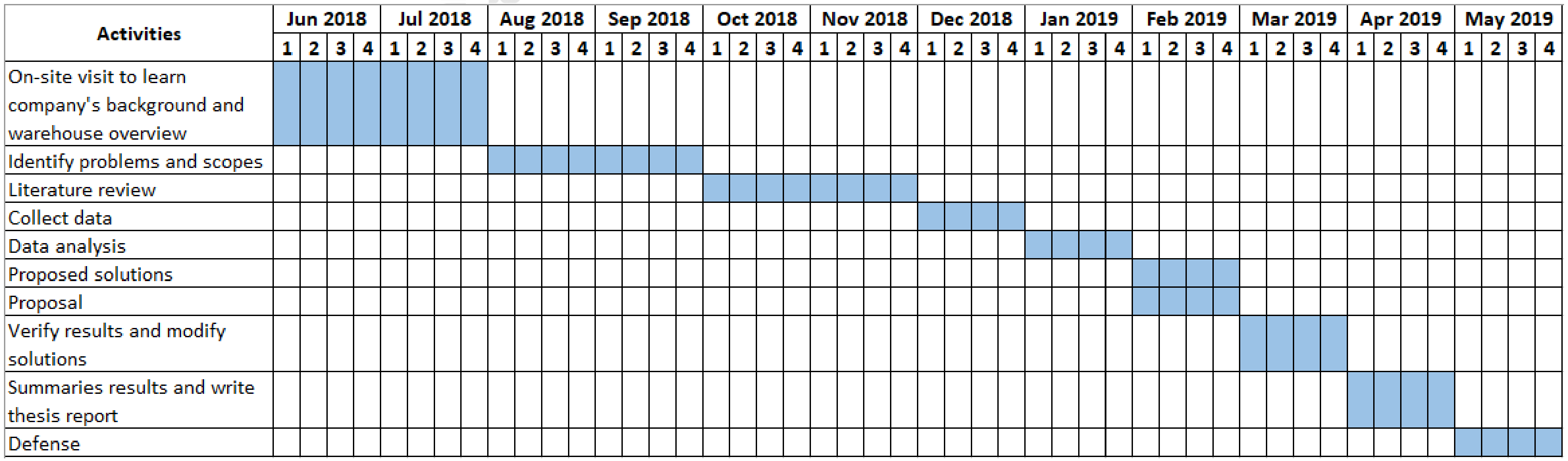


Figure 7. Research timeline

Chapter 2

Literature Review

This chapter presents related theories and related research used as reference for this thesis.

2.1. Related Theories

2.1.1 Types of Warehouse

There are two main types of warehouse which are private warehouse and public warehouse according to [1].

- **Private warehouse:** Private warehouse is own by company which includes the ownership in land, building, and equipment. However, operating activities within warehouse can be performed by company's employees or outsources. Private warehouse can be on-site and off-side. The benefits of private warehouse are low operating cost, high controllability and visibility, and high responsiveness.
- **Public warehouse:** Public warehouse offers storage areas and operations for the company that decides not to construct its own warehouse. In exchange, company has to pay renting cost for storage areas and operating cost for transporting products within and across building to warehouse's owner. The key advantages of public warehouse are high flexibility, professional operation, low risks, and low investment cost.

2.1.2. Warehouse Process

According to [2], there are four common activities occurring in warehouse which are receiving, put-away, picking, and dispatching. However, some warehouses may have additional activities such as pre-receipt, replenishment, and value adding services depending on their warehouse layout and work process design [3].

- **Pre-receipt process:** It is process that warehouse manager and material planner have to deal an agreement with suppliers on packaging's specification including packing size, number of items per carton, number of cartons per pallet, height of pallet, transporting vehicles, and required label on packaging. This process is to ensure that there will be no problem during receiving process and materials received from suppliers are comply with storage types and material handling used within warehouse.
- **Receiving Process:** This process includes receiving materials from suppliers and checking quantity, quality, and condition of products before transferring them to storage location.
- **Put-Away Process:** After receiving process, products will be moved to be stored at storage location. This is part of put-away process. Some warehouses use fixed location which warehouse manager will assign a certain location for a particular product but some warehouses use random location which each product can be placed in any locations within warehouse with help of computer system for monitoring.
- **Picking Process [2]:** This process occurs after warehouse operators receive orders from customers or another function and they have to select products from warehouse to serve to customers. There are many picking methods including basic order picking which operators will pick only one order per travel time, batch picking where multiple orders will be picked at the same time, zone picking which each operator will be assigned to pick products in different zones,

and wave picking where operators in each zone picked products at the same time and those products will be sorted into individual orders later. During picking process, operators may pick each product by item, carton, or full pallet unit according to requested volume of that product. Picking process is considered as the costliest activity within warehouse accounting for 50% to 75% of total operating costs [4]. Travel to product location spends longest time during picking process or around 50% of total picking time, followed by searching (20%), picking (15%), setting up (10%), and others (5%) [5].

- **Replenishment Process [3]:** For warehouse layout that is divided into forward and reserved area, operators have to replenish forward area with stocks in reserve area to enhance the efficiency of picking process in forward area.
- **Value Adding Process:** Based on the historical data, warehouse is only used to store material's inventory without value adding during storing process. Currently, warehouse is also used to perform value adding services such as labeling, repacking, bundling, and stickering.
- **Dispatching Process [2]:** This process is to ship products from warehouse to customers. So, operators have to ensure that products are in right quantity, quality, and condition prior to sending to loading area. During loading process, products are usually loaded in reverse orders so that product shipped to the first customer is easiest to access [6].

2.1.3. Storage Equipment

There are different types of storage systems used in today's warehouse. Each one is suitable to use in different warehouse layout and operation design [3].

- **Block stacking:** This type of storage is usually used when warehouse height is quite low and budget is limit. Nevertheless, it is only suitable for storing large quantities of small number of SKUs as it is hard for accessibility.

- **Wide aisle pallet racking (WAR) or adjustable pallet racking (APR):** It is common racking that is widely used in many warehouses as it does not require special material handling and height of rack is also adjustable to the required height. Furthermore, it is easy for accessible compared to other types of racking.
- **Double-deep racking:** This type of racking is similar to wide aisle pallet racking but it allows to store two pallets of products per one location. So, it requires special forklift that can extend its fork and also requires wider aisles. The pros of this racking is space saving but the cons is lower level of accessibility compared to wide aisle pallet racking.
- **Narrow aisle racking:** The key differences between this type of racking and APR are aisle width and handling equipment. This rack requires very narrow aisle which has to be used with narrow aisle trucks. Thus, this type of racking is appropriate for warehouse that has constrain on space as it efficiently uses of space.
- **Drive-in-racking and drive-through racking:** they are suitable to use with single SKUs that is stored in large quantities as it is hardly accessible to products that are kept inside column. Drive-in-racking does also not support FIFO of materials while drive-through-racking allows to pick pallets from the other end of racking.
- **Flow racking or live storage:** Movement of this racking is driven by gravity. It allows to use products by FIFO as picking and loading areas are on different sides. This type of racking is appropriate for fast moving materials which require FIFO stock rotation. Storage depth of flow rack is commonly limited to eight pallets due to weight consideration [6].
- **Push-back racking:** Picking and loading areas of push-back racking are on the same side. Pallet will be loaded from front end and it will push the pallet behind back for one location. During picking process, front pallet will be removed and the rear pallets will automatically move to the front. However, products will be spent by LIFO not FIFO. The advantages of this type of racking

compared to drive-in racking are greater accessibility as each lane can be independently operated.

To demonstrate the clearer picture on the different characteristics of each storage type, it can be studied from Figure 8 that presents warehouse performance index of each storage.

Performance of racking system	APR	Double deep	Narrow aisle	Drive-in/ drive-through	Live storage	Push back	Mobile	Satellite
Use of floor space	50%	70%	60%	80%	80%	70%	80%	85%
Use of height	70%	70%	80%	70%	70%	70%	70%	80%
Speed of access and throughput	80%	60%	70%	50%	80%	70%	60%	70%
Access to individual pallets	100%	50%	100%	40%	40%	60%	90%	60%
Occupancy rates	90%	70%	90%	60%	80%	80%	90%	80%
Stock rotation	70%	50%	90%	60%	100%	60%	60%	90%
Ease of management and control	60%	60%	60%	60%	80%	60%	60%	60%
Specialist handling equipment required*	No	Yes	Yes	No but restricted	No	Possibly	No	Yes
Ease of relocation	100%	100%	100%	70%	70%	80%	80%	100%
System adjustability	100%	100%	80%	100%	40%	100%	100%	70%

Figure 8. Warehouse performance of each storage type [3]

2.1.4. Storage Assignment

Three types of storage assignment including random storage, dedicated storage, and class-based storage are mentioned in [7].

- **Random Storage or shared location [2]:** With this storage type, each material can be placed in any locations within warehouse. In practical, this storage type is usually used in warehouse that has warehouse management system or computer system that helps to suggest available locations or suggest optimal locations within warehouse during put-away process and indicate location of required materials during picking process. This storage type usually has higher utilization rate than other types of storage assignment.

- **Dedicated storage or fixed locatio**n **[7]**: Each material is assigned to a fixed location meaning that other materials could not store in that location. This storage type benefits to warehouse that still uses manual process in indicating material locations as operators will become familiar with material locations. Nevertheless, drawback of this method has mentioned in [3]. In case that there is no inventory for a particular product, the location for that product will be vacantly left resulting in low utilization of warehouse.
- **Class-based storage [7]:** For class-based storage, materials are divided into classes such as class A, class B, and class C. Then each class is assigned into specific areas within warehouse. However, materials within the same class are stored in random location within assigned areas. Warehouse that uses this type of storage assignment normally utilizes Pareto's method to classify products into groups. Based on Pareto's method as applied in [8], only 15% of total materials account for 80% of total movement within warehouse, 30% of total materials account for 15% of total movement, and 55% of total materials account for 5% of movement. Hence, class A should be located closure to usage area and followed by class B and class C, accordingly.

  According to [4], after materials are assigned into class A, B, and C, another decision to make is either to use within-aisle storage or across-aisle storage. For within-aisle storage assignment, each class is located in the same aisle and the higher pick frequency class is located closer to depot as shown in Figure 9. For across-aisle storage assignment, all three classes are located in every aisle but the higher pick frequency class is assigned closer to depot as demonstrated in Figure 10.

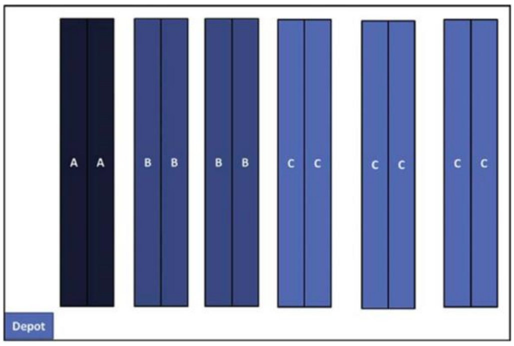


Figure 9. Within-aisle storage assignment [4]

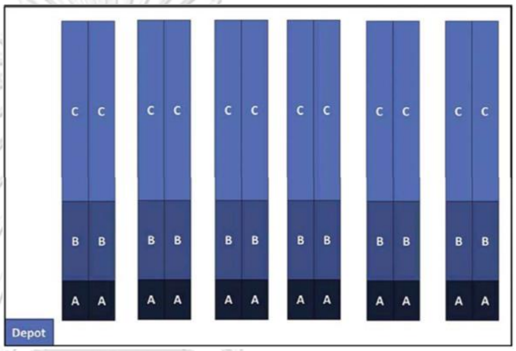


Figure 10. Across-aisle storage assignment [4]

In multi-level rack warehouse, storage assignment for class-based storage can be assigned by either horizontal or vertical as mentioned in [9]. For horizontal ABC class-based storage as presented in Figure 11, fast-moving items are stored closer to depot so thus travel distance can be reduced. For vertical ABC class-based storage as shown in Figure 12, fast-moving items are stored at lower level of rack in order that travel time can be reduced.

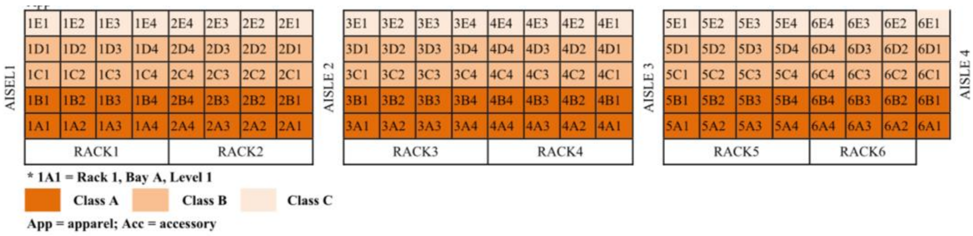


Figure 11. Horizontal ABC class-based storage [9]

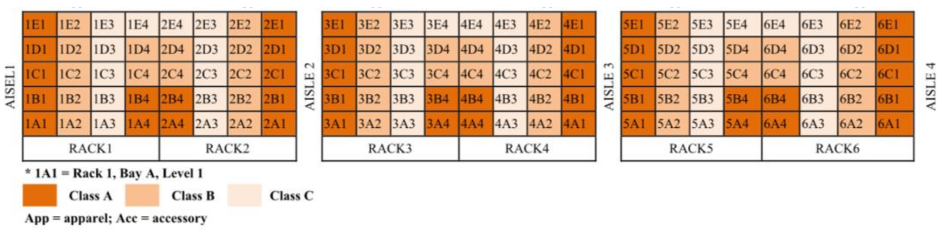


Figure 12. Vertical ABC class-based storage [9]

For dedicated and class-based storage, there are three criteria typically used to assign product to storage location as discussed in [10]. The first one is popularity which can be represented by picking frequency. Class with higher popularity should be located closer to usage area. The second criteria is maximum inventory. Class with lower maximum inventory should be located closer to usage location. The last criteria is cube-per-order (COI) which is ratio between maximum inventory and picking frequency. Class with lower COI should be located closer to usage area. By using COI with dedicated storage, it can minimize material handling cost.

In addition to classic storage strategies: random storage, dedicated storage, and class-based storage as mentioned earlier, clustering storage is popularly used when multiple items are picked in each tour as discussed in [11]. For the methodology, correlation among items is considered and items that often present in the same order are located close to each other. This storage type helps to reduce travel distance and time during picking process. However, the advantage of clustering storage is vanished if correlation among items is considerably low. In that case, applying picking frequency-based strategy is more attractive. Some research as revealed in [12] also considered sequence of picking lists after clustering SKUs in order to further minimize travel distance and time.

2.1.5. Warehouse Layout [3]

The desirable warehouse layout is warehouse layout that results in maximizing space utilization while minimizing travel time and touch point during operation. All operating areas within warehouse with required space for each area should be included during design phase. The common areas within warehouse are receiving area, storage areas, value adding service area, dispatch area, areas for locating empty pallet, charging area for material handling equipment, warehouse office, and restroom. For calculation of space for each area, using an average inventory level might not be an appropriate number because materials can overflow during peak demand period. On the other hand, using peak demand to indicate required space can result in low utilization of warehouse. Thus, [13] recommends that size of warehouse should close to an average inventory level if peak period is short and peak to average inventory is high. However, size of warehouse should close to peak inventory in case that peak period is long and ratio between peak to average is low. This paper also suggests that storage utilization should not exceeds 85%. Even though, productivity and safety can decline. However, this number also depends on operation design, layout of each warehouse and experience of operation team.

There are two typical warehouse layouts which are u-flow warehouse and through-flow warehouse according to [3].

- **U-flow warehouse:** This layout has high utilization at dock area as receiving and dispatch areas are on the same side as shown in Figure 13. However, it can cause congestion if huge volume of received materials and dispatched materials are operated at the same period.

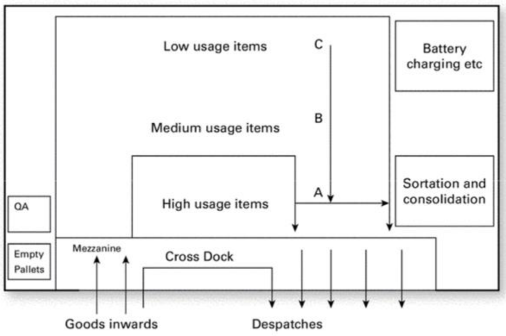


Figure 13. Layout of U-flow Warehouse [3]

- **Though-flow warehouse:** This layout locates receiving area and dispatch area at different sides of the building as presented in Figure 14. So, there is no concern on congestion if these two areas are busy at the same time but travel distance can increase compared to u-flow warehouse.

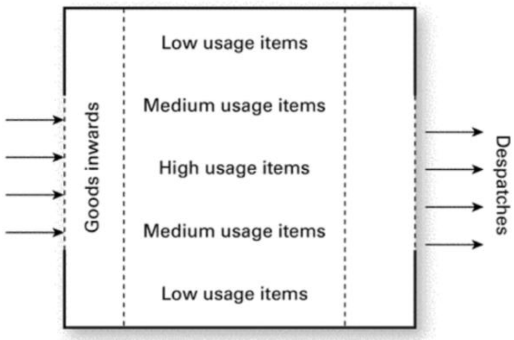


Figure 14. Layout of Through-Flow Warehouse [3]

Some warehouses are divided storage area into forward area and reserve area as discussed in [14]. The forward area is designed to use for efficient order picking while the reserve area is used to hold inventories for replenishing to forward area. Hence, forward area is usually smaller and located closer to usage area than reserve area. Some products that are not assigned in forward area are directly picked from reserve area. The typical decisions related to forward and reserve areas are determining sizes of forward and reserve areas, choosing SKUs to be stored in forward and reserve areas, and identifying product quantities that should be located in forward area. The key objective under making these decisions is to minimize total costs for picking and replenishing processes.

In case that warehouse manager found that current space within warehouse are not enough to store all required materials, the solutions can be expanding warehouse, renting additional space, and creating additional space within current warehouse [3]. First two options usually come with high investment cost. So, warehouse manager should study the potential of third option first. The possible ways to create more space within current warehouse are reducing inventory level, moving expired, obsolete, damaged and off-quality products out from warehouse, reducing height of racking according to actual size of materials, and changing from fixed location to random location or class-based storage. These options can be easily done without huge investment cost. [7] also suggests that company should schedule review period for obsolete products and write-off them on a regular basis.

2.1.6. Performance Measurement

According to [3], performance measurement is an important process to evaluate performance within warehouse. The objectives of performance measurement are ensuring customer satisfaction, discovering problems within warehouse in order to fix those problems, and constructing continuous improvement culture within organization. There are four main matrixes that are used to measure performance in warehouse which are reliability, flexibility, cost, and utilization.

- **Reliability:** Components that can represent reliability are on-time delivery, fill rates, and accuracy.

- **Flexibility:** Order cycle time that considers throughout the processes from customer ordering process to shipping process is often used to represent flexibility of that warehouse.
- **Cost:** Cost is a critical component for every warehouse. Majority of warehouses measures cost as a percentage of sales and productivity against labor cost.
- **Utilization:** Utilization represents efficiency use of warehouse space, storage and material handling equipment. Some warehouses measure utilization by comparing floor space used with total available floor space but some warehouses may use cubic utilization or look at pallet locations utilization. Utilization can be calculated by using Eq. (1)

$$Utilization = \frac{Space\ used}{Space\ available} \times 100 \quad (1)$$

2.2. Related Research

2.2.1. Creating additional space within current warehouse

According to [8], one way to increase capacity within current warehouse is to review and remove non-moving stocks from warehouse. In this research, author extracted historical sale data from the SAP system in the last five year and analyzed total sales volume of each SKU. Then, each SKU was grouped into class A, B, C, D according picking frequency. Group A represented fast-moving items or items that had higher picking rate than other groups. Group B was medium-moving items and group C was slow-moving items. Products classified in class D were non-moving items or items that did not have movement in the last five years and they were accounted for 14% of total product’s volume in warehouse. After classifying products into each group, products in group D were separated into other areas in order to create more available space in warehouse area. For the next step, warehouse manager had to ask for permission to destroy or remove those products out from company's area.

Another method to create additional space as purposed by [8] was to reduce beam height of racking. As author observed that size of products was smaller than size of storage bin. So, author changed beam height to match the product size resulting in more locations available within the same racking.

2.2.2. Using class-based storage to reduce picking distance

[8] grouped products into ABC classes based on sale volume and picking frequency. However, using picking frequency to identify products into class A, B, and C was more popular and more appropriate for designing warehouse layout. This study had compared random location with class-based location and found that class-based storage can save picking distance by 60% and also reduce picking time as fast-moving items were stored closer to usage area. Nevertheless, [15] stated that even class-based policy can reduce travel distance, larger number of classes is also required more storage space which can increase travel distance as well. So, trading off between number of classes and space required were necessary. The author also proposed that class-based policy with less than or equal to five classes is optimal.

[16] also arranged products into ABC groups according to picking frequency. In addition, author took constrain and requirement of each product into consideration. Picking frequency can be extracted from invoice orders. Many models of warehouse layout were created and compared in terms of picking distance, remain space, and flexibility in order to identify the most suitable warehouse layout.

[4] compared average system utilization (worker utilization) between within aisle assignment and across-aisle storage in ABC class-based storage assignment. The results demonstrated that within-aisle storage had higher average system utilization than across aisle storage because there was high impact from walk-back in across-

aisle assignment. On the other hand, across-aisle storage resulted yield lower average cycle time and higher average throughput than within aisle storage.

In multi-level rack warehouse, using vertical ABC class-based storage resulted in lower picking time and shorter travel distance in high pick density than using horizontal ABC class-based storage. However, using horizontal class-based storage resulted in shorter travel distance in low pick density than using vertical ABC class-based storage [9].

[17] did not use within aisle, across-aisle, horizontal ABC class-based or vertical ABC class-based storage in locating each class of products. On the other hand, this research computed weight for each slot in warehouse according to travel time required to reach each slot and used colors to represent three groups of slots which red was for hot slot (low-weighted which required shorter travel time), yellow was for warm slot (medium-weighted which required average travel time), and blue was for cold slot (high-weighted which required more travel time) as shown in Figure 15. This research suggested that products that had similar turnover rate should be located to same weighted slot.

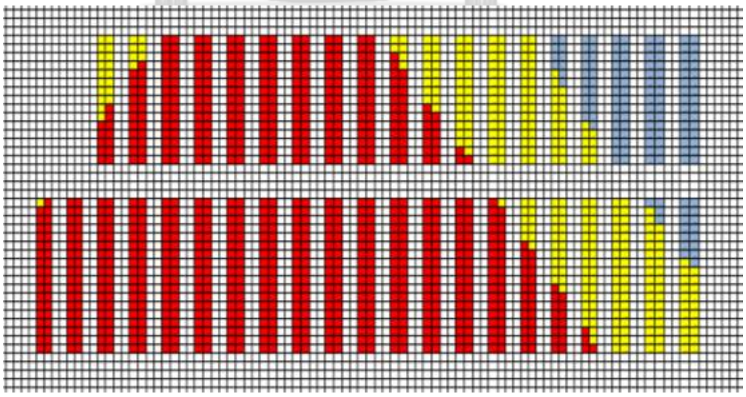


Figure 15. Warehouse layout with colors to represent each type of slots [17]

[18] applied ABC class-based storage and mathematical linear programming (using Lingo software program version 10.0) to identify optimized locations for each

commodity. The objective function was to minimize travel distance of products from origins to destinations. Inputs required in the model were demand, space required, and frequency transfer of each commodity, maximum capacity of destinations, and transfer distance of each commodity to each destination. There were two constraints included in the model. First, total amount of each commodity in all destinations should be equal to demand of that commodity. Second, total amount of all commodities in each destination should not exceed maximum capacity of that destination. The results presented that overall travel distance and total picking time were reduced by 45% and 42%, respectively.

2.2.3. Warehouse reshuffling

An assigned location for each type of materials can be changed over the period of time due to changing in demand profile. Warehouse reshuffling or warehouse reslotting is a process of moving materials from one assigned location to another assigned location. Costs related to warehouse reshuffling have to be traded-off with benefits from assigning new locations for materials in warehouse. [19] developed mathematical programming for solving reshuffling problems with an objective function to minimize total loaded and unloaded travel distance. The result demonstrated that reshuffling cost can be reduced about 6%.

2.2.4. Calculation for number of storage space required for each group of products

[17] created two different formula for calculating space required in dedicated storage policy and random storage policy as shown in Eq. (2) and Eq. (3). For dedicated policy, required number of space was sum of maximum inventory level of

each product during periods. For random storage policy, required number of space was maximum of aggregate number of space required for all products in each period.

$$M_{Dedicated} = \sum_p max_t(M_{pt}) \tag{2}$$

$$M_{Random} = max_t(\sum_p M_{pt}) \tag{3}$$

Where M_{pt} was number of space used by product p at time t.

[16] also calculated number of spaces required based on maximum inventory in the past one year instead of using an average number.

2.2.5. Storing products into two warehouses

[16] studied on how to group and locate products if company had two warehouses. This research proposed that first priority was to understand company's requirement especially safety and quality requirements. Second priority was to consider about distance. Products should be located closer to usage area as much as possible to minimize travel distance. After considering on suitable locations for each product, required space for each product were calculated. This research converted maximum stock data throughout the last year to required space for each type of materials. The next step was trying to allocate as many as products to their appropriate locations as determined earlier. In case that materials cannot fit in one warehouse, they had to overflow to another warehouse.

[20] had discussed on location selection problem in case that company had two warehouses which one was company owned warehouse and another was rented warehouse. Both warehouses can be used to store both raw materials and finished products. This research had constructed four policies and compared results in terms of transportation and storage cost minimization using four time-staged network flow-

based optimization. First policy was shipment level policy which warehouse manager responded to decide on which warehouse to receive each shipment based on inventory level of each warehouse at that time. Second policy was material level policy. With this policy, each material was assigned to be either onsite or offsite material and were always received at that assigned location. However, materials can be allocated to be stored in another warehouse after received based on decision from warehouse manager. Third policy was material level strict storage policy. This policy was similar to second policy but materials were not allowed to flow across warehouse after received. The last policy was material level flexible storage policy which reserved certain space for onsite materials and allowed offsite materials to be stored onsite if there were available space. For clearer picture, models of four policies were depicted in Figure 16. The results demonstrated that shipment level policy had the lowest cost, followed by material level policy, material level flexible storage policy, material level strict storage policy, respectively.

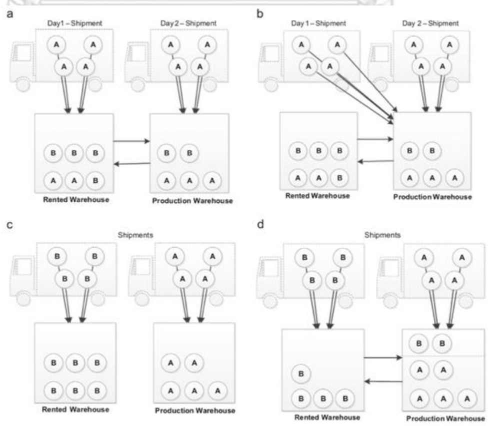


Figure 16. (a), (b), (c), and (d) represented shipment level policy, material level policy, material level strict storage policy, and material level flexible storage policy, respectively [20]

Chapter 3

Methodology

The objective of this chapter is to introduce the methods used in this thesis. The overall research methodology is presented in Figure 17.

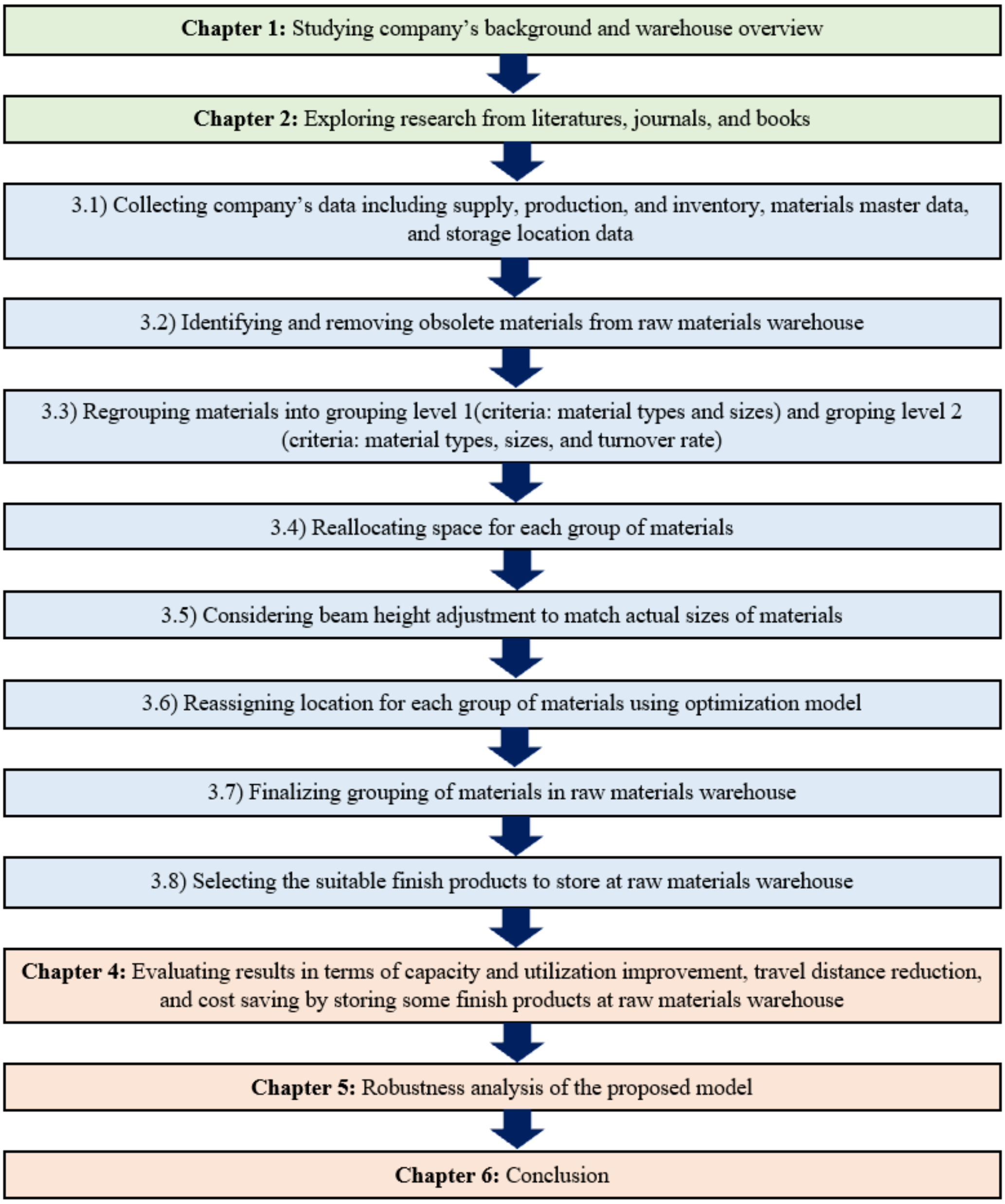


Figure 17. Research methodology overview

3.1. Collecting company's data

3.1.1. Month-end inventory data

Month-end inventory data reported by SKU as shown in Table 5 is used to calculate the required space for each SKU. This data can be downloaded from the SAP system which allows users to extract data for the next 12 months. Raw data downloaded from the SAP system are presented in original units of each material such as grams or kilograms for raw materials and pieces for pack materials. In order to use this data to analyze required space in the warehouse, it is required to convert a quantity from the original unit to pallet unit using unit conversion from material master data (quantity per pallet).

Table 5. Example of month-end inventory data from January to December 2019

Forecasted Inventory from January to December, 2019

GCAS	Material Description	Unit	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
1057261	SODIUM SULFITE	G	70,484.00	78,544.00	77,324.00	45,164.00	88,344.91	74,364.91	74,924.91	61,544.91	63,124.91	53,944.91	44,244.91	41,604.91
1057262	P-PHENYLENEDIAMINE	G	474,384.28	596,725.12	529,329.16	578,471.96	505,595.36	451,161.20	381,472.76	361,785.76	359,960.16	364,510.88	367,678.12	365,451.84
1057449	PROPYLENE GLYCOL	KG	1,048.44	563.78	901.12	513.46	424.70	751.04	779.72	706.40	430.08	318.42	486.76	283.44
1057453	ISOPROPYL ALCOHOL	KG	285.76	195.76	231.76	231.76	231.76	231.76	213.76	177.76	303.76	321.76	303.76	285.76
1057475	Phosphoric Acid, 85% in water	KG	393.72	346.25	277.30	220.30	159.80	114.83	105.88	41.63	70.10	88.60	47.10	93.85
1057573	MEA COSMETIC GRADE (30(	KG	385.35	391.23	20.09	90.73	45.31	30.79	59.55	78.75	31.98	26.26	12.91	48.38
1057622	BEESWAX	KG	179.60	136.60	112.10	59.10	107.10	162.10	98.60	79.10	104.10	77.10	83.10	108.10
1057640	ERYTHORBIC ACID	G	32,738.00	37,578.00	23,698.00	36,258.00	31,538.00	16,218.00	42,258.00	19,738.00	30,858.00	22,738.00	18,938.00	27,178.00
1057762	OLEYL ALCOHOL	KG	579.75	564.75	527.25	497.25	459.75	444.75	392.25	354.75	339.75	302.25	287.25	249.75
1057818	TALL OIL ACID	KG	372.58	268.90	250.06	239.86	137.86	111.28	226.24	161.14	142.84	154.06	188.14	154.90
1057983	OLETH-5	KG	2,158.34	1,916.66	1,599.98	1,308.30	608.26	1,126.58	568.22	819.86	386.50	829.82	588.14	839.78
1074381	SODIUM PCA (L-Form), 50% i	KG	10.89	8.89	6.89	3.89	24.89	22.89	22.89	18.89	16.89	16.89	12.89	10.89
1074511	ACRYLATES STEARETH-20 M	KG	959.00	1,063.50	849.75	678.75	1,105.00	974.50	585.25	876.50	746.00	487.25	996.75	693.00
1074707	PEG-12 Dimethicone	KG	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.41	0.41	0.41	0.41
1074873	SODIUM SULFATE, anhydrous	KG	215.10	207.70	163.20	68.20	171.98	145.68	163.88	147.73	105.08	71.88	95.78	73.13
1074956	OLETH-2	KG	785.76	1,334.92	1,051.58	805.74	330.72	879.88	425.70	766.52	499.84	216.50	765.66	386.48
1075072	Dicetyldimonium Chloride in Pro	KG	1,000.00	877.85	877.85	864.99	826.42	800.70	787.85	749.27	682.84	629.27	616.41	562.83
1075084	POLYQUATERNIUM-22	KG	2.20	13.00	5.30	3.40	3.40	9.20	8.00	0.50	11.90	3.40	13.00	3.60
1075094	ACRYLATES COPOLYMER, 2	KG	4,327.58	4,590.98	3,412.73	3,290.33	2,938.88	3,269.98	3,373.23	3,700.58	3,189.38	3,705.33	3,051.03	3,476.08
1075169	Simethicone Emulsion	KG	21.43	20.63	17.38	16.78	16.03	12.73	11.18	7.93	7.63	3.88	3.58	20.33
1075272	C12-15 PARETH-3	KG	81.25	49.31	205.37	173.43	77.61	45.67	169.79	105.91	42.03	10.09	166.15	102.27
1075297	STEARETH-21	KG	757.68	657.68	407.68	207.68	557.68	457.68	707.68	457.68	357.68	107.68	607.68	357.68
1075314	SOYTRIMONIUM CHLORIDE	KG	2,040.80	1,574.34	3,938.28	3,471.82	2,072.44	1,605.98	3,503.46	2,570.54	1,637.62	1,171.16	3,535.10	2,602.18
1075378	C11-15 PARETH-9	KG	259.39	195.49	131.59	67.69	80.11	220.33	92.53	168.85	41.05	181.27	117.37	193.69
1075468	NIACIN	KG	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.20
1120455	Aloe Barbadensis Leaf Juice	KG	-	19.10	19.10	19.10	19.10	19.10	18.95	18.80	18.35	18.05	17.90	17.60
1128541	PHENYL METHYL PYRAZOL	G	129,320.60	124,748.60	115,226.60	131,498.20	119,067.80	134,501.40	123,078.60	112,241.40	127,843.00	119,794.60	112,628.60	127,842.20
1138061	PEG-50 Hydrogenated Palmamid	KG	1,380.00	1,330.00	1,205.00	1,105.00	980.00	930.00	755.00	630.00	580.00	455.00	405.00	280.00
10045059	POLYQUATERNIUM-4	KG	-	-	45.36	45.36	45.36	45.36	45.36	45.36	44.76	44.76	44.76	44.76

Based on daily inventory data in 2018 as shown in Figure 18, the average month-end inventory is 3,818 pallets at 58.7 percentile, while the maximum month-end inventory is 4,456 pallets at 99.1 percentile. This means that if the required space for each group of materials is allocated based on the maximum month-end inventory data, 99.1% of days in a year will have enough space in the raw materials warehouse. On the other hand, there is only 0.9% chance that the allocated space is not enough for certain groups of materials. This evidence supports the use of maximum month-end inventory to represent the maximum inventory in the raw materials warehouse.

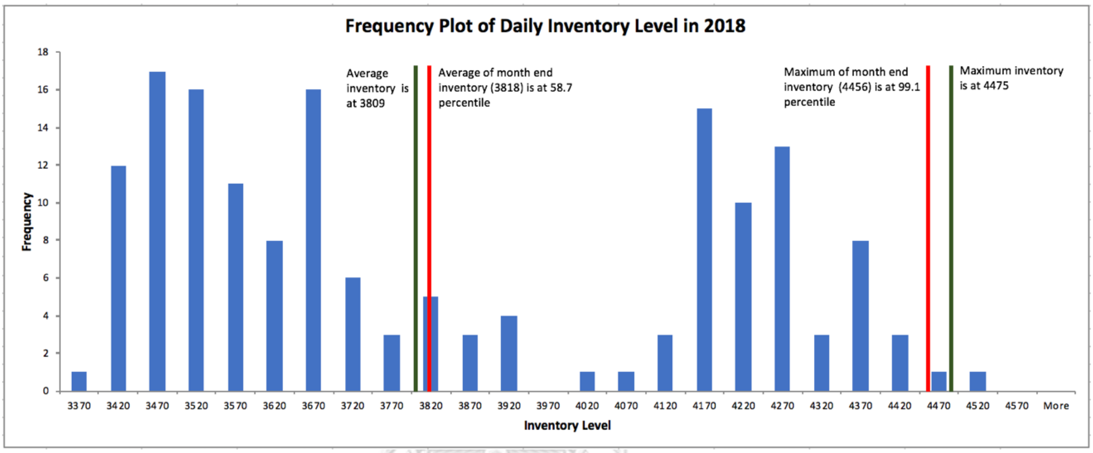


Figure 18. Frequency plot of daily inventory data in 2018

3.1.2. Supply and production data

Monthly supply and production or demand data as shown in Table 6 and Table 7 are used to calculate the inventory turnover rate in order to identify fast-moving and slow-moving materials. The fast-moving materials should be located closer to the usage area while slow-moving materials can be located further to the usage area. This strategy can help to reduce the travel distance and time during the picking process. These data can be downloaded from the SAP system in the same transaction window with the inventory data.

Table 6. Example of supply data from January to December 2019

			Forecasted Demand from January to December, 2019											
GCAS	Material Description	Unit	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
1057261	SODIUM SULFITE	G	153,400.00	91,940.00	126,220.00	157,160.00	131,819.09	113,980.00	174,440.00	113,380.00	123,420.00	109,180.00	84,700.00	102,640.00
1057262	P-PHENYLENEDIAMINE	G	33,516.72	27,659.16	67,395.96	50,857.20	72,876.60	54,434.16	69,688.44	69,687.00	51,825.60	45,449.28	46,832.76	52,226.28
1057449	PROPYLENE GLYCOL	KG	2,003.66	914.66	1,167.66	1,247.66	1,593.76	963.66	1,691.32	1,363.32	1,351.32	971.66	691.66	1,063.32
1057453	ISOPROPYL ALCOHOL	KG	270.00	252.00	450.00	486.00	648.00	486.00	666.00	522.00	522.00	468.00	342.00	504.00
1057475	Phosphoric Acid, 85% in wate	KG	135.70	47.47	68.95	57.00	60.50	44.97	99.67	64.25	62.25	72.22	41.50	43.97
1057573	MEA COSMETIC GRADE (3	KG	275.65	184.11	601.32	269.18	235.42	204.52	351.24	170.80	236.77	248.24	176.65	225.46
1057622	BEESWAX	KG	156.00	43.00	99.50	103.00	52.00	120.00	163.50	119.50	75.00	127.00	94.00	100.00
1057640	ERYTHORBIC ACID	G	21,600.00	20,160.00	38,880.00	37,440.00	54,720.00	40,320.00	48,960.00	47,520.00	38,880.00	33,120.00	28,800.00	41,760.00
1057762	OLEYL ALCOHOL	KG	7.50	15.00	37.50	30.00	37.50	15.00	52.50	37.50	15.00	37.50	15.00	37.50
1057818	TALL OIL ACID	KG	112.68	103.68	204.84	196.20	288.00	212.58	257.04	251.10	204.30	174.78	151.92	219.24
1057983	OLETH-5	KG	216.68	241.68	316.68	291.68	700.04	241.68	558.36	508.36	433.36	316.68	241.68	508.36
1074381	SODIUM PCA (L-Form), 50%	KG	4.00	2.00	2.00	3.00	4.00	2.00	-	4.00	2.00	-	4.00	2.00
1074511	ACRYLATES STEARETH-2	KG	42.75	535.50	213.75	171.00	213.75	130.50	389.25	348.75	130.50	258.75	130.50	303.75
1074707	PEG-12 Dimethicone	KG	-	-	-	-	-	-	-	-	0.06	-	-	-
1074873	SODIUM SULFATE, anhydro	KG	226.40	157.40	194.50	245.00	196.22	176.30	281.80	166.15	192.65	183.20	126.10	172.65
1074956	OLETH-2	KG	133.34	170.84	283.34	245.84	475.02	170.84	454.18	379.18	266.68	283.34	170.84	379.18
1075072	Dicetyldimonium Chloride in F	KG	-	122.15	-	12.86	38.57	25.72	12.86	38.57	66.43	53.57	12.86	53.57
1075084	POLYQUATERNIUM-22	KG	51.40	10.80	12.30	18.10	13.20	12.60	18.80	11.50	12.40	11.50	9.60	10.60
1075094	ACRYLATES COPOLYMER	KG	640.45	596.60	1,178.25	982.40	1,211.45	528.90	1,616.75	1,392.65	511.20	1,204.05	654.30	1,294.95
1075169	Simethicone Emulsion	KG	5.15	0.80	3.25	0.60	0.75	3.30	1.55	3.25	0.30	3.75	0.30	1.25
1075272	C12-15 PARETH-3	KG	31.94	31.94	31.94	31.94	95.82	31.94	63.88	63.88	63.88	31.94	31.94	63.88
1075297	STEARETH-21	KG	50.00	100.00	250.00	200.00	250.00	100.00	350.00	250.00	100.00	250.00	100.00	250.00
1075314	SOYTRIMONIUM CHLORII	KG	466.46	466.46	466.46	466.46	1,399.38	466.46	932.92	932.92	932.92	466.46	466.46	932.92
1075378	C11-15 PARETH-9	KG	63.90	63.90	63.90	63.90	191.70	63.90	127.80	127.80	127.80	63.90	63.90	127.80
1075468	NIACIN	KG	0.30	-	-	-	-	-	-	-	-	-	-	0.20
1120455	Aloe Barbadensis Leaf Juice	KG	-	0.90	-	-	-	-	0.15	0.15	0.45	0.30	0.15	0.30
1128541	PHENYL METHYL PYRAZ	G	6,352.40	4,572.00	9,522.00	8,728.40	12,430.40	9,566.40	11,422.80	10,837.20	9,398.40	8,048.40	7,166.00	9,786.40
1138061	PEG-50 Hydrogenated Palmai	KG	25.00	50.00	125.00	100.00	125.00	50.00	175.00	125.00	50.00	125.00	50.00	125.00
10045059	POLYQUATERNIUM-4	KG	-	-	-	-	-	-	-	-	0.60	-	-	-

Table 7. Example of production (supply) data from January to December 2019

			Forecasted Supply from January to December, 2019											
GCAS	Material Description	Unit	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
1057261	SODIUM SULFITE	G	-	100,000.00	125,000.00	125,000.00	175,000.00	100,000.00	175,000.00	100,000.00	125,000.00	100,000.00	75,000.00	100,000.00
1057262	P-PHENYLENEDIAMINE	G	-	150,000.00	-	100,000.00	-	-	-	50,000.00	50,000.00	50,000.00	50,000.00	50,000.00
1057449	PROPYLENE GLYCOL	KG	-	430.00	1,505.00	860.00	1,505.00	1,290.00	1,720.00	1,290.00	1,075.00	860.00	860.00	860.00
1057453	ISOPROPYL ALCOHOL	KG	162.00	162.00	486.00	486.00	648.00	486.00	648.00	486.00	648.00	486.00	324.00	486.00
1057475	Phosphoric Acid, 85% in water	KG	-	-	-	-	-	-	90.72	-	90.72	90.72	-	90.72
1057573	MEA COSMETIC GRADE (300 PPI	KG	190.00	190.00	190.00	380.00	190.00	190.00	380.00	190.00	190.00	190.00	190.00	190.00
1057622	BEESWAX	KG	-	-	75.00	50.00	100.00	175.00	100.00	100.00	100.00	100.00	100.00	125.00
1057640	ERYTHORBIC ACID	G	-	25,000.00	25,000.00	50,000.00	50,000.00	25,000.00	75,000.00	25,000.00	50,000.00	25,000.00	25,000.00	50,000.00
1057762	OLEYL ALCOHOL	KG	-	-	-	-	-	-	-	-	-	-	-	-
1057818	TALL OIL ACID	KG	186.00	-	186.00	186.00	186.00	186.00	372.00	186.00	186.00	186.00	186.00	186.00
1057983	OLETH-5	KG	760.00	-	-	-	-	760.00	-	760.00	-	760.00	-	760.00
1074381	SODIUM PCA (L-Form), 50% in w	KG	-	-	-	-	25.00	-	-	-	-	-	-	-
1074511	ACRYLATES STEARETH-20 METH.	KG	-	640.00	-	-	640.00	-	-	640.00	-	-	640.00	-
1074707	PEG-12 Dimethicone	KG	-	-	-	-	-	-	-	-	-	-	-	-
1074873	SODIUM SULFATE, anhydrous	KG	150.00	150.00	150.00	150.00	300.00	150.00	300.00	150.00	150.00	150.00	150.00	150.00
1074956	OLETH-2	KG	-	720.00	-	-	-	720.00	-	720.00	-	-	720.00	-
1075072	Dicetyldimonium Chloride in Pro	KG	1,000.00	-	-	-	-	-	-	-	-	-	-	-
1075084	POLYQUATERNIUM-22	KG	20.00	-	20.00	20.00	20.00	-	20.00	20.00	-	20.00	-	20.00
1075094	ACRYLATES COPOLYMER, 28% ir	KG	-	860.00	-	860.00	860.00	860.00	1,720.00	1,720.00	-	1,720.00	-	1,720.00
1075169	Simethicone Emulsion	KG	-	-	-	-	-	-	-	-	-	-	-	18.00
1075272	C12-15 PARETH-3	KG	-	-	188.00	-	-	-	188.00	-	-	-	188.00	-
1075297	STEARETH-21	KG	600.00	-	-	-	600.00	-	600.00	-	-	-	600.00	-
1075314	SOYTRIMONIUM CHLORIDE, 60%	KG	-	-	2,830.40	-	-	-	2,830.40	-	-	-	2,830.40	-
1075378	C11-15 PARETH-9	KG	-	-	-	-	204.12	204.12	-	204.12	-	204.12	-	204.12
1075468	NIACIN	KG	-	-	-	-	-	-	-	-	-	-	-	-
1120455	Aloe Barbadensis Leaf Juice	KG	-	20.00	-	-	-	-	-	-	-	-	-	-
1128541	PHENYL METHYL PYRAZOLONE	G	-	-	-	25,000.00	-	25,000.00	-	-	25,000.00	-	-	25,000.00
1138061	PEG-50 Hydrogenated Palmamic	KG	-	-	-	-	-	-	-	-	-	-	-	-
10045059	POLYQUATERNIUM-4	KG	-	-	45.36	-	-	-	-	-	-	-	-	-

3.1.3. Materials Master Data

Materials master data includes the type of materials (combustible raw materials, general raw materials, perm pack materials, color pack materials, and bulk materials), number of pieces or weight per pallet, and height of materials per pallet are collected and recorded in excel format as shown in Table 8.

Table 8. Example of materials master data

GCAS	Material Description	PCE/PAL	Uom	Final Material Types	Material Height
1057261	SODIUM SULFITE	225000	G	General Raw Materials	Medium
1057262	P-PHENYLENEDIAMINE	75000	G	General Raw Materials	Medium
1057449	PROPYLENE GLYCOL	860	KG	General Raw Materials	Medium
1057453	ISOPROPYL ALCOHOL	648	KG	Combustible raw materials	Medium
1057475	Phosphoric Acid, 85% in water	100	KG	General Raw Materials	Medium
1057573	MEA COSMETIC GRADE (300 PPM DEA)	190	KG	General Raw Materials	Medium
1057622	BEESWAX	200	KG	General Raw Materials	Medium
1057640	ERYTHORBIC ACID	100000	G	General Raw Materials	Medium
1057762	OLEYL ALCOHOL	170	KG	General Raw Materials	Medium
1057818	TALL OIL ACID	372	KG	General Raw Materials	Medium
1057983	OLETH-5	760	KG	General Raw Materials	Medium
1074381	SODIUM PCA (L-Form), 50% in water	200	KG	General Raw Materials	Medium
1074511	ACRYLATES STEARETH-20 METHACRYLATE C(	640	KG	General Raw Materials	Medium
1074873	SODIUM SULFATE, anhydrous	600	KG	General Raw Materials	Medium
1074956	OLETH-2	720	KG	General Raw Materials	Medium
1075072	Dicetyldimonium Chloride in Propylene Gl	1000	KG	General Raw Materials	Medium
1075084	POLYQUATERNIUM-22	60	KG	General Raw Materials	Medium
1075094	ACRYLATES COPOLYMER, 28% in water	860	KG	General Raw Materials	Medium
1075169	Simethicone Emulsion	18	KG	General Raw Materials	Medium
1075272	C12-15 PARETH-3	186	KG	General Raw Materials	Medium

Type of materials is used to divide materials into each category which is assigned into different storage areas. For example, combustible raw materials and general raw materials should be located closer to the making area, perm pack materials should be located closer to the perm packing area, and color pack materials should be located closer to the color packing area.

The number of pieces and weight per pallet are used to convert the quantity of each SKU into the number of pallets, as most of the data extracted from the SAP system including supply, production, and inventory data are normally reported in piece or gram or kilogram units. Therefore, converting into pallet units is required for managing locations in the warehouse.

As the raw materials warehouse has four storage bin types with different dimensions and each material is received with different pallet heights, the height of material per pallet of each SKU is an important information used to match material types with storage types.

3.1.4. Storage Location Data

Storage location data includes the total number of storage bins and storage bin types in each location. This information is used to match material types with storage locations. Details of storage locations at the raw materials warehouse are shown in Figure 19.

Location	Rack Type									Number of BIN								
	L0	L1	L2	L3	L4	L5	L6	L7	L8	L0	L1	L2	L3	L4	L5	L6	L7	L8
CA		R3	R3	R3	R3	R3					10	10	10	10	10			
CB		R3	R3	R3	R3	R3	R5				10	10	10	10	10	10		
WLB		R5	R5	R5	R5						40	40	40	40				
JIT		R5	R5	R5	R5						60	60	60	60				
RA		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RB		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RC		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RD		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RE		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RF		R3	R3	R3	R3	R3	R3	R5			8	8	8	8	8	8	8	
RG		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RH		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RI		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RJ	R1	R1	R3	R3	R3	R3	R3	R5		18	18	18	18	18	18	18	18	
RK		R3	R3	R3	R3	R3	R3	R5			18	18	18	18	18	18	18	
RL		R3	R3	R3	R3	R3	R3	R5			18	18	18	18	18	18	18	
RM		R3	R3	R3	R3	R3	R3	R5			16	16	16	16	16	16	16	
WA		R4	R4	R4	R4	R4	R5				16	16	16	16	16	16		
WB		R4	R4	R4	R4	R4	R5				16	16	16	16	16	16		
WC		R4	R4	R4	R4	R4	R5				16	16	16	16	16	16		
WD		R4	R4	R4	R4	R4	R5				14	14	14	14	14	14		
WE		R4	R4	R4	R4	R4	R5				11	11	11	11	11	11		
WF		R4	R4	R4	R4	R4					24	28	31	31	31			
PA		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PB		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PC		R1	R1	R5	R5	R5	R5				22	22	22	22	22	22		
PD		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PE		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PF		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PG		R1	R1	R5	R5	R5	R5				17	17	17	17	17	17		
PH		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PI		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PJ		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PK		R1	R1	R5	R5	R5	R5				17	17	17	17	17	17		
PL		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PM		R4	R4	R4	R4	R5					24	28	35	35	35			
LA		R2	R2	R2	R2	R2	R2	R2	R2		12	12	12	12	12	12	12	12
LB		R2	R2	R2	R2	R2	R2	R2	R2		11	11	11	11	11	11	11	11
RN		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RO		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RP		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RQ		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RR		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RS		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RT		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RU		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RV		R4	R4	R4	R4	R4	R5				5	5	5	5	5	5		

Figure 19. Details of storage locations at raw materials warehouse

3.2. Identifying and removing obsolete materials from raw materials warehouse

This step is to create additional space within the current warehouse with the lowest investment cost based on the recommendation from [3] and [7]. In addition, [8] had done research on this and results showed that about 14% of additional space within the warehouse was obtained after removing this group of products from the warehouse.

According to the company's policy, products are considered to be written-off in case that they are off-quality, damaged, expired, and obsolete or discontinued. In addition, materials that are used for the testing machine (EO materials or experimental order materials) can be considered to be written-off if they are out of specification after use.

Off-quality, damaged and expired materials are regularly tracked by the QA (Quality Assurance) department. EO materials that require writing-off are recorded by the operation or material team. However, obsolete or discontinued materials are not often reviewed by the planning team as ownership is not assigned. Thus, there are many non-moving materials found in the warehouse.

In this thesis, all inventories in the raw materials warehouse are reviewed in order to identify discontinued materials. The overall methodology to identify and remove write-off materials from the warehouse is shown in Figure 20.

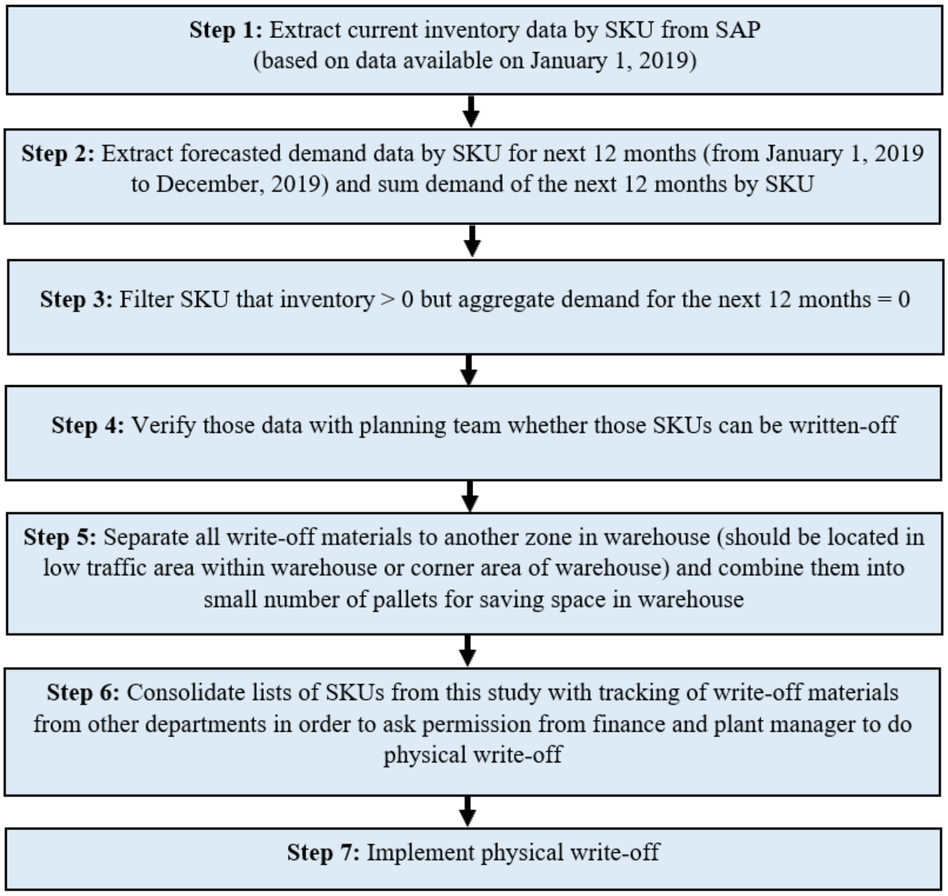


Figure 20. Overall processes to identify and remove write-off materials from warehouse

In addition, the tracking process alone does not help to create more available space in the warehouse. The company should create a schedule to review total write-off materials and do physical write-off on a continuous basis.

3.3. Regrouping materials into grouping level 1 (criteria: material types and sizes) and grouping level 2 (criteria: material types, sizes, and turnover rates)

As there are too many SKUs of materials including 1,774 SKUs of pack materials, 299 SKUs of raw materials, and 36 SKUs of bulk materials storing at the raw materials warehouse and some SKUs have inventory more than one pallet.

Therefore, it is not possible to assign a fixed storage location for each SKU due to space constraint and it can result in low utilization within the warehouse according to [7]. By assigning random storage, it can result in high utilization but it can also cause higher average travel distance during the picking process. Thus, the group-based location should be applied as researched by [8]. Considering for group-based location in this study does not only include the turnover rate of materials but also material types and total height of received materials (pallet height + height of materials).

Materials currently stored at the raw materials warehouse are used in three main production areas, namely making area, color packing area, and perm packing area. Hence, the warehouse layout should be divided into three zones for separating materials used in different areas. Within the area for storing raw materials used in the making area, there are two sub-areas required for general raw materials and combustible raw materials according to the requirements of the company. For pack materials of color production and perm production, there are three sub-areas required for materials stored in drive-in-rack area, materials stored in single selective rack area, and bulk materials. Materials that are appropriate to be stored in drive-in-rack should be SKUs that are received in high volume and have high turnover rate.

The observed height of received materials from suppliers vary greatly. A warehouse with one size of storage bin will have fewer storage locations and lower utilization, as the storage bin size has to be equal to the maximum size of the received pallet. In order to create greater space within the warehouse, the beam height can be reduced to match the actual height of materials as recommended by [3] and implemented by [8]. Currently, single selective rack used in the warehouse has four different sizes. Therefore, materials are categorized into different groups according to received pallet heights.

The last item under consideration is the turnover rate of each type of materials. Higher turnover rate materials should be located closer to usage area and lower turnover rate materials should be located further to the usage area in order to minimize the overall travel distance and travel time during the picking process. In this study, Pareto's method is applied and materials are divided into three classes according to picking frequency. Fast-moving materials are assigned to class A, medium-moving materials to class B, and slow-moving materials to class C.

To summarize, materials in this warehouse are grouped according to material types, sizes, and turnover rates. The first priority in grouping is type of materials, followed by material heights and turnover rates, respectively.

For trading-off between the number of material groups and storage space required, two grouping levels are arranged and compared in terms of storage space required and total picking distance. For grouping level 1, materials are classified into groups based on type of materials and height of materials. For grouping level 2, materials are classified into groups based on type of materials, height of materials and turnover rates. As [15] noted that though class-based storage can reduce travel distance, too many classes require larger space which can also result in higher travel distance. Since the main objective of this research is to improve space utilization and reduce picking distance, if travel distance reduction is small compared to the larger space required, grouping level 1 will be selected for implementation in the raw materials warehouse.

3.4. Reallocating space for each group of materials

After separating materials into each group, the required space for each group has to be calculated. According to [17], the space required for dedicated and random storage location can be calculated using Eq. (2) and Eq. (3) as presented in part 2.2.4.

In this thesis, group-based or class-based storage is used. Therefore, the formula used for calculation of required space can be developed by applying dedicated and random storage formula as shown in Eq. (4).

$$M_{class-based} = \sum_g max_t(M_{gt}) \quad (4)$$

Where M_{gt} is the number of space used by group g at time t and $M_{class-based}$ is the total space required for class-based storage.

In this research, forecasted month-end inventory of each material in the next 12 months (from January to December 2019) is extracted from the SAP system and converted to the number of pallets. All decimal points are rounded up. By summing up the total inventory in pallets for each group of materials, the total required space for each group of materials in each month is obtained. The final space allocated for each group of materials is based on the maximum month-end inventory. In this part, the total required space is calculated for both grouping level 1 and grouping level 2 and the results of these two groups will be compared and traded-off with the total picking distance required in the later part, in order to identify the most appropriate grouping to be implemented in the raw materials warehouse.

3.5. Considering beam height adjustment to match the actual size of materials

After the required space for each group of materials is finalized, this data is used to compare with the current capacity of each rack type in the raw materials warehouse. In case there are more high racks than are required, lowering beam height can lend to increase storage locations within the warehouse as proposed by [3] and [8].

At this step, the space left unused after the allocation of each group of materials is identified will be used for storing some finished products at the raw materials warehouse.

3.6. Reassigning location for each group of materials

The assigning locations for each group of materials is based on priority set in Figure 21.

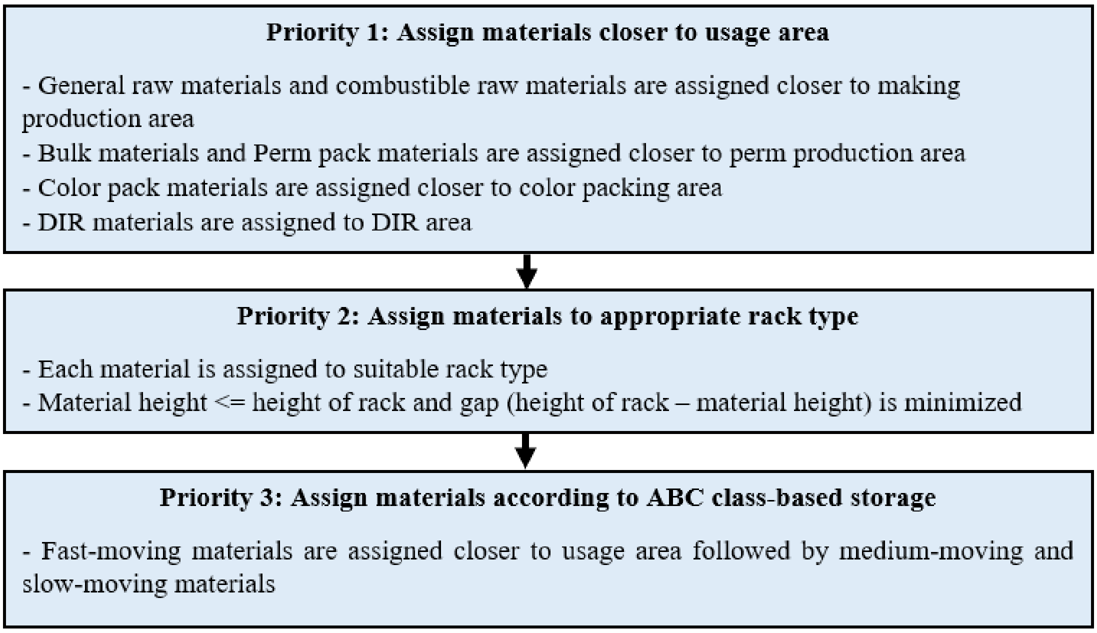


Figure 21. Priority in assigning location for each group of materials

As there are many storage locations in the raw materials warehouse, assigning locations for each material group manually is difficult to obtain the best solution. Hence, the optimization model (linear mathematical programming) is used to identify the most appropriate locations for each group of materials.

After each group of materials under grouping level 1 and grouping level 2 has its assigned locations, the total picking distances for grouping level 1 and grouping level 2 can be calculated.

3.7. Finalizing grouping of materials in raw materials warehouse

In this part, grouping level 1 and grouping level 2 are compared in terms of storage space required and total picking distance. The grouping that results in lower storage space required and shorter picking distance is chosen for implementation in the raw materials warehouse.

3.8. Selecting the most suitable finished products to be stored at raw materials warehouse

In order to select finished products to be stored at the raw materials warehouse, all possible solutions have to be compared in terms of costs and benefits. The solution that results in the highest net benefit will be selected to be implemented in this raw materials warehouse. However, costs and benefits of each option can vary according to allocated locations for finished products from part 3.4. Key consideration points for choosing finished products to be stored at the raw materials warehouse are shown below:

- Currently, finished products are only picked and shipped from the external warehouse to seaport
- Only Japan products are shipped in full pallets. Other products are needed to be repacked in pallets at the external warehouse before shipping to customers.
- QA lead time for finished products is three days on average. At present, finished products are shipped to the external warehouse before they are released. Sometimes, products that fail QA tests are recalled for retest or rework at the manufacturing plant resulting in additional transporting cost.

Chapter 4

Results and Discussion

In this chapter, the conceptual methodologies from chapter 3 are implemented and the results are discussed. The first part of this chapter is reviewing current inventory in the raw materials warehouse and demand forecast in the next 12 months in order to identify and remove obsolete materials from the raw materials warehouse. After obsolete materials are identified and separated from active materials (materials that are still used within the manufacturing plant), the active materials are re-grouped according to material types, sizes, and turnover rates. Two levels of grouping are created which are grouping level 1 (considers only material types and sizes) and grouping level 2 (considers materials types, sizes, and turnover rates). These two levels of grouping will be compared and selected for implementation based on the required space and the total picking distance in the later part. Then, the third step is reallocating space for each group of materials and considering beam height adjustment to match the actual size of materials. In the fourth step, each group of materials is assigned to a suitable location within the raw materials warehouse using the optimization model and the total picking distances are calculated. After the required space and the total picking distance for grouping level 1 and grouping level 2 are obtained, they are compared and grouping that results in lower required space and shorter picking distance will be selected to be applied in this raw materials warehouse. For the last step, some finished products are selected to be stored at the raw materials warehouse in case that there is remaining space after reallocating space for current materials. At the end of this chapter, results are reported in terms of capacity and utilization improvement, travel distance reduction, and cost savings from storing some of the finished products at the internal raw materials warehouse instead of the external public warehouse.

4.1. Identifying and removing obsolete materials from raw materials warehouse

In the first step, current inventory by SKU has to be extracted from the SAP system. In this thesis, current inventory by SKU is downloaded from the SAP system on January 1, 2019, as shown in Table 9.

Table 9. Example of current inventory data by SKU extracted from the SAP system on January 1, 2019

GCAS	Material Description	Unit	Current Inventory
1057261	SODIUM SULFITE	G	223,884.00
1057262	P-PHENYLENEDIAMINE	G	507,901.00
1057449	PROPYLENE GLYCOL	KG	3,052.10
1057453	ISOPROPYL ALCOHOL	KG	393.76
1057475	Phosphoric Acid, 85% in water	KG	529.42
1057573	MEA COSMETIC GRADE (300 PPM DEA)	KG	471.00
1057622	BEESWAX	KG	335.60
1057640	ERYTHORBIC ACID	G	54,338.00
1057762	OLEYL ALCOHOL	KG	587.25
1057818	TALL OIL ACID	KG	299.26
1057983	OLETH-5	KG	1,615.02
1074381	SODIUM PCA (L-Form), 50% in water	KG	14.89
1074511	ACRYLATES STEARETH-20 METHACRYLATE C	KG	1,001.75
1074707	PEG-12 Dimethicone	KG	0.47
1074873	SODIUM SULFATE, anhydrous	KG	291.50
1074956	OLETH-2	KG	919.10
1075072	Dicetyldimonium Chloride in Propylene Gl	KG	-
1075084	POLYQUATERNIUM-22	KG	29.20
1075094	ACRYLATES COPOLYMER, 28% in water	KG	4,968.03
1075169	Simethicone Emulsion	KG	26.58
1075272	C12-15 PARETH-3	KG	113.19
1075297	STEARETH-21	KG	207.68
1075314	SOYTRIMONIUM CHLORIDE, 60%	KG	2,507.26
1075378	C11-15 PARETH-9	KG	323.29
1075468	NIACIN	KG	15.70
1120455	Aloe Barbadensis Leaf Juice	KG	-
1128541	PHENYL METHYL PYRAZOLONE	G	135,673.00
1138061	PEG-50 Hydrogenated Palmamide	KG	1,405.00
10045059	POLYQUATERNIUM-4	KG	-

In the second step, forecasted demand data by SKU in the next 12 months (January to December 2019) is extracted from the SAP system on January 1, 2019, and aggregate demand in the next 12 months by SKU is calculated as shown in "sum" column in Table 10.

Table 10. Example of forecasted demand data by SKU extracted from the SAP system on January 1, 2019

			Forecasted Demand from January to December, 2019												
GCAS	Material Description	Unit	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Sum
1057261	SODIUM SULFITE	G	153,400.00	91,940.00	126,220.00	157,160.00	131,819.09	113,980.00	174,440.00	113,380.00	123,420.00	109,180.00	84,700.00	102,640.00	1,482,279.09
1057262	P-PHENYLENEDIAMINE	G	33,516.72	27,659.16	67,395.96	50,857.20	72,876.60	54,434.16	69,688.44	69,687.00	51,825.60	45,449.28	46,832.76	52,226.28	642,449.16
1057449	PROPYLENE GLYCOL	KG	2,003.66	914.66	1,167.66	1,247.66	1,593.76	963.66	1,691.32	1,363.32	1,351.32	971.66	691.66	1,063.32	15,023.66
1057453	ISOPROPYL ALCOHOL	KG	270.00	252.00	450.00	486.00	648.00	486.00	666.00	522.00	522.00	468.00	342.00	504.00	5,616.00
1057475	Phosphoric Acid, 85% in water	KG	135.70	47.47	68.95	57.00	60.50	44.97	99.67	64.25	62.25	72.22	41.50	43.97	798.45
1057573	MEA COSMETIC GRADE (300 PPM DEA)	KG	275.65	184.11	601.32	269.18	235.42	204.52	351.24	170.80	236.77	248.24	176.65	225.46	3,179.37
1057622	BEESWAX	KG	156.00	43.00	99.50	103.00	52.00	120.00	163.50	119.50	75.00	127.00	94.00	100.00	1,252.50
1057640	ERYTHORBIC ACID	G	21,600.00	20,160.00	38,880.00	37,440.00	54,720.00	40,320.00	48,960.00	47,520.00	38,880.00	33,120.00	28,800.00	41,760.00	452,160.00
1057762	OLEYL ALCOHOL	KG	7.50	15.00	37.50	30.00	37.50	15.00	52.50	37.50	15.00	37.50	15.00	37.50	337.50
1057818	TALL OIL ACID	KG	112.68	103.68	204.84	196.20	288.00	212.58	257.04	251.10	204.30	174.78	151.92	219.24	2,376.36
1057983	OLETH-5	KG	216.68	241.68	316.68	291.68	700.04	241.68	558.36	508.36	433.36	316.68	241.68	508.36	4,575.24
1074381	SODIUM PCA (L-Form), 50% in water	KG	4.00	2.00	2.00	3.00	4.00	2.00	-	4.00	2.00	-	4.00	2.00	29.00
1074511	ACRYLATES STEARETH-20 METHACRY	KG	42.75	535.50	213.75	171.00	213.75	130.50	389.25	348.75	130.50	258.75	130.50	303.75	2,868.75
1074707	PEG-12 Dimethicone	KG	-	-	-	-	-	-	-	-	0.06	-	-	-	0.06
1074873	SODIUM SULFATE, anhydrous	KG	226.40	157.40	194.50	245.00	196.22	176.30	281.80	166.15	192.65	183.20	126.10	172.65	2,318.37
1074956	OLETH-2	KG	133.34	170.84	283.34	245.84	475.02	170.84	454.18	379.18	266.68	283.34	170.84	379.18	3,412.62
1075072	Dicetyldimonium Chloride in Propylene Gl	KG	-	122.15	-	12.86	38.57	25.72	12.86	38.57	66.43	53.57	12.86	53.57	437.17
1075084	POLYQUATERNIUM-22	KG	51.40	10.80	12.30	18.10	13.20	12.60	18.80	11.50	12.40	11.50	9.60	10.60	192.80
1075094	ACRYLATES COPOLYMER, 28% in water	KG	640.45	596.60	1,178.25	982.40	1,211.45	528.90	1,616.75	1,392.65	511.20	1,204.05	654.30	1,294.95	11,811.95
1075169	Simethicone Emulsion	KG	5.15	0.80	3.25	0.60	0.75	3.30	1.55	3.25	0.30	3.75	0.30	1.25	24.25
1075272	C12-15 PARETH-3	KG	31.94	31.94	31.94	31.94	95.82	31.94	63.88	63.88	63.88	31.94	31.94	63.88	574.92
1075297	STEARETH-21	KG	50.00	100.00	250.00	200.00	250.00	100.00	350.00	250.00	100.00	250.00	100.00	250.00	2,250.00
1075314	SOYTRIMONIUM CHLORIDE, 60%	KG	466.46	466.46	466.46	466.46	1,399.38	466.46	932.92	932.92	932.92	466.46	466.46	932.92	8,396.28
1075378	C11-15 PARETH-9	KG	63.90	63.90	63.90	63.90	191.70	63.90	127.80	127.80	127.80	63.90	63.90	127.80	1,150.20
1075468	NIACIN	KG	0.30	-	-	-	-	-	-	-	-	-	-	0.20	0.50
1120455	Aloe Barbadensis Leaf Juice	KG	-	0.90	-	-	-	-	0.15	0.15	0.45	0.30	0.15	0.30	2.40
1128541	PHENYL METHYL PYRAZOLONE	G	6,352.40	4,572.00	9,522.00	8,728.40	12,430.40	9,566.40	11,422.80	10,837.20	9,398.40	8,048.40	7,166.00	9,786.40	107,830.80
1138061	PEG-50 Hydrogenated Palmamide	KG	25.00	50.00	125.00	100.00	125.00	50.00	175.00	125.00	50.00	125.00	50.00	125.00	1,125.00
10045059	POLYQUATERNIUM-4	KG	-	-	-	-	-	-	-	-	0.60	-	-	-	0.60

The interesting SKUs in this part are SKUs that have current inventories more than zero but their aggregate demand in the next 12 months are zero. Thus, these SKUs are filtered out in the third step in order to verify with planning team whether they can be written-off and removed from the raw materials warehouse. Table 11 demonstrates an example of SKUs that have inventory more than zero but their aggregate demand in the next 12 months is zero.

Table 11. Example of SKUs that have inventory more than zero but their aggregate demand in the next 12 months are zero

GCAS	Material Description	Unit	Current Inventory (in PCE or KG or G)	PCE or KG or G/Pallet	Current Inventory (in pallet)	Sum Demand in the next 12 months	Need to Check Write-off?	Confirm to write-off?
90588532	FOCA KLSTNP COLCRM 8_47 80G JP	PCE	8,082.00	6,211.00	2	-	Yes	Keep
90588595	FOCA KLSTNP COLCRM 6_47 80G JP	PCE	4,900.00	6,210.00	1	-	Yes	Keep
90622669	LBWR WP ENR FINE SHAM250ML ANZ IN CN ADO	PCE	7,732.00	9,000.00	1	-	Yes	Keep
90672777	FOCA CLAPROF PCOLCR 6_56 60G ANZ	PCE	2,980.00	4,800.00	1	-	Yes	Write-off
90723266	FOCA CF YELLOW GOLD 33 150G JP KR	PCE	950.00	3,500.00	1	-	Yes	Keep
90747505	LBWR WP RES STR SHAM250ML ANZ IN CN ADO	PCE	6,430.00	12,000.00	1	-	Yes	Keep
90759781	FOCA KLSTNP COLCRM 6_17 80G JP	PCE	3,220.00	6,000.00	1	-	Yes	Keep
90766802	FOCA WELLATN 2PLUS1 PCOLCM 7PB 60G JP	PCE	2.00	14,000.00	1	-	Yes	Write-off
90767570	SHPR NNE RTU PCOL DG 11 G 12EA AU NZ	PCE	26.00	500.00	1	-	Yes	Write-off
90769813	FOCA NNE PCOL 98 60ML AU NZ	PCE	8,190.00	16,000.00	1	-	Yes	Keep
90769880	FOCA NNE PCOL 112 60ML AU NZ	PCE	6,320.00	12,000.00	1	-	Yes	Write-off
90769971	FOCA NNE PCOL 115A 60ML AU NZ	PCE	1,580.00	16,000.00	1	-	Yes	Write-off
90769973	FOCA NNE PCOL 116A 60ML AU NZ	PCE	19,900.00	16,000.00	2	-	Yes	Keep
90770063	FOCA NNE PCOL 124 60ML AU NZ	PCE	6,730.00	12,600.00	1	-	Yes	Keep
90770064	FOCA NNE PCOL 131 60ML AU NZ	PCE	6,725.00	12,600.00	1	-	Yes	Write-off
90770065	FOCA NNE PCOL 132 60ML AU NZ	PCE	6,716.00	12,415.00	1	-	Yes	Keep
90789121	FOCA KLSTNP COLCRM 8_33 80G JP	PCE	480.00	6,074.00	1	-	Yes	Write-off
90798864	FOCA KLSTNP COLCRM 10_34 80G JP	PCE	2,200.00	6,300.00	1	-	Yes	Write-off
90799709	FOCA KLSTNP COLCRM 8_34 80G JP	PCE	4,648.00	6,287.00	1	-	Yes	Write-off
90799932	FOCA KLSTNP COLCRM 10_44 80G JP	PCE	16,170.00	12,095.00	2	-	Yes	Write-off
90823525	FOCA CF CHERRY RED 45 150G JP KR	PCE	1,700.00	3,500.00	1	-	Yes	Keep
90823548	FOCA CF BLUE SILVER 88 150G JP KR	PCE	1,300.00	3,500.00	1	-	Yes	Write-off
90823556	FOCA CF MATT BROWN 02 150G JP KR	PCE	950.00	3,500.00	1	-	Yes	Write-off
90823575	SHPR CF MATT BROWN 02 150G JP KR DG	PCE	34.00	100.00	1	-	Yes	Write-off
90823577	SHPR CF VIOLET 6 150G JP KR DG	PCE	21.00	100.00	1	-	Yes	Write-off
90824015	PACKER CF MATT BROWN 02 150G JP KR	PCE	739.00	1,000.00	1	-	Yes	Keep
90825103	PACKER CF VIOLET 6 150G JP KR	PCE	736.00	1,000.00	1	-	Yes	Keep
90827448	FOCA CLAPROF PCOLCR 0.43 60G ANZ	PCE	4,180.00	4,800.00	1	-	Yes	Keep
90827450	FOCA CLAPROF PCOLCR 10.1 60G ANZ	PCE	300.00	4,800.00	1	-	Yes	Write-off
90827730	FOCA CLAPROF PCOLCR 10.3 60G ANZ	PCE	4,230.00	4,800.00	1	-	Yes	Write-off
90828138	FOCA CLAPROF PCOLCR 7.03 60G ANZ	PCE	2,850.00	4,800.00	1	-	Yes	Keep

From the third step, there are 457 SKUs of raw materials with totally 649 pallets that are considered as obsolete materials due to no demand present in the next 12 months. The result after verified with planning team as presented in Table 12 is confirming that 283 SKUs with 368 pallets are already discontinued and can be removed from the raw materials warehouse. The remaining of 174 SKUs with 281 pallets are not discontinued and will have demand triggering in the future. For the short term, these 283 SKUs are moved to be stored at a tent location beside the raw materials warehouse before removing from the manufacturing plant for further destroying process by the third party. Thus, the available space in the raw materials warehouse is increased by 368 locations or 9.04% (368 out of 4,070 locations in raw materials warehouse) from clearing out obsolete materials from the raw materials warehouse.

Table 12. Decision from planning team to handle with zero demand materials

Decision	Current Inventory (in pallet)	#SKU
Keep	281	174
Write-off	368	283
Total	**649**	**457**

4.2. Regrouping materials into grouping level 1 (criteria: material types and sizes) and grouping level 2 (criteria: material types, sizes, and turnover rate)

The objective of grouping raw materials is to group raw materials that are appropriate to share locations together into the same group in order to save space within the raw materials warehouse.

Starting from material types, all materials in the raw materials warehouse should be divided into seven types, namely general raw materials, combustible raw materials, bulk materials, drive-in-rack materials (perm pack materials with huge volume and color pack materials with huge volume), perm pack materials, and color pack materials. The criteria used to divide materials into each type are usage area, specific requirement of materials, and specific characteristic of materials. For the first criteria which is usage area, there are three production areas that trigger raw materials from the raw materials warehouse which are making production, perm production, and color production. Each production area is connected to the raw materials warehouse with different entrances as shown in Figure 22. So, materials should be divided into three types according to usage areas.

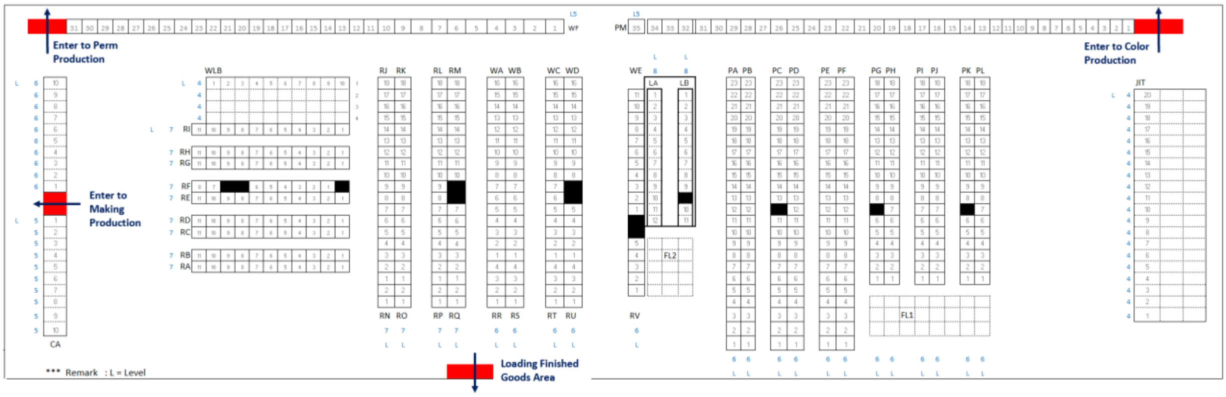


Figure 22. Location of entrances to each production area

For the second criteria which is the specific requirement of materials, materials used in making production are divided into two groups which are general raw materials and combustible raw materials. Combustible raw materials can be located only in rack location CA and CB as they have special safety requirement. Another group of materials that has the specific requirement is bulk materials. Bulk materials can be located only on the first floor as they have heavy weight. So, materials used in perm production are divided into perm pack materials and bulk materials.

The last criteria is the specific characteristic of materials. Some SKUs of perm pack materials and color pack materials have huge volume on both demand and supply. Hence, they are suitable to be located in drive-in-rack locations rather than single selective rack locations. Seven types of materials as grouped according to these three criteria are summarized in Table 13. Each material is assigned into one type of material.

Table 13. Criteria for grouping materials into seven types

Criteria 1: Usage Area	Criteria 2: Specific Requirement	Criteria 3: Specific Characteristic	Final Material Types
Making Production	General Raw Materials	N/A	General Raw Materials
	Combustible Raw Materials	N/A	Combustible Raw Materials
Perm Production	Perm Pack Materials	Normal Materials	Perm Pack Materials
		Huge Volume Materials	Perm Pack Materials with Huge Volume
	Bulk Materials	N/A	Bulk Materials
Color Production	N/A	Normal Materials	Color Pack Materials
		Huge Volume Materials	Color Pack Materials with Huge Volume

After classifying materials into each type, the second priority for grouping materials is material height. As received raw materials have various sizes, using only one size of storage rack can result in low utilization of warehouse. On the other hand, using too many sizes of storage rack can also result in low flexibility. Currently, there are four sizes of single selective rack using in the raw materials warehouse which are racking R1 for material height less than 65 cm, racking R3 for material height less than 120 cm, racking R4 for material height less than 140 cm, and racking R5 for material height less than 190 cm. From observing the actual height of raw materials, there is an opportunity to combine racking type R3 and R4. Thus, three sizes of single selective rack and one size of drive-in-rack are proposed to use in this raw materials warehouse as summarized in Table 14.

Table 14. Proposed rack types to use in raw materials warehouse

Rack Types	Height of Racks (cm)
Single selective rack: Low (R1)	65
Single selective rack: Medium (R2)	120
Single selective rack: High (R3)	190
Drive-in-rack (R4)	200

Each material is assigned into an appropriate rack height according to received pallet height. Table 15 is the summary of grouping level 1 categorized by material types and sizes. Each material is assigned into one group of materials under grouping level 1 as shown in Table 16.

Table 15. Criteria and final groups of materials under grouping level 1

Priority 1: Material Types	**Priority 2: Material Height**	**Grouping Level 1**
General Raw Materials	Medium (R2)	Group A (247 SKUs)
Combustible Raw materials	Medium (R2)	Group B (2 SKUs)
Bulk materials	Medium (R2)	Group C (36 SKUs)
Perm Pack Materials with huge volume	DIR (R4)	Group D (1 SKU)
Perm Pack Materials	High (R3)	Group E (131 SKUs)
	Medium (R2)	Group F (97 SKUs)
Color Pack Materials	High (R3)	Group G (134 SKUs)
	Medium (R2)	Group H (449 SKUs)
	Low (R1)	Group I (500 SKUs)
Color Pack Materials with huge volume	DIR (R4)	Group J (14 SKUs)

Table 16. Example of assigning each material into one group under grouping level 1

GCAS	Material Description	Unit	Material Types	Material Height	Grouping Level 1
13000087	TRIMETHYLSILOXYSILICATE - MQ RESIN	KG	General Raw Materials	Medium	Group A
13000103	Propylparaben NF	KG	General Raw Materials	Medium	Group A
13000104	Phenoxyethanol 98	KG	General Raw Materials	Medium	Group A
13000594	Sodium Cocoyl Isethionate	KG	General Raw Materials	Medium	Group A
13045076	CITRIC ACID, ANHYDROUS	KG	General Raw Materials	Medium	Group A
58019198	2-AMINO-5-ETHYLPHENOL HCL	G	General Raw Materials	Medium	Group A
58019205	ACID RED 52, AKA 106	G	General Raw Materials	Medium	Group A
58019207	PIGMENT RED 57, AKA 201	G	General Raw Materials	Medium	Group A
70485212	Hydroxypropyl Guar Hydroxypropyltrimoniu	KG	General Raw Materials	Medium	Group A
90509179	FOCA KLSTNP COLCRM 66_74 80G JP	PCE	Color pack materials	Low	Group I
90522297	SHPR WELLASTRATE 400ML 24EA JP	PCE	Perm pack materials	High	Group E
90522298	SHPR WELLASTRATE LIQ 2 400ML 24EA JP	PCE	Perm pack materials	High	Group E
90530475	BC231 B (1.99/1.64TB, GLYCACIL) COING OS	kg	Bulk materials	Medium	Group C
90530525	BC231 B (2.0/1.64TB, GLYCACIL) SKYE Q OS	kg	Bulk materials	Medium	Group C
90588532	FOCA KLSTNP COLCRM 8_47 80G JP	PCE	Color pack materials	Low	Group I
90588595	FOCA KLSTNP COLCRM 6_47 80G JP	PCE	Color pack materials	Low	Group I

The third priority in grouping materials is material turnover rate. Grouping materials according to material turnover rate can benefit in terms of picking distance reduction as materials with high turnover rate can be arranged to be located closer to the usage area and materials with lower turnover rate are arranged to be located further to the usage area. In this research, aggregate demand in the next 12 months in pallet unit by SKU is used to represent picking frequency of each SKU. In terms of implementation, materials in each group under grouping level 1 are ranked from highest picking frequency to lowest picking frequency. Then, the aggregate picking frequency is determined and converted to percentile. According to Pareto's method, SKUs that account for 80% of picking frequency are assigned to class A, SKUs that account for the next 15% of picking frequency are assigned to class B, and the rest of SKUs are assigned to class C. Table 17 presents example of method used to classify materials into class A, B, and C for color pack materials with low height.

Table 17. Example of method used to classify color pack materials with low height into class A, B, and C

GCAS	Material Description	Unit	Material Types	Material Height	Turnover Rate/ Picking frequency	Grouping Level 1	Aggregate Demand	%Aggregate Demand
99260007393	FOCA KOLESTON PERFECT + 80G JP 8/77	PCE	Color pack materials	Low	A	Group I	22	2%
99260006003	FOCA KOLEST PERF PLATINUM 99/81 JP	PCE	Color pack materials	Low	A	Group I	42	4%
99260005968	FOCA KOLESTON PERFECT J 8/11 R2 JP	PCE	Color pack materials	Low	A	Group I	60	5%
99260005958	FOCA KOLESTON PERFECT J 12/11 R2 JP	PCE	Color pack materials	Low	A	Group I	77	7%
99260007383	FOCA KOLESTON PERFECT + 80G JP 7/77	PCE	Color pack materials	Low	A	Group I	93	8%
99260007398	FOCA KOLESTON PERFECT + 80G JP 9/77	PCE	Color pack materials	Low	A	Group I	109	9%
99260005868	FOCA KOLESTON PERFECT J 8/7 R2 JP	PCE	Color pack materials	Low	A	Group I	120	10%
99260005999	FOCA KOLEST PERF CRM J 99/77 80G JP/KR	PCE	Color pack materials	Low	A	Group I	130	11%
99260006002	FOCA KOLEST PERF PLATINUM 88/81 JP	PCE	Color pack materials	Low	A	Group I	140	12%
99260005953	FOCA KOLESTON PERFECT J 10/2 R2 JP	PCE	Color pack materials	Low	A	Group I	149	13%
90844057	FOCA COLT CRM 4_0 60ML AU NZ	PCE	Color pack materials	Low	A	Group I	157	13%
90844071	FOCA COLT CRM 8_81 60ML AU NZ	PCE	Color pack materials	Low	A	Group I	165	14%
90844097	FOCA COLT CRM 10_6 60ML AU NZ	PCE	Color pack materials	Low	A	Group I	173	15%
99260005873	FOCA KP COLOR CONTROL PINK 6/45 JP	PCE	Color pack materials	Low	A	Group I	181	15%
99260005964	FOCA KOLESTON PERFECT J 6/6 R2 JP	PCE	Color pack materials	Low	A	Group I	189	16%
99260005973	FOCA KOLESTON PERFECT J 8/91 JP	PCE	Color pack materials	Low	A	Group I	197	17%
99260006001	FOCAKOLEST PERF PLATINUM 77/81 JP	PCE	Color pack materials	Low	A	Group I	205	17%
99260007361	FOCA KOLESTON PERFECT + 80G JP 4/0	PCE	Color pack materials	Low	A	Group I	213	18%
90844073	FOCA COLT CRM 7_89 60ML AU NZ	PCE	Color pack materials	Low	A	Group I	220	19%
90864764	FOCA KLSTNP PCOLCRM 7_77 60G AAI	PCE	Color pack materials	Low	A	Group I	227	19%
90970266	FOCA KLSTNP PCOLCRM 12_11 60G AAI	PCE	Color pack materials	Low	A	Group I	234	20%
99260005420	FOCA SOFTOUCH S6/04 60G	PCE	Color pack materials	Low	A	Group I	241	21%
99260005934	FOCA KOLESTON PERFECT J 6/2 R2	PCE	Color pack materials	Low	A	Group I	248	21%
99260005940	FOCA KOLESTON PERFECT J 3/6 R2	PCE	Color pack materials	Low	A	Group I	255	22%
99260005943	FOCA KOLESTON PERFECT J 6/45 R2	PCE	Color pack materials	Low	A	Group I	262	22%
99260007370	FOCA KOLESTON PERFECT + 80G JP 6/02	PCE	Color pack materials	Low	A	Group I	269	23%
99260007389	FOCA KOLESTON PERFECT + 80G JP 8/17	PCE	Color pack materials	Low	A	Group I	276	24%
99260007392	FOCA KOLESTON PERFECT + 80G JP 8/47	PCE	Color pack materials	Low	A	Group I	283	24%
90844058	FOCA COLT CRM 5_0 60ML AU NZ	PCE	Color pack materials	Low	A	Group I	289	25%
90844059	FOCA COLT CRM 6_0 60ML AU NZ	PCE	Color pack materials	Low	A	Group I	295	25%

As combustible raw materials, bulk materials, perm pack materials and color pack materials with huge volume have small number of SKUs, they are not sub-divided by material turnover rate.

With the combination of grouping according to material types, material heights, and material turnover rates, grouping level 2 is obtained as shown in Table 18. Each material is assigned into one group under grouping level 2 as presented in Table 19.

Table 18. Criteria and final groups of materials under grouping level 2

Priority 1: Material Types	Priority 2: Material Height	Priority 3: Material Turnover Rate	Grouping Level 2
General Raw Materials	Medium (R2)	Class A	Group 1 (62 SKUs)
		Class B	Group 2 (80 SKUs)
		Class C	Group 3 (105 SKUs)
Combustible Raw materials	Medium (R2)	N/A	Group 4 (2 SKUs)
Bulk materials	Medium (R2)	N/A	Group 5 (36 SKUs)
Perm Pack Materials with huge volume	DIR (R4)	N/A	Group 6 (1 SKU)
Perm Pack Materials	High (R3)	Class A	Group 7 (23 SKUs)
		Class B	Group 8 (35 SKUs)
		Class C	Group 9 (73 SKUs)
	Medium (R2)	Class A	Group 10 (20 SKUs)
		Class B	Group 11 (31 SKUs)
		Class C	Group 12 (46 SKUs)
Color Pack Materials	High (R3)	Class A	Group 13 (38 SKUs)
		Class B	Group 14 (36 SKUs)
		Class C	Group 15 (60 SKUs)
	Medium (R2)	Class A	Group 16 (98 SKUs)
		Class B	Group 17 (154 SKUs)
		Class C	Group 18 (197 SKUs)
	Low (R1)	Class A	Group 19 (227 SKUs)
		Class B	Group 20 (142 SKUs)
		Class C	Group 21 (131 SKUs)
Color Pack Materials with huge volume	DIR (R4)	N/A	Group 22 (14 SKUs)

Table 19. Example of assigning each material into one group under grouping level 2

GCAS	Material Description	Unit	Material Types	Material Height	Turnover Rate/ Picking frequency	Grouping Level 2
13000087	TRIMETHYLSILOXYSILICATE - MQ RESIN	KG	General Raw Materials	Medium	C	Group 3
13000103	Propylparaben NF	KG	General Raw Materials	Medium	C	Group 3
13000104	Phenoxyethanol 98	KG	General Raw Materials	Medium	B	Group 2
13000594	Sodium Cocoyl Isethionate	KG	General Raw Materials	Medium	A	Group 1
13045076	CITRIC ACID, ANHYDROUS	KG	General Raw Materials	Medium	C	Group 3
58019198	2-AMINO-5-ETHYLPHENOL HCL	G	General Raw Materials	Medium	C	Group 3
58019205	ACID RED 52, AKA 106	G	General Raw Materials	Medium	C	Group 3
58019207	PIGMENT RED 57, AKA 201	G	General Raw Materials	Medium	C	Group 3
70485212	Hydroxypropyl Guar Hydroxypropyltrimoniu	KG	General Raw Materials	Medium	C	Group 3
90509179	FOCA KLSTNP COLCRM 66_74 80G JP	PCE	Color pack materials	Low	B	Group 20
90522297	SHPR WELLASTRATE 400ML 24EA JP	PCE	Perm pack materials	High	C	Group 9
90522298	SHPR WELLASTRATE LIQ 2 400ML 24EA JP	PCE	Perm pack materials	High	C	Group 9
90530475	BC231 B (1.99/1.64TB, GLYCACIL) COING OS	kg	Bulk materials	Medium		Group 5
90530525	BC231 B (2.0/1.64TB, GLYCACIL) SKYE Q OS	kg	Bulk materials	Medium		Group 5
90588532	FOCA KLSTNP COLCRM 8_47 80G JP	PCE	Color pack materials	Low	C	Group 21
90588595	FOCA KLSTNP COLCRM 6_47 80G JP	PCE	Color pack materials	Low	C	Group 21

In part 4.7, grouping level 1 and grouping level 2 are compared in terms of space required and picking distance reduction. The grouping that results in lower space required and shorter picking distance will be selected for implementation in the raw materials warehouse.

4.3. Reallocating space for each group of materials

In this part, space is allocated for each group of materials under grouping level 1 and grouping level 2. In the first step, month-end inventory by SKU from January to December 2019 is extracted from the SAP system. Data downloaded from the SAP system are reported in the original unit of each material which is gram, kilogram, or piece units as shown in Table 20.

Table 20. Example of month-end inventory by SKU in gram, kilogram, or piece unit

GCAS	Material Description	Unit	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
1057261	SODIUM SULFITE	G	70,484.00	78,544.00	77,324.00	45,164.00	88,344.91	74,364.91	74,924.91	61,544.91	63,124.91	53,944.91	44,244.91	41,604.91
1057262	P-PHENYLENEDIAMINE	G	474,384.28	596,725.12	529,329.16	578,471.96	505,595.36	451,161.20	381,472.76	361,785.76	359,960.16	364,510.88	367,678.12	365,451.84
1057449	PROPYLENE GLYCOL	KG	1,048.44	563.78	901.12	513.46	424.70	751.04	779.72	706.40	430.08	318.42	486.76	283.44
1057453	ISOPROPYL ALCOHOL	KG	285.76	195.76	231.76	231.76	231.76	231.76	213.76	177.76	303.76	321.76	303.76	285.76
1057475	Phosphoric Acid, 85% in water	KG	393.72	346.25	277.30	220.30	159.80	114.83	105.88	41.63	70.10	88.60	47.10	93.85
1057573	MEA COSMETIC GRADE (300 PPM DEA)	KG	385.35	391.23	20.09	90.73	45.31	30.79	59.55	78.75	31.98	26.26	12.91	48.38
1057622	BEESWAX	KG	179.60	136.60	112.10	59.10	107.10	162.10	98.60	79.10	104.10	77.10	83.10	108.10
1057640	ERYTHORBIC ACID	G	32,738.00	37,578.00	23,698.00	36,258.00	31,538.00	16,218.00	42,258.00	19,738.00	30,858.00	22,738.00	18,938.00	27,178.00
1057762	OLEYL ALCOHOL	KG	579.75	564.75	527.25	497.25	459.75	444.75	392.25	354.75	339.75	302.25	287.25	249.75
1057818	TALL OIL ACID	KG	372.58	268.90	250.06	239.86	137.86	111.28	226.24	161.14	142.84	154.06	188.14	154.90
1057983	OLETH-5	KG	2,158.34	1,916.66	1,599.98	1,308.30	608.26	1,126.58	568.22	819.86	386.50	829.82	588.14	839.78
1074381	SODIUM PCA (L-Form), 50% in water	KG	10.89	8.89	6.89	3.89	24.89	22.89	22.89	18.89	16.89	16.89	12.89	10.89
1074511	ACRYLATES STEARETH-20 METHACRYLATE	KG	959.00	1,063.50	849.75	678.75	1,105.00	974.50	585.25	876.50	746.00	487.25	996.75	693.00
1074707	PEG-12 Dimethicone	KG	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.41	0.41	0.41	0.41
1074873	SODIUM SULFATE, anhydrous	KG	215.10	207.70	163.20	68.20	171.98	145.68	163.88	147.73	105.08	71.88	95.78	73.13
1074956	OLETH-2	KG	785.76	1,334.92	1,051.58	805.74	330.72	879.88	425.70	766.52	499.84	216.50	765.66	386.48
1075072	Dicetyldimonium Chloride in Propylene Gl	KG	1,000.00	877.85	877.85	864.99	826.42	800.70	787.85	749.27	682.84	629.27	616.41	562.83
1075084	POLYQUATERNIUM-22	KG	2.20	13.00	5.30	3.40	3.40	9.20	8.00	0.50	11.90	3.40	13.00	3.60
1075094	ACRYLATES COPOLYMER, 28% in water	KG	4,327.58	4,590.98	3,412.73	3,290.33	2,938.88	3,269.98	3,373.23	3,700.58	3,189.38	3,705.33	3,051.03	3,476.08
1075169	Simethicone Emulsion	KG	21.43	20.63	17.38	16.78	16.03	12.73	11.18	7.93	7.63	3.88	3.58	20.33
1075272	C12-15 PARETH-3	KG	81.25	49.31	205.37	173.43	77.61	45.67	169.79	105.91	42.03	10.09	166.15	102.27
1075297	STEARETH-21	KG	757.68	657.68	407.68	207.68	557.68	457.68	707.68	457.68	357.68	107.68	607.68	357.68
1075314	SOYTRIMONIUM CHLORIDE, 60%	KG	2,040.80	1,574.34	3,938.28	3,471.82	2,072.44	1,605.98	3,503.46	2,570.54	1,637.62	1,171.16	3,535.10	2,602.18
1075378	C11-15 PARETH-9	KG	259.39	195.49	131.59	67.69	80.11	220.33	92.53	168.85	41.05	181.27	117.37	193.69
1075468	NIACIN	KG	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.40	15.20
1120455	Aloe Barbadensis Leaf Juice	KG	-	19.10	19.10	19.10	19.10	19.10	18.95	18.80	18.35	18.05	17.90	17.60
1128541	PHENYL METHYL PYRAZOLONE	G	129,320.60	124,748.60	115,226.60	131,498.20	119,067.80	134,501.40	123,078.60	112,241.40	127,843.00	119,794.60	112,628.60	127,842.20
1138061	PEG-50 Hydrogenated Palmamide	KG	1,380.00	1,330.00	1,205.00	1,105.00	980.00	930.00	755.00	630.00	580.00	455.00	405.00	280.00
10045059	POLYQUATERNIUM-4	KG	-	-	45.36	45.36	45.36	45.36	45.36	45.36	44.76	44.76	44.76	44.76

In the second step, month-end inventory by SKU in the first step has to be converted from their original unit to pallet unit using unit conversion from material master data as collected from chapter 3. All decimal points from the conversion are rounded up to integer number. The results from this step are shown in Table 21.

Table 21. Example of month-end inventory by SKU in pallet unit

GCAS	Material Description	Unit	PCE/Pallet	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
1057261	SODIUM SULFITE	G	225000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1057262	P-PHENYLENEDIAMINE	G	75000	7.00	8.00	8.00	8.00	7.00	7.00	6.00	5.00	5.00	5.00	5.00	5.00
1057449	PROPYLENE GLYCOL	KG	860	2.00	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1057453	ISOPROPYL ALCOHOL	KG	648	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1057475	Phosphoric Acid, 85% in water	KG	100	4.00	4.00	3.00	3.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.00
1057573	MEA COSMETIC GRADE (300 PPM DEA)	KG	190	3.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1057622	BEESWAX	KG	200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1057640	ERYTHORBIC ACID	G	100000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1057762	OLEYL ALCOHOL	KG	170	4.00	4.00	4.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00
1057818	TALL OIL ACID	KG	372	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1057983	OLETH-5	KG	760	3.00	3.00	3.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00
1074381	SODIUM PCA (L-Form), 50% in water	KG	200	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1074511	ACRYLATES STEARETH-20 METHACRYLAT	KG	640	2.00	2.00	2.00	2.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00
1074707	PEG-12 Dimethicone	KG	45	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1074873	SODIUM SULFATE, anhydrous	KG	600	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1074956	OLETH-2	KG	720	2.00	2.00	2.00	2.00	1.00	2.00	1.00	2.00	1.00	1.00	2.00	1.00
1075072	Dicetyldimonium Chloride in Propylene Gl	KG	1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1075084	POLYQUATERNIUM-22	KG	60	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1075094	ACRYLATES COPOLYMER, 28% in water	KG	860	6.00	6.00	4.00	4.00	4.00	4.00	4.00	5.00	4.00	5.00	4.00	5.00
1075169	Simethicone Emulsion	KG	18	2.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
1075272	C12-15 PARETH-3	KG	186	1.00	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1075297	STEARETH-21	KG	600	2.00	2.00	1.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00	2.00	1.00
1075314	SOYTRIMONIUM CHLORIDE, 60%	KG	800	3.00	2.00	5.00	5.00	3.00	3.00	5.00	4.00	3.00	2.00	5.00	4.00
1075378	C11-15 PARETH-9	KG	500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1075468	NIACIN	KG	160	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1120455	Aloe Barbadensis Leaf Juice	KG	20	-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1128541	PHENYL METHYL PYRAZOLONE	G	25000	6.00	5.00	5.00	6.00	5.00	6.00	5.00	5.00	6.00	5.00	5.00	6.00
1138061	PEG-50 Hydrogenated Palmamide	KG	200	7.00	7.00	7.00	6.00	5.00	5.00	4.00	4.00	3.00	3.00	3.00	2.00
10045059	POLYQUATERNIUM-4	KG	230	-	-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

In the third step, the summation of month-end inventory for each group under grouping level 1 and grouping level 2 is calculated and presented in Table 22 and Table 23.

Table 22. Month-end inventory of each material group under grouping level 1

CASE I: Grouping Level 1

Groups	Material Groups	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Max Inventory
Group A	General Raw Materials	508	552	626	636	613	592	592	596	572	573	601	533	636
Group B	Combustible Raw Materials	2	2	2	2	2	2	2	2	2	2	2	2	2
Group C	Bulk	130	130	130	130	130	130	126	123	122	124	124	122	130
Group D	Perm Pack Material with Huge Volume	121	202	12	118	175	33	67	110	162	225	44	124	225
Group E	Perm High	560	548	603	714	676	675	634	549	597	554	573	555	714
Group F	Perm Medium	306	308	274	268	248	256	260	247	239	225	232	227	308
Group G	Color High	285	307	359	305	298	276	251	272	239	302	298	284	359
Group H	Color Medium	703	728	701	680	722	632	666	648	672	652	672	646	728
Group I	Color Low	562	567	558	551	549	552	547	562	516	532	520	526	567
Group J	Color Pack Material with Huge Volume	180	262	183	250	198	170	312	274	204	247	222	207	312
	Total	**3357**	**3606**	**3448**	**3654**	**3611**	**3318**	**3457**	**3383**	**3325**	**3436**	**3288**	**3226**	**3654**

Table 23. Month-end inventory of each material group under grouping level 2

CASE II: Grouping Level 2														
Groups	**Material Groups**	**Jan-19**	**Feb-19**	**Mar-19**	**Apr-19**	**May-19**	**Jun-19**	**Jul-19**	**Aug-19**	**Sep-19**	**Oct-19**	**Nov-19**	**Dec-19**	**Max Inventory**
Group 1	General raw materials (A)	249	268	312	297	286	264	280	286	260	273	293	225	312
Group 2	General raw materials (B)	154	164	192	208	195	194	179	175	180	169	176	175	208
Group 3	General raw materials (D)	105	120	122	131	132	134	133	135	132	131	132	133	135
Group 4	Combustible raw materials	2	2	2	2	2	2	2	2	2	2	2	2	2
Group 5	Bulk	130	130	130	130	130	130	126	123	122	124	124	122	130
Group 6	Perm Pack Material with Huge Volume	121	202	12	118	175	33	67	110	162	225	44	124	225
Group 7	Perm High (A)	121	111	178	275	261	268	236	163	204	168	186	182	275
Group 8	Perm High (B)	210	204	198	210	191	181	178	166	171	164	168	155	210
Group 9	Perm High (C)	229	233	227	229	224	226	220	220	222	222	219	218	233
Group 10	Perm Medium (A)	151	145	108	102	84	96	101	91	89	74	81	74	151
Group 11	Perm Medium (B)	82	89	94	95	93	90	89	83	75	76	75	77	95
Group 12	Perm Medium (C)	73	74	72	71	71	70	70	73	75	75	76	76	76
Group 13	Color High (A)	132	150	201	154	156	144	122	136	113	175	175	155	201
Group 14	Color High (B)	65	69	72	67	58	49	48	53	48	50	48	53	72
Group 15	Color High (C)	88	88	86	84	84	83	81	83	78	77	75	76	88
Group 16	Color Medium (A)	294	305	286	264	302	215	250	239	259	229	258	234	305
Group 17	Color Medium (B)	174	182	177	177	180	174	173	168	170	178	171	169	182
Group 18	Color Medium (C)	235	241	238	239	240	243	243	241	243	245	243	243	245
Group 19	Color Low (A)	274	272	261	261	259	262	257	272	234	247	237	244	274
Group 20	Color Low (B)	148	150	152	148	148	148	148	148	144	147	146	145	152
Group 21	Color Low (C)	140	145	145	142	142	142	142	142	138	138	137	137	145
Group 22	Color Pack Material with Huge Volume	180	262	183	250	198	170	312	274	204	247	222	207	312
	Total	**3357**	**3606**	**3448**	**3654**	**3611**	**3318**	**3457**	**3383**	**3325**	**3436**	**3288**	**3226**	**3654**

Space allocated for each group of materials should be allocated based on maximum month-end inventory in order to avoid overflow of materials from assigned locations to other locations. For perm pack materials and color pack materials with huge volume, the number of assigned space is fixed with number locations of drive-in-rack which are 160 locations for perm pack materials and 240 locations for color pack material. In case that actual inventory of materials in these groups are higher than assigned locations, they can share locations with perm high and color high groups. For other groups of materials, space allocated will be equal to the maximum month-end inventory of those groups. The final space allocated for each group under grouping level 1 and grouping level 2 is demonstrated in Table 24 and Table 25, respectively.

Table 24. Space allocated for each group of materials under grouping level 1

Groups	Material Groups	Allocated Space
Group A	General Raw Materials	636
Group B	Combustible Raw Materials	2
Group C	Bulk	130
Group D	Perm Pack Material with Huge Volume	160
Group E	Perm High	714
Group F	Perm Medium	308
Group G	Color High	359
Group H	Color Medium	728
Group I	Color Low	567
Group J	Color Pack Material with Huge Volume	240
	Total	**3844**

Table 25. Space allocated for each group of materials under grouping level 2

Groups	Material Groups	Allocated Space
Group 1	General raw materials (A)	312
Group 2	General raw materials (B)	208
Group 3	General raw materials (D)	135
Group 4	Combustible raw materials	2
Group 5	Bulk	130
Group 6	Perm Pack Material with Huge Volume	160
Group 7	Perm High (A)	275
Group 8	Perm High (B)	210
Group 9	Perm High (C)	233
Group 10	Perm Medium (A)	151
Group 11	Perm Medium (B)	95
Group 12	Perm Medium (C)	76
Group 13	Color High (A)	201
Group 14	Color High (B)	72
Group 15	Color High (C)	88
Group 16	Color Medium (A)	305
Group 17	Color Medium (B)	182
Group 18	Color Medium (C)	245
Group 19	Color Low (A)	274
Group 20	Color Low (B)	152
Group 21	Color Low (C)	145
Group 22	Color Pack Material with Huge Volume	240
	Total	**3891**

4.4. Considering beam height adjustment to match the actual size of materials

Based on space allocation for each group of materials in part 4.3, the number of locations required for each type of racks is summarized in Table 26.

Table 26. Current rack available and number of locations required for each type of racks

Rack Types	Current Racks Available (#Location)	Required #Locations	
		Grouping Level 1	Grouping Level 2
Low Rack (R1)	522	567	571
Medium Rack (R3, R4)	1,863	1,804	1,841
High Rack (R5)	1,285	1,073	1,079
Drive-in-rack (DIR)	400	400	400
Total	**4,070**	**3,844**	**3,891**

The data present that required locations for low rack are greater than the current racks available in the raw material warehouse for both grouping level 1 and grouping level 2. On the other hand, the availability of medium rack and high rack locations are more than the requirement. Thus, beam height adjustment is required to match the actual size of raw materials in the raw materials warehouse. For the strategy, excess high racks are converted to low racks as required and the rest of high racks are converted to medium racks as it is the suitable rack size for storing finished products. In addition, locations for each type of racks are considered to be rearranged in this research in order to enhance the efficiency during the picking process.

Figure 23 presents the current layout and number of locations for each rack type in the raw materials warehouse. Two alphabets in the first column represent the name of each racking row. L1 to L8 represents level 1 to level 8. R1, R3, R4, R5, and DIR represent types of racking in each row and each level. Number in each excel represents the number of columns in each row and each level. For the drawbacks of the current layout, certain types of racks are located in only one area and absent in another area resulting in higher picking distance required. For example, medium racks type R3 are located closer to making and perm production while materials used for color production also require to be stored on medium racks. In this case, materials used for color production have to be located farther from the color production area resulting in higher picking distance required.

Location	Rack Types									Number of BINs								
	L0	L1	L2	L3	L4	L5	L6	L7	L8	L0	L1	L2	L3	L4	L5	L6	L7	L8
CA		R3	R3	R3	R3	R3					10	10	10	10	10			
CB		R3	R3	R3	R3	R3	R5				10	10	10	10	10	10		
WLB		DIR	DIR	DIR	DIR						40	40	40	40				
JIT		DIR	DIR	DIR	DIR						60	60	60	60				
RA		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RB		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RC		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RD		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RE		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RF		R3	R3	R3	R3	R3	R3	R5			8	8	8	8	8	8	8	
RG		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RH		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RI		R3	R3	R3	R3	R3	R3	R5			11	11	11	11	11	11	11	
RJ	R1	R1	R3	R3	R3	R3	R3	R5		18	18	18	18	18	18	18	18	
RK		R3	R3	R3	R3	R3	R3	R5			18	18	18	18	18	18	18	
RL		R3	R3	R3	R3	R3	R3	R5			18	18	18	18	18	18	18	
RM		R3	R3	R3	R3	R3	R3	R5			16	16	16	16	16	16	16	
WA		R4	R4	R4	R4	R4	R5				16	16	16	16	16	16		
WB		R4	R4	R4	R4	R4	R5				16	16	16	16	16	16		
WC		R4	R4	R4	R4	R4	R5				16	16	16	16	16	16		
WD		R4	R4	R4	R4	R4	R5				14	14	14	14	14	14		
WE		R4	R4	R4	R4	R4	R5				11	11	11	11	11	11		
WF		R4	R4	R4	R4	R4					24	28	31	31	31			
PA		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PB		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PC		R1	R1	R5	R5	R5	R5				22	22	22	22	22	22		
PD		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PE		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PF		R1	R1	R5	R5	R5	R5				23	23	23	23	23	23		
PG		R1	R1	R5	R5	R5	R5				17	17	17	17	17	17		
PH		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PI		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PJ		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PK		R1	R1	R5	R5	R5	R5				17	17	17	17	17	17		
PL		R1	R1	R5	R5	R5	R5				18	18	18	18	18	18		
PM		R4	R4	R4	R4	R5					24	28	35	35	35			
RN		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RO		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RP		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RQ		R3	R3	R3	R3	R3	R3	R5			2	2	2	2	2	2	2	
RR		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RS		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RT		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RU		R4	R4	R4	R4	R4	R5				4	4	4	4	4	4		
RV		R4	R4	R4	R4	R4	R5				5	5	5	5	5	5		

Figure 23. Current layout and number of locations for each rack type

Figure 24 presents proposed new allocation of each rack type in the raw materials warehouse under the requirements that locations and number of each rack type should be balanced with the required space and usage area of each material group.

Location	Rack Types								Number of BINs							
	L1	L2	L3	L4	L5	L6	L7	L8	L1	L2	L3	L4	L5	L6	L7	L8
CA	R2	R2	R2	R2	R2				10	10	10	10	10			
CB	R2	R2	R2	R2	R2	R3			10	10	10	10	10	10		
WLB	R4	R4	R4	R4					40	40	40	40				
JIT	R4	R4	R4	R4					60	60	60	60				
RA	R2	R2	R2	R2	R2	R2	R3		11	11	11	11	11	11	11	
RB	R2	R2	R2	R2	R2	R2	R3		11	11	11	11	11	11	11	
RC	R2	R2	R2	R2	R2	R2	R3		11	11	11	11	11	11	11	
RD	R2	R2	R2	R2	R2	R2	R3		11	11	11	11	11	11	11	
RE	R2	R2	R2	R2	R2	R2	R3		11	11	11	11	11	11	11	
RF	R2	R2	R2	R2	R2	R2	R3		8	8	8	8	8	8	8	
RG	R2	R2	R2	R2	R2	R2	R3		11	11	11	11	11	11	11	
RH	R2	R2	R2	R2	R2	R2	R3		11	11	11	11	11	11	11	
RI	R2	R2	R2	R2	R2	R2	R3		11	11	11	11	11	11	11	
RJ	R2	R2	R2	R3	R3	R3			18	18	18	18	18	18		
RK	R2	R2	R2	R3	R3	R3			18	18	18	18	18	18		
RL	R2	R2	R2	R3	R3	R3			18	18	18	18	18	18		
RM	R2	R2	R2	R3	R3	R3			16	16	16	16	16	16		
WA	R2	R2	R2	R3	R3	R3			16	16	16	16	16	16		
WB	R2	R2	R2	R3	R3	R3			16	16	16	16	16	16		
WC	R2	R2	R2	R3	R3	R3			16	16	16	16	16	16		
WD	R2	R2	R2	R3	R3	R3			14	14	14	14	14	14		
WE	R2	R2	R2	R3	R3	R3			11	11	11	11	11	11		
WF	R2	R2	R2	R2	R2				24	28	31	31	31			
PA	R2	R2	R2	R2	R2	R2	R3		23	23	23	23	23	23	23	
PB	R2	R2	R2	R2	R2	R2	R3		23	23	23	23	23	23	23	
PC	R1	R1	R1	R2	R2	R3	R3		22	22	22	22	22	22	22	
PD	R1	R1	R1	R2	R2	R3	R3		23	23	23	23	23	23	23	
PE	R1	R1	R1	R2	R2	R3	R3		23	23	23	23	23	23	23	
PF	R1	R1	R1	R2	R2	R3	R3		23	23	23	23	23	23	23	
PG	R1	R1	R1	R2	R2	R3	R3		17	17	17	17	17	17	17	
PH	R1	R1	R1	R2	R2	R3	R3		18	18	18	18	18	18	18	
PI	R1	R1	R1	R2	R2	R3	R3		18	18	18	18	18	18	18	
PJ	R1	R1	R1	R2	R2	R3	R3		18	18	18	18	18	18	18	
PK	R1	R1	R1	R2	R2	R3	R3		17	17	17	17	17	17	17	
PL	R1	R1	R2	R2	R2	R3	R3		18	18	18	18	18	18	18	
PM	R2	R2	R2	R2	R3				24	28	35	35	35			
RN	R2	R2	R2	R3	R3	R3			2	2	2	2	2	2		
RO	R2	R2	R2	R3	R3	R3			2	2	2	2	2	2		
RP	R2	R2	R2	R3	R3	R3			2	2	2	2	2	2		
RQ	R2	R2	R2	R3	R3	R3			2	2	2	2	2	2		
RR	R2	R2	R2	R3	R3	R3			4	4	4	4	4	4		
RS	R2	R2	R2	R3	R3	R3			4	4	4	4	4	4		
RT	R2	R2	R2	R3	R3	R3			4	4	4	4	4	4		
RU	R2	R2	R2	R3	R3	R3			4	4	4	4	4	4		
RV	R2	R2	R2	R3	R3	R3			5	5	5	5	5	5		

Figure 24. New allocation of each rack type in raw materials warehouse

For the logic behind this new allocation, all possible patterns of racks in each row are considered as shown in Table 27. The key constraint for each pattern is the total height of racks that cannot exceed the ceiling height of the raw materials warehouse. At the same time, each rack pattern is designed to maximize the utilization of the raw materials warehouse.

Table 27. Possible patterns of racks in raw materials warehouse

Rack Pattern	Levels						
	L1	L2	L3	L4	L5	L6	L7
1	R1	R1	R2	R2	R2	R3	R3
2	R1	R1	R3	R3	R3	R3	
3	R1	R1	R1	R2	R3	R3	R3
4	R1	R1	R1	R2	R2	R3	R3
5	R2	R2	R2	R3	R3	R3	
6	R2	R2	R2	R2	R3	R3	
7	R2	R2	R2	R2	R2	R2	R3
8	R2	R2	R2	R2	R2		
9	R2	R2	R2	R2	R3		
10	R2	R2	R2	R2	R2	R3	

Then, the number of locations required for each rack type in each usage area are identified as demonstrated in Table 28. Suitable rack patterns are assigned into each area based on the required rack types in each usage area and average picking frequency per location.

Table 28. Number of locations required for each rack type in each usage area

Usage Area	Rack Types	Space Required (#Locations)	Average Picking Frequency Per Location
Making Production	R2	657	5.0
Perm Production	R2	452	2.7
	R3	718	2.9
	R4	160	14.2
Color Production	R1	571	2.1
	R2	732	5.3
	R3	361	5.5
	R4	240	14.5
Total		**3,891**	

As materials used in the making production require to be stored only on the medium rack (rack type R2), racking rows that are closer to the making production

(RA, RB, RC, RD, RE, RF, RG, RH, RI) are appropriate to be assigned rack pattern #7. Racking rows CA and CB also close to the making production but ceiling heights in that areas are lower than other areas. Hence, rack patterns #8 and #9 are applied with racking CA and CB, respectively. After locations of medium racks are enough for materials used in the making production, rack locations required for materials used in the perm production are considered in the next step. From Table 28, materials used in the perm production require a large number of high racks (rack type R3) and the moderate number of medium racks. So, an appropriate rack pattern for locations closer to perm production is rack pattern #5. Rows of racks that are assigned to use rack pattern #5 include rows RJ, RK, RL, RM, WA, WB, WC, WD, WE, RN, RO, RP, RQ, RR, RS, RT, RU, and RV. Racking rows WF and PM are located in lower ceiling areas of the raw materials warehouse and they are fitted with rack patterns #8 and #9, consecutively. For the last areas which are the areas closer to the color production area, rack patterns that match with materials used in the color production are rack patterns #1 and #4 as materials used in the color production require low rack (rack type R1), medium rack (rack type R2), and high rack (rack type R3). Thus, racking rows PC, PD, PE, PF, PG, PH, PI, PJ, and PK are assigned to be applied rack pattern #4 and racking row PL is assigned to be used rack pattern #1 as the required number of low racks is already fulfill the requirement. Lastly, racking rows PA and PB are assigned to be used rack pattern #7 due to the popularity of medium racks that can be used to store finished products.

For the new allocation of each rack type in the raw materials warehouse, only four types of racks are used which are single selective rack type R1 with height 65 cm, single selective rack type R2 with height 120 cm, single selective rack type R3 with height 190 cm, and drive-in-rack type R4 with height 200 cm. The advantages of this new allocation are not only balancing the rack allocation with the material requirement but also enhancing the capacity within the raw materials warehouse by 3.6% as summarized in Table 29.

Table 29. The comparison of rack available in raw materials warehouse before and after improvement

Before			After			%Capacity Improvement
Rack Types	Rack Height (cm)	Number of Locations	Rack Types	Rack Height (cm)	Number of Locations	
R1	65	522	R1	65	573	
R3	120	1,126	R2	120	2,147	
R4	140	737	R3	190	1,097	
R5	190	1,285	R4	200	400	
DIR	200	400				
Total		**4,070**	**Total**		**4,217**	**3.6%**

After updated rack allocation in the raw materials warehouse, the availabilities of each rack type match the rack requirement for both grouping level 1 and grouping level 2 as shown in Table 30. It is noticeable that the excess locations are allocated to medium rack size as it is the suitable size for storing finished products.

Table 30. New rack available and number of locations required for each type of racks

Rack Types	New Racks Available (#Location)	Required #Locations	
		Grouping Level 1	Grouping Level 2
Low Rack (R1)	573	567	571
Medium Rack (R2)	2,147	1,804	1,841
High Rack (R3)	1,097	1,073	1,079
Drive-in-rack (R4)	400	400	400
Total	**4,217**	**3,844**	**3,891**

4.5. Reassigning location for each group of materials

In this part, each group of materials is assigned to certain locations in the raw materials warehouse using the optimization model. The objective function of the optimization model is to minimize the total picking distance and the decision variable is whether to locate or not to locate each material in each location. Parameters required for constructing the optimization model are travel distance from each location to each usage area and the average picking frequency per location of each material group. Two main constraints are input in the model. First, each location can be used to store one material at most. Second, each material has to be assigned to be stored in only one location.

In the first step, travel distances from each location to each usage area have to be collected and visualized using heat mapping diagram. As there are three usage areas which are making production, perm production, and color production, three heat mapping diagrams are created as shown in Figure 25 to Figure 27. Green color, yellow color, and red color represent the shortest distance, the medium distance, and the longest distance from each location to the usage area, respectively.

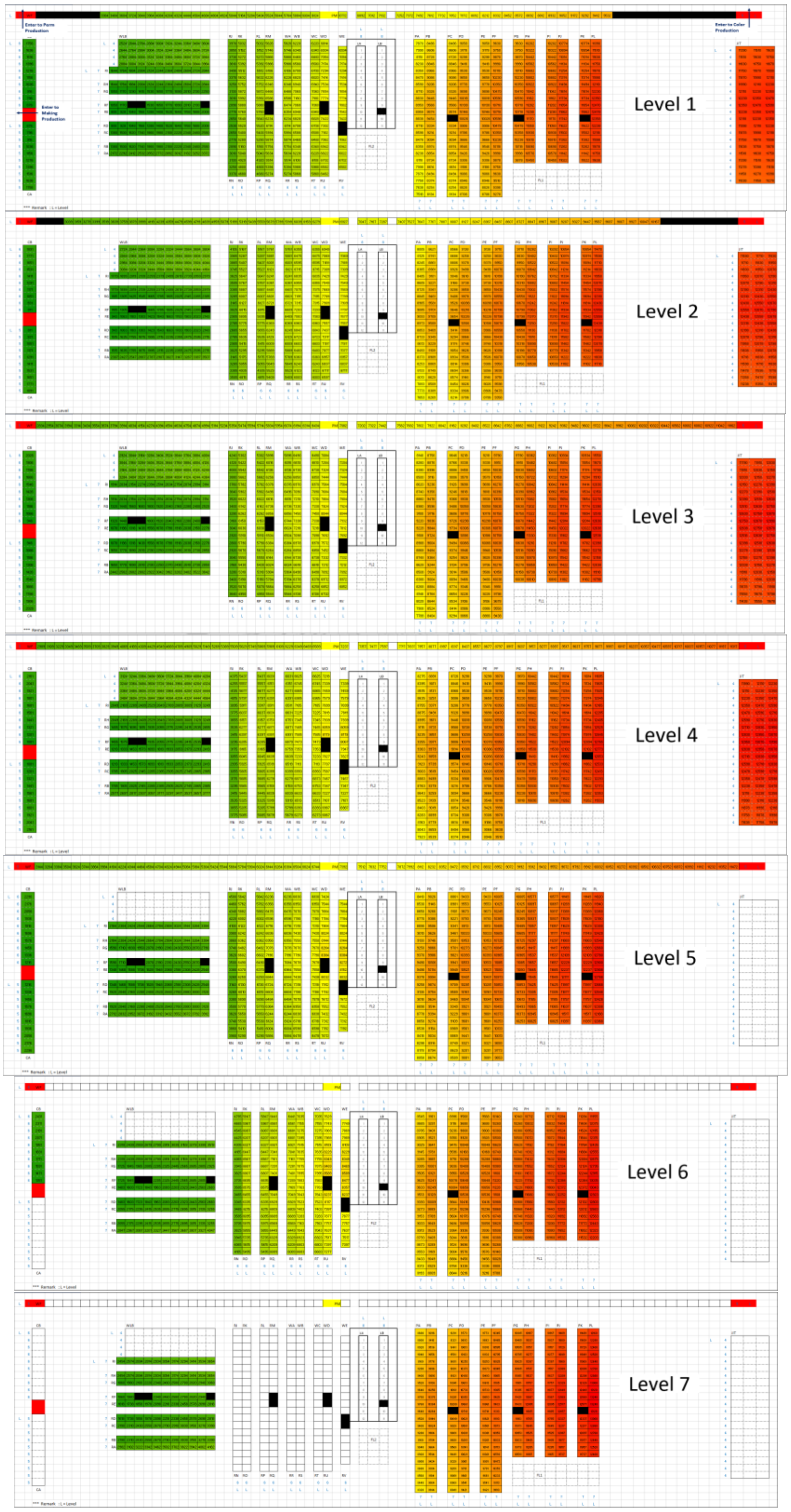


Figure 25. Heat mapping diagram to represent travel distance from each storage location to making production

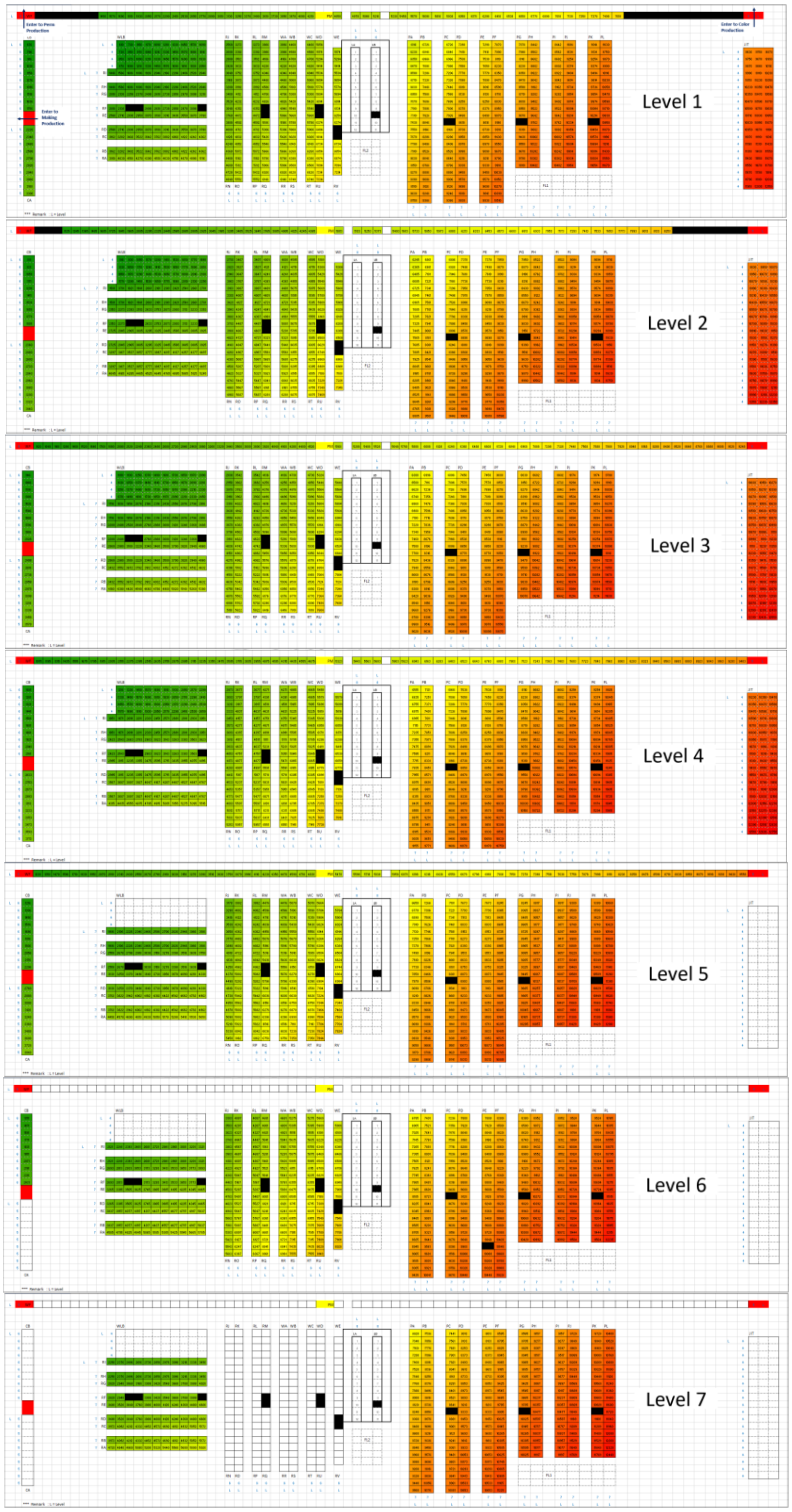


Figure 26. Heat mapping diagram to represent travel distance from each storage location to perm production

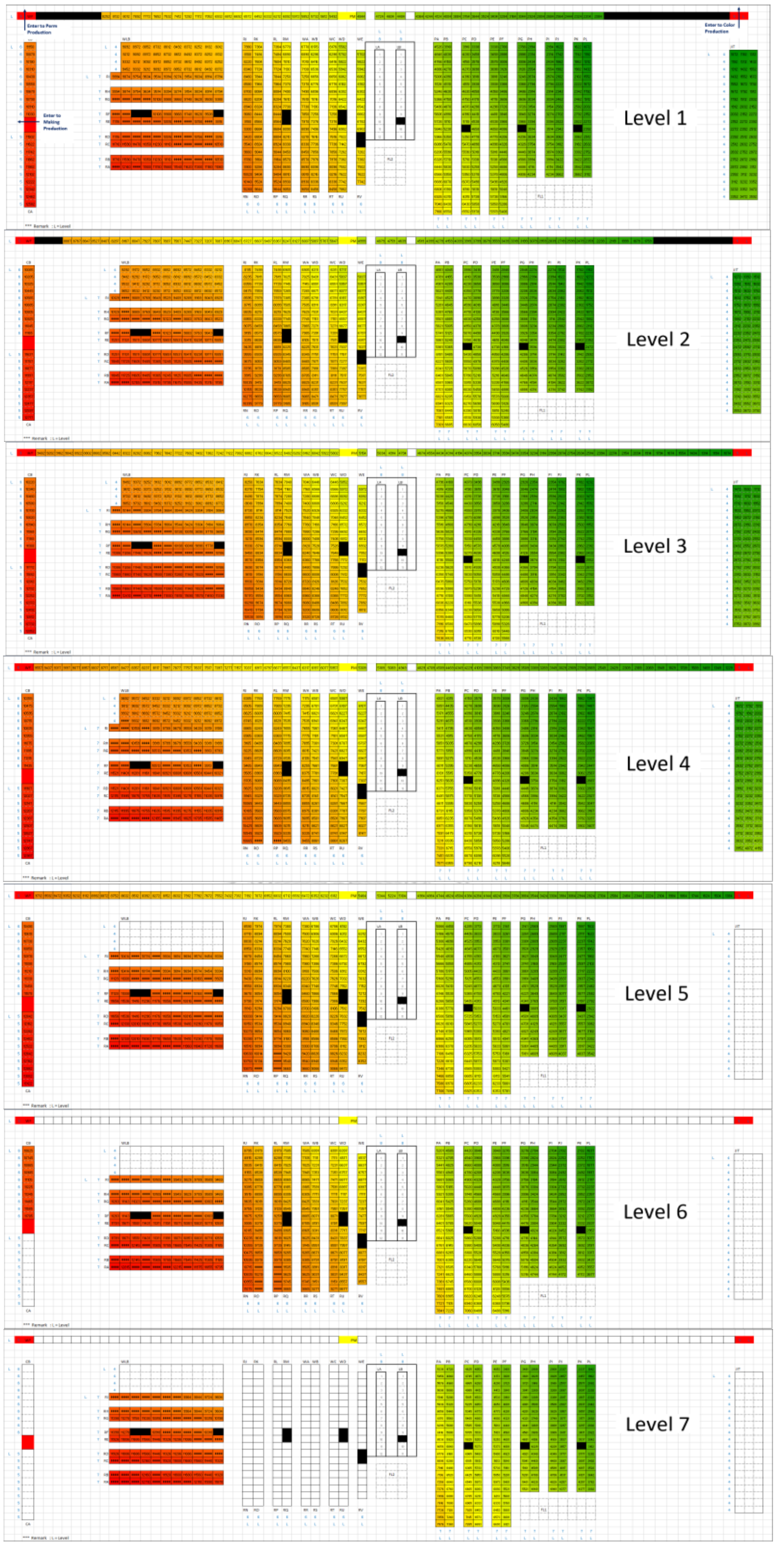


Figure 27. Heat mapping diagram to represent travel distance from each storage location to color production

In the second step, the average picking frequency per location for each group of materials is determined as shown in Table 31 and Table 32.

Table 31. Average picking frequency per location of each product's group under grouping level 1

Grouping Level 1		Allocated Space	Picking Frequency from Jan-Dec'19	Average Picking per Location
Group A	General Raw Materials	636	3,292	5.2
Group B	Combustible Raw Materials	2	12	6.0
Group C	Bulk	260	520	2.0
Group D	Perm Pack Material with Huge Volume	160	2,275	14.2
Group E	Perm High	714	2,058	2.9
Group F	Perm Medium	308	946	3.1
Group G	Color High	359	1,999	5.6
Group H	Color Medium	728	3,895	5.4
Group I	Color Low	567	1,174	2.1
Group J	Color Pack Material with Huge Volume	240	3,487	14.5

Table 32. Average picking frequency per of each product's group under grouping level 2

Grouping Level 2		Allocated Space	Picking Frequency from Jan-Dec'19	Average Picking per Location
Group 1	General raw materials (A)	312	2,642	8.5
Group 2	General raw materials (B)	208	499	2.4
Group 3	General raw materials (C)	135	151	1.1
Group 4	Combustible raw materials	2	12	6.0
Group 5	Bulk	260	260	1.0
Group 6	Perm Pack Material with Huge Volume	160	2,275	14.2
Group 7	Perm High (A)	275	1,645	6.0
Group 8	Perm High (B)	210	317	1.5
Group 9	Perm High (C)	233	96	0.4
Group 10	Perm Medium (A)	151	755	5.0
Group 11	Perm Medium (B)	95	147	1.5
Group 12	Perm Medium (C)	76	44	0.6
Group 13	Color High (A)	201	1,605	8.0
Group 14	Color High (B)	72	302	4.2
Group 15	Color High (C)	88	92	1.0
Group 16	Color Medium (A)	305	3,129	10.3
Group 17	Color Medium (B)	182	590	3.2
Group 18	Color Medium (C)	245	176	0.7
Group 19	Color Low (A)	274	945	3.4
Group 20	Color Low (B)	152	176	1.2
Group 21	Color Low (C)	145	53	0.4
Group 22	Color Pack Material with Huge Volume	240	3,487	14.5

After all necessary parameters for creating the optimization model are collected, the next step is to construct and generate results from optimization model using OPL program (IBM ILOG CPLEX Optimization Studio) as presented in Figure 28.

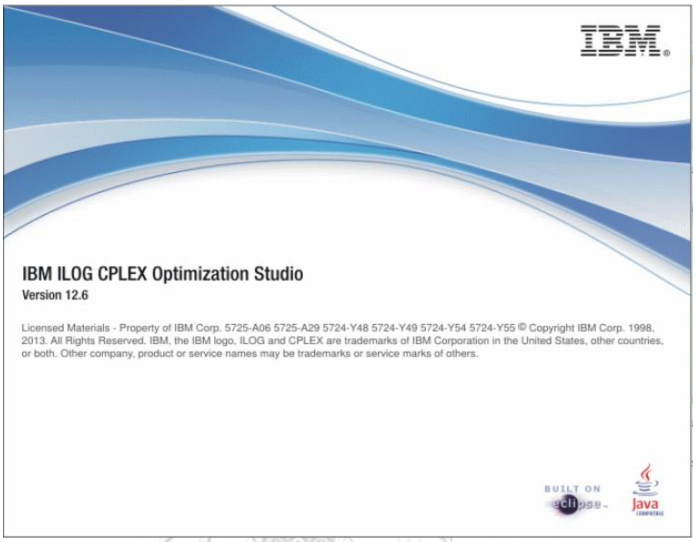


Figure 28. Optimization program

Optimization models for grouping level 1 and grouping level 2 are presented in part 4.5.1 and 4.5.2, respectively. Under each grouping level, three sub-optimization models are run separately according to rack types (low, medium, and high racks). So, there are total six optimization models are used to identify the most appropriate locations for each group of materials under grouping level 1 and grouping level 2 as summarized in table 33.

Table 33. Summary of six optimization models

Grouping Level	Optimization Model	Group of Materials under each Optimization Model
4.5.1. Grouping level 1	**4.5.1.1.** Low rack	Color low
	4.5.1.2. Medium rack	General raw materials (GRM), Combustible raw materials (CRM), Bulk materials, Perm medium materials, Color medium materials
	4.5.1.3. High rack	Perm high materials, Color high materials
4.5.2. Grouping level 2	**4.5.2.1.** Low rack	Color low A, Color low B, Color low C
	4.5.2.2. Medium rack	GRM A, GRM B, GRM C, CRM, Bulk, Perm med A, Perm med B, Perm med C, Color med A, Color med B, Color med C
	4.5.2.3. High rack	Perm high A, Perm high B, Perm high C, Color high A, Color high B, Color high C

4.5.1. Optimization models for grouping level 1

For a shorter running time, optimizing locations for materials that are suitable to locate in different types of racks are run separately.

4.5.1.1. Optimizing locations for materials that are required to be located in low racks (R1)

Sets:

I = Location number of low racks

A = Color Low materials

Parameters:

$DistCL_i$ = Distance from color production to location i

FreqColorLow = Average picking frequency per location of color low materials

Decision variable:

$ColorLow_{ai}$ = 1 if color low material a is in location i; 0 otherwise

Objective Function:

Minimize total picking distance = $\sum_{i \in I} \sum_{a \in A} (ColorLow_{ai} \times DistCL_i \times 2 \times FreqColorLow)$ (5)

Constraints:

$$\sum_{a \in A} ColorLow_{ai} \leq 1, \qquad \forall_{i \in I} \tag{6}$$

$$\sum_{i \in I} ColorLow_{ai} = 1, \qquad \forall_{a \in A} \tag{7}$$

Eq. (5) presents an objective function that is to minimize total picking distance. Two constraints are included in the optimization model. For the first constraint as presented in Eq. (6), each i location can be used to store one material at most. For the second constraint as shown in Eq. (7), each color low material a must be assigned in one location.

Results:

Total picking distance of color low materials is 9,097,107.60 cm or 90.97 km. Final locations for color low materials are shown in Table 34. Where the first two alphabets indicate the row of racking, the first digit number after the alphabets indicates the level of racking, and the rest numbers indicate the column of racking.

Table 34. Final locations for color low materials

Final Location for Color Low Materials											
PC12	PC314	PD218	PE122	PF13	PF37	PG218	PH215	PI211	PJ27	PK24	PL22
PC13	PC315	PD219	PE123	PF14	PF38	PG31	PH216	PI212	PJ28	PK25	PL23
PC14	PC316	PD220	PE21	PF15	PF39	PG32	PH217	PI213	PJ29	PK26	PL24
PC15	PC317	PD221	PE22	PF16	PF310	PG33	PH218	PI214	PJ210	PK28	PL25
PC16	PC318	PD222	PE23	PF17	PF311	PG34	PH31	PI215	PJ211	PK29	PL26
PC17	PC319	PD223	PE24	PF18	PF312	PG35	PH32	PI216	PJ212	PK210	PL27
PC18	PC320	PD31	PE25	PF19	PF313	PG36	PH33	PI217	PJ213	PK211	PL28
PC19	PC321	PD32	PE26	PF110	PF314	PG38	PH34	PI218	PJ214	PK212	PL29
PC110	PC322	PD33	PE27	PF111	PF315	PG39	PH35	PI31	PJ215	PK213	PL210
PC111	PC323	PD34	PE28	PF112	PF316	PG310	PH36	PI32	PJ216	PK214	PL211
PC113	PD11	PD35	PE29	PF113	PF317	PG311	PH37	PI33	PJ217	PK215	PL212
PC114	PD12	PD36	PE210	PF114	PF318	PG312	PH38	PI34	PJ218	PK216	PL213
PC115	PD13	PD37	PE211	PF115	PF319	PG313	PH39	PI35	PJ31	PK217	PL214
PC116	PD14	PD38	PE212	PF116	PF320	PG314	PH310	PI36	PJ32	PK218	PL215
PC117	PD15	PD39	PE213	PF117	PF321	PG315	PH311	PI37	PJ33	PK31	PL216
PC118	PD16	PD310	PE214	PF118	PF322	PG316	PH312	PI38	PJ34	PK32	PL217
PC119	PD17	PD311	PE215	PF119	PF323	PG317	PH313	PI39	PJ35	PK33	PL218
PC120	PD18	PD312	PE216	PF120	PG11	PG318	PH314	PI310	PJ36	PK34	
PC121	PD19	PD313	PE217	PF121	PG12	PH11	PH315	PI311	PJ37	PK35	
PC122	PD110	PD314	PE218	PF122	PG13	PH12	PH316	PI312	PJ38	PK36	
PC123	PD111	PD315	PE219	PF123	PG14	PH13	PH317	PI313	PJ39	PK38	
PC23	PD112	PD316	PE220	PF21	PG15	PH14	PH318	PI314	PJ310	PK39	
PC24	PD113	PD317	PE221	PF22	PG16	PH15	PI11	PI315	PJ311	PK310	
PC25	PD114	PD318	PE222	PF23	PG18	PH16	PI12	PI316	PJ312	PK311	
PC26	PD115	PD319	PE223	PF24	PG19	PH17	PI13	PI317	PJ313	PK312	
PC27	PD116	PD320	PE31	PF25	PG110	PH18	PI14	PI318	PJ314	PK313	
PC28	PD117	PD321	PE32	PF26	PG111	PH19	PI15	PJ11	PJ315	PK314	
PC29	PD118	PD322	PE33	PF27	PG112	PH110	PI16	PJ12	PJ316	PK315	
PC210	PD119	PD323	PE34	PF28	PG113	PH111	PI17	PJ13	PJ317	PK316	
PC211	PD120	PE11	PE35	PF29	PG114	PH112	PI18	PJ14	PJ318	PK317	
PC213	PD121	PE12	PE36	PF210	PG115	PH113	PI19	PJ15	PK11	PK318	
PC214	PD122	PE13	PE37	PF211	PG116	PH114	PI110	PJ16	PK12	PL11	
PC215	PD123	PE14	PE38	PF212	PG117	PH115	PI111	PJ17	PK13	PL12	
PC216	PD21	PE15	PE39	PF213	PG118	PH116	PI112	PJ18	PK14	PL13	
PC217	PD22	PE16	PE310	PF214	PG21	PH117	PI113	PJ19	PK15	PL14	
PC218	PD23	PE17	PE311	PF215	PG22	PH118	PI114	PJ110	PK16	PL15	
PC219	PD24	PE18	PE312	PF216	PG23	PH21	PI115	PJ111	PK18	PL16	
PC220	PD25	PE19	PE313	PF217	PG24	PH22	PI116	PJ112	PK19	PL17	
PC221	PD26	PE110	PE314	PF218	PG25	PH23	PI117	PJ113	PK110	PL18	
PC222	PD27	PE111	PE315	PF219	PG26	PH24	PI118	PJ114	PK111	PL19	
PC223	PD28	PE112	PE316	PF220	PG28	PH25	PI21	PJ115	PK112	PL110	
PC34	PD29	PE113	PE317	PF221	PG29	PH26	PI22	PJ116	PK113	PL111	
PC35	PD210	PE114	PE318	PF222	PG210	PH27	PI23	PJ117	PK114	PL112	
PC36	PD211	PE115	PE319	PF223	PG211	PH28	PI24	PJ118	PK115	PL113	
PC37	PD212	PE116	PE320	PF31	PG212	PH29	PI25	PJ21	PK116	PL114	
PC38	PD213	PE117	PE321	PF32	PG213	PH210	PI26	PJ22	PK117	PL115	
PC39	PD214	PE118	PE322	PF33	PG214	PH211	PI27	PJ23	PK118	PL116	
PC310	PD215	PE119	PE323	PF34	PG215	PH212	PI28	PJ24	PK21	PL117	
PC311	PD216	PE120	PF11	PF35	PG216	PH213	PI29	PJ25	PK22	PL118	
PC313	PD217	PE121	PF12	PF36	PG217	PH214	PI210	PJ26	PK23	PL21	

4.5.1.2. Optimizing locations for materials that are required to be located in medium racks (R2)

Sets:

J = Location number of medium racks

B = General raw materials

C = Combustible raw materials

D = Bulk materials

E = Perm medium materials

F = Color medium materials

Parameters:

$DistMM_j$ = Distance from making production to location j

$DistPM_j$ = Distance from perm production to location j

$DistCM_j$ = Distance from color production to location j

FreqGRM= Average picking frequency per location of general raw materials

FreqCRM= Average picking frequency per location of combustible raw materials

FreqBulk= Average picking frequency per location of bulk materials

FreqPermMed= Average picking frequency per location of perm medium materials

FreqColorMed= Average picking frequency per location of color medium materials

Decision variable:

GRM_{bj} = 1 if general raw material b is in location j; 0 otherwise

CRM_{cj} = 1 if combustible raw material c is in location j; 0 otherwise

$Bulk_{dj}$ = 1 if bulk material d is in location j; 0 otherwise

$PermMed_{ej}$ = 1 if perm medium material e is in location j; 0 otherwise

$ColorMed_{fj}$ = 1 if color medium material f is in location j; 0 otherwise

Objective Function:

Minimize picking distance = $\sum_{j\in J}\sum_{b\in B}\left(GRM_{bj} \times DistMM_j \times 2 \times FreqGRM\right) + \sum_{j\in J}\sum_{c\in C}(CRM_{cj} \times DistMM_j \times 2 \times FreqCRM) + \sum_{j\in J}\sum_{d\in D}(Bulk_{dj} \times DistPM_j \times 2 \times FreqBulk) + \sum_{j\in J}\sum_{e\in E}(PermMed_{ej} \times DistPM_j \times 2 \times FreqPermMed) + \sum_{j\in J}\sum_{f\in F}(ColorMed_{fj} \times DistCM_j \times 2 \times FreqColorMed)$ (8)

Constraints:

$$\sum_{b\in B} GRM_{bj} + \sum_{c\in C} CRM_{cj} + \sum_{d\in D} Bulk_{dj} + \sum_{e\in E} PermMed_{ej} + \sum_{f\in F} ColorMed_{fj} \leq 1, \quad \forall_{j\in J} \quad (9)$$

$$\sum_{j\in J} GRM_{bj} = 1, \quad \forall_{b\in B} \quad (10)$$

$$\sum_{j\in J} CRM_{cj} = 1, \quad \forall_{c\in C} \quad (11)$$

$$\sum_{j\in J} Bulk_{dJ} = 1, \quad \forall_{d\in D} \quad (12)$$

$$\sum_{j\in J} PermMed_{ej} = 1, \quad \forall_{e\in E} \quad (13)$$

$$\sum_{j\in J} ColorMed_{fj} = 1, \quad \forall_{f\in F} \quad (14)$$

$$\sum_{j=1}^{266}\sum_{d\in D} Bulk_{dj} = 130 \quad (15)$$

Objective function is presented in Eq. (8). Seven constraints are included in the optimization model. For the first constraint as presented in Eq. (9), each j location can be used to store one material at most. From Eq. (10) to Eq. (14), each material in each group must be assigned in one location. For the last constraint as shown in Eq. (15), bulk materials can be stored only on the first floor of the warehouse which includes locations j from 1 to 266.

Results:

Total picking distance of materials located in medium racks is 55,711,383.80 cm or 577.11 km. Final locations for general raw materials, combustible raw materials, bulk materials, perm medium materials, and color medium materials are shown in Table 35 to Table 39.

Table 35. Final locations for general raw materials

Final Locations for General Raw Materials												
RN11	CA410	RA11	RA57	RB42	RC28	RD13	RD59	RE44	RF35	RG31	RH110	RI48
RN12	CA51	RA12	RA58	RB43	RC29	RD14	RD510	RE45	RF36	RG32	RH111	RI49
RJ11	CA52	RA13	RA59	RB44	RC210	RD15	RD511	RE46	RF37	RG33	RH25	RI410
RJ12	CA53	RA14	RA510	RB45	RC211	RD16	RD61	RE47	RF38	RG34	RH26	RI411
RJ13	CA54	RA15	RA511	RB46	RC31	RD17	RD62	RE48	RF41	RG35	RH27	RI58
RJ14	CA55	RA16	RA61	RB47	RC32	RD18	RD63	RE49	RF42	RG36	RH28	RI59
RJ15	CA56	RA17	RA62	RB48	RC33	RD19	RD64	RE410	RF43	RG37	RH29	RI510
RJ16	CA57	RA18	RA63	RB49	RC34	RD110	RD65	RE411	RF44	RG38	RH210	RI511
RJ17	CA58	RA19	RA64	RB410	RC35	RD111	RD66	RE51	RF45	RG39	RH211	RI69
RJ18	CA59	RA110	RA65	RB411	RC36	RD21	RD67	RE52	RF46	RG310	RH36	RI610
RJ19	CA510	RA111	RA66	RB51	RC37	RD22	RD68	RE53	RF47	RG311	RH37	RI611
RJ110	CB12	RA21	RA67	RB52	RC38	RD23	RD69	RE54	RF48	RG41	RH38	RN21
CA12	CB13	RA22	RA68	RB53	RC39	RD24	RD610	RE55	RF51	RG42	RH39	RN22
CA13	CB14	RA23	RA69	RB54	RC310	RD25	RD611	RE56	RF52	RG43	RH310	RJ21
CA14	CB15	RA24	RA610	RB55	RC311	RD26	RE11	RE57	RF53	RG44	RH311	RJ22
CA15	CB16	RA25	RA611	RB56	RC41	RD27	RE12	RE58	RF54	RG45	RH47	RJ23
CA16	CB17	RA26	RB11	RB57	RC42	RD28	RE13	RE59	RF55	RG46	RH48	RJ24
CA17	CB18	RA27	RB12	RB58	RC43	RD29	RE14	RE510	RF56	RG47	RH49	RJ25
CA18	CB19	RA28	RB13	RB59	RC44	RD210	RE15	RE511	RF57	RG48	RH410	RJ26
CA19	CB21	RA29	RB14	RB510	RC45	RD211	RE16	RE61	RF58	RG49	RH411	RJ27
CA110	CB22	RA210	RB15	RB511	RC46	RD31	RE17	RE62	RF61	RG410	RH58	RJ28
CA21	CB23	RA211	RB16	RB61	RC47	RD32	RE18	RE63	RF62	RG411	RH59	RJ29
CA22	CB24	RA31	RB17	RB62	RC48	RD33	RE19	RE64	RF63	RG51	RH510	RJ210
CA23	CB25	RA32	RB18	RB63	RC49	RD34	RE110	RE65	RF64	RG52	RH511	RJ211
CA24	CB26	RA33	RB19	RB64	RC410	RD35	RE111	RE66	RF65	RG53	RH69	RN31
CA25	CB27	RA34	RB110	RB65	RC411	RD36	RE21	RE67	RF66	RG54	RH610	RN32
CA26	CB28	RA35	RB111	RB66	RC51	RD37	RE22	RE68	RF67	RG55	RH611	RJ31
CA27	CB31	RA36	RB21	RB67	RC52	RD38	RE23	RE69	RF68	RG56	RI13	RJ32
CA28	CB32	RA37	RB22	RB68	RC53	RD39	RE24	RE610	RG11	RG57	RI14	RJ33
CA29	CB33	RA38	RB23	RB69	RC54	RD310	RE25	RE611	RG12	RG58	RI15	RJ34
CA210	CB34	RA39	RB24	RB610	RC55	RD311	RE26	RF11	RG13	RG59	RI16	RJ35
CA31	CB35	RA310	RB25	RB611	RC56	RD41	RE27	RF12	RG14	RG510	RI17	RJ36
CA32	CB36	RA311	RB26	RC11	RC57	RD42	RE28	RF13	RG15	RG511	RI18	RJ37
CA33	CB37	RA41	RB27	RC12	RC58	RD43	RE29	RF14	RG16	RG61	RI19	RJ38
CA34	CB38	RA42	RB28	RC13	RC59	RD44	RE210	RF15	RG17	RG62	RI110	RJ39
CA35	CB41	RA43	RB29	RC14	RC510	RD45	RE211	RF16	RG18	RG63	RI111	RJ310
CA36	CB42	RA44	RB210	RC15	RC511	RD46	RE31	RF17	RG19	RG64	RI25	
CA37	CB43	RA45	RB211	RC16	RC61	RD47	RE32	RF18	RG110	RG65	RI26	
CA38	CB44	RA46	RB31	RC17	RC62	RD48	RE33	RF21	RG111	RG66	RI27	
CA39	CB45	RA47	RB32	RC18	RC63	RD49	RE34	RF22	RG21	RG67	RI28	
CA310	CB46	RA48	RB33	RC19	RC64	RD410	RE35	RF23	RG22	RG68	RI29	
CA41	CB47	RA49	RB34	RC110	RC65	RD411	RE36	RF24	RG23	RG69	RI210	
CA42	CB48	RA410	RB35	RC111	RC66	RD51	RE37	RF25	RG24	RG610	RI211	
CA43	CB51	RA411	RB36	RC21	RC67	RD52	RE38	RF26	RG25	RG611	RI36	
CA44	CB52	RA51	RB37	RC22	RC68	RD53	RE39	RF27	RG26	RH14	RI37	
CA45	CB53	RA52	RB38	RC23	RC69	RD54	RE310	RF28	RG27	RH15	RI38	
CA46	CB54	RA53	RB39	RC24	RC610	RD55	RE311	RF31	RG28	RH16	RI39	
CA47	CB55	RA54	RB310	RC25	RC611	RD56	RE41	RF32	RG29	RH17	RI310	
CA48	CB56	RA55	RB311	RC26	RD11	RD57	RE42	RF33	RG210	RH18	RI311	
CA49	CB57	RA56	RB41	RC27	RD12	RD58	RE43	RF34	RG211	RH19	RI47	

Table 36. Final locations for combustible raw materials

Final Locations for Combustible Raw Materials
CA11
CB11

Table 37. Final locations for bulk materials

Final Locations for Bulk Materials												
RJ111	RK13	RK113	RL13	RL113	RM14	RM116	WA15	WA115	WB111	WC17	WD18	WF14
RJ112	RK14	RK114	RL14	RL114	RM15	RM117	WA16	WA116	WB112	WC18	WD19	WF15
RJ113	RK15	RK115	RL15	RL115	RM16	RM118	WA17	WB13	WB113	WC19	WD110	WF16
RJ114	RK16	RK116	RL16	RL116	RM17	RR12	WA18	WB14	WB114	WC110	WD111	WF17
RJ115	RK17	RK117	RL17	RL117	RM110	RR13	WA19	WB15	WB115	WC111	WE14	WF18
RJ116	RK18	RK118	RL18	RL118	RM111	RR14	WA110	WB16	WB116	WC112	WE15	WF19
RO11	RK19	RP11	RL19	RQ12	RM112	WA11	WA111	WB17	WC13	WC113	WE16	WF110
RO12	RK110	RP12	RL110	RM11	RM113	WA12	WA112	WB18	WC14	WC114	WE17	WF111
RK11	RK111	RL11	RL111	RM12	RM114	WA13	WA113	WB19	WC15	WC115	WF12	WF112
RK12	RK112	RL12	RL112	RM13	RM115	WA14	WA114	WB110	WC16	WC116	WF13	WF113

Table 38. Final locations for perm medium materials

Final Locations for Perm Medium Materials												
RJ117	RH12	RH61	RI46	RJ312	RK311	RL310	WA29	WC316	WF226	WF324	WF418	WF512
RJ118	RH13	RH62	RI51	RJ313	RK312	RL311	WA210	WF23	WF227	WF325	WF419	WF513
WF114	RH21	RH63	RI52	RJ314	RK313	RL312	WA211	WF24	WF228	WF326	WF420	WF514
WF115	RH22	RH64	RI53	RJ315	RK314	RL313	WA212	WF25	WF33	WF327	WF421	WF515
WF116	RH23	RH65	RI54	RJ316	RK315	RL314	WA213	WF26	WF34	WF328	WF422	WF516
WF117	RH24	RH66	RI55	RJ317	RK316	RL315	WA214	WF27	WF35	WF329	WF423	WF517
WF118	RH31	RH67	RI56	RJ318	RK317	RL316	WA215	WF28	WF36	WF330	WF424	WF518
WF119	RH32	RH68	RI57	RK26	RK318	RL317	WA216	WF29	WF37	WF331	WF425	WF519
WF120	RH33	RI11	RI61	RK27	RL26	RL318	WA310	WF210	WF38	WF42	WF426	WF520
WF121	RH34	RI12	RI62	RK28	RL27	RM211	WA311	WF211	WF39	WF43	WF427	WF521
WF122	RH35	RI21	RI63	RK29	RL28	RM212	WA312	WF212	WF310	WF44	WF428	WF522
WF123	RH41	RI22	RI64	RK210	RL29	RM213	WA313	WF213	WF311	WF45	WF429	WF523
WF124	RH42	RI23	RI65	RK211	RL210	RM214	WA314	WF214	WF312	WF46	WF430	WF524
CB110	RH43	RI24	RI66	RK212	RL211	RM215	WA315	WF215	WF313	WF47	WF431	WF525
CB29	RH44	RI31	RI67	RK213	RL212	RM216	WA316	WF216	WF314	WF48	WF52	WF526
CB210	RH45	RI32	RI68	RK214	RL213	RM217	WB214	WF217	WF315	WF49	WF53	WF527
CB39	RH46	RI33	RJ212	RK215	RL214	RM218	WB215	WF218	WF316	WF410	WF54	WF528
CB310	RH51	RI34	RJ213	RK216	RL215	RM312	WB216	WF219	WF317	WF411	WF55	WF529
CB49	RH52	RI35	RJ214	RK217	RL216	RM313	WB315	WF220	WF318	WF412	WF56	WF530
CB410	RH53	RI41	RJ215	RK218	RL217	RM314	WB316	WF221	WF319	WF413	WF57	WF531
CB58	RH54	RI42	RJ216	RK37	RL218	RM315	WC214	WF222	WF320	WF414	WF58	
CB59	RH55	RI43	RJ217	RK38	RL37	RM316	WC215	WF223	WF321	WF415	WF59	
CB510	RH56	RI44	RJ218	RK39	RL38	RM317	WC216	WF224	WF322	WF416	WF510	
RH11	RH57	RI45	RJ311	RK310	RL39	RM318	WC315	WF225	WF323	WF417	WF511	

Table 39. Final locations for color medium materials

Final Locations for Color Medium Materials														
WD112	PB15	PM217	PM332	PA221	PB29	PB59	PC511	PD517	PE522	PG43	PH51	PI515	PK412	PL49
WD113	PB16	PM218	PM333	PA222	PB210	PB510	PC513	PD518	PE523	PG44	PH52	PI516	PK413	PL410
WD114	PB17	PM219	PM334	PA223	PB211	PB511	PC514	PD519	PF41	PG45	PH53	PI517	PK414	PL411
WD115	PB18	PM220	PM335	PA311	PB212	PB512	PC515	PD520	PF42	PG46	PH54	PI518	PK415	PL412
WD116	PB19	PM221	PM41	PA312	PB213	PB513	PC516	PD521	PF43	PG48	PH55	PJ41	PK416	PL413
WE18	PB110	PM222	PM42	PA313	PB214	PB514	PC517	PD522	PF44	PG49	PH56	PJ42	PK417	PL414
WE19	PB111	PM223	PM43	PA314	PB215	PB515	PC518	PD523	PF45	PG410	PH57	PJ43	PK418	PL415
WE110	PB112	PM224	PM44	PA315	PB216	PB516	PC519	PE41	PF46	PG411	PH58	PJ44	PK51	PL416
WE111	PB113	PM225	PM45	PA316	PB217	PB517	PC520	PE42	PF47	PG412	PH59	PJ45	PK52	PL417
WF11	PB114	PM226	PM46	PA317	PB218	PB518	PC521	PE43	PF48	PG413	PH510	PJ46	PK53	PL418
PM112	PB115	PM227	PM47	PA318	PB219	PB519	PC522	PE44	PF49	PG414	PH511	PJ47	PK54	PL51
PM113	PB116	PM228	PM48	PA319	PB220	PB520	PC523	PE45	PF410	PG415	PH512	PJ48	PK55	PL52
PM114	PB117	PM229	PM49	PA320	PB221	PB521	PD41	PE46	PF411	PG416	PH513	PJ49	PK56	PL53
PM115	PB118	PM230	PM410	PA321	PB222	PB522	PD42	PE47	PF412	PG417	PH514	PJ410	PK58	PL54
PM116	PB119	PM231	PM411	PA322	PB223	PB523	PD43	PE48	PF413	PG418	PH515	PJ411	PK59	PL55
PM117	PB120	PM232	PM412	PA323	PB36	PB610	PD44	PE49	PF414	PG51	PH516	PJ412	PK510	PL56
PM118	PB121	PM233	PM413	PA413	PB37	PB611	PD45	PE410	PF415	PG52	PH517	PJ413	PK511	PL57
PM119	PB122	PM234	PM414	PA414	PB38	PB612	PD46	PE411	PF416	PG53	PH518	PJ414	PK512	PL58
PM120	PB123	PM235	PM415	PA415	PB39	PB613	PD47	PE412	PF417	PG54	PI41	PJ415	PK513	PL59
PM121	WD212	PM31	PM416	PA416	PB310	PB614	PD48	PE413	PF418	PG55	PI42	PJ416	PK514	PL510
PM122	WD213	PM32	PM417	PA417	PB311	PB615	PD49	PE414	PF419	PG56	PI43	PJ417	PK515	PL511
PM123	WD214	PM33	PM418	PA418	PB312	PB616	PD410	PE415	PF420	PG58	PI44	PJ418	PK516	PL512
PM124	WD215	PM34	PM419	PA419	PB313	PB617	PD411	PE416	PF421	PG59	PI45	PJ51	PK517	PL513
PM125	WD216	PM35	PM420	PA420	PB314	PB618	PD412	PE417	PF422	PG510	PI46	PJ52	PK518	PL514
PM126	WD313	PM36	PM421	PA421	PB315	PB619	PD413	PE418	PF423	PG511	PI47	PJ53	PL31	PL515
PM127	WD314	PM37	PM422	PA422	PB316	PB620	PD414	PE419	PF51	PG512	PI48	PJ54	PL32	PL516
PM128	WD315	PM38	PM423	PA423	PB317	PB621	PD415	PE420	PF52	PG513	PI49	PJ55	PL33	PL517
PM129	WD316	PM39	PM424	PA514	PB318	PB622	PD416	PE421	PF53	PG514	PI410	PJ56	PL34	PL518
PM130	WE28	PM310	PM425	PA515	PB319	PB623	PD417	PE422	PF54	PG515	PI411	PJ57	PL35	
PM131	WE29	PM311	PM426	PA516	PB320	PC46	PD418	PE423	PF55	PG516	PI412	PJ58	PL36	
PM132	WE210	PM312	PM427	PA517	PB321	PC47	PD419	PE52	PF56	PG517	PI413	PJ59	PL37	
PM133	WE211	PM313	PM428	PA518	PB322	PC48	PD420	PE53	PF57	PG518	PI414	PJ510	PL38	
PM134	WE39	PM314	PM429	PA519	PB323	PC49	PD421	PE54	PF58	PH41	PI415	PJ511	PL39	
PM135	WE310	PM315	PM430	PA520	PB47	PC410	PD422	PE55	PF59	PH42	PI416	PJ512	PL310	
PA19	WE311	PM316	PM431	PA521	PB48	PC411	PD423	PE56	PF510	PH43	PI417	PJ513	PL311	
PA110	WF21	PM317	PM432	PA522	PB49	PC413	PD52	PE57	PF511	PH44	PI418	PJ514	PL312	
PA111	WF22	PM318	PM433	PA523	PB410	PC414	PD53	PE58	PF512	PH45	PI51	PJ515	PL313	
PA112	WF31	PM319	PM434	PA615	PB411	PC415	PD54	PE59	PF513	PH46	PI52	PJ516	PL314	
PA113	WF32	PM320	PM435	PA616	PB412	PC416	PD55	PE510	PF514	PH47	PI53	PJ517	PL315	
PA114	WF41	PM321	PA210	PA617	PB413	PC417	PD56	PE511	PF515	PH48	PI54	PJ518	PL316	
PA115	WF51	PM322	PA211	PA618	PB414	PC418	PD57	PE512	PF516	PH49	PI55	PK41	PL317	
PA116	PM28	PM323	PA212	PA619	PB415	PC419	PD58	PE513	PF517	PH410	PI56	PK42	PL318	
PA117	PM29	PM324	PA213	PA620	PB416	PC420	PD59	PE514	PF518	PH411	PI57	PK43	PL41	
PA118	PM210	PM325	PA214	PA621	PB417	PC421	PD510	PE515	PF519	PH412	PI58	PK44	PL42	
PA119	PM211	PM326	PA215	PA622	PB418	PC422	PD511	PE516	PF520	PH413	PI59	PK45	PL43	
PA120	PM212	PM327	PA216	PA623	PB419	PC423	PD512	PE517	PF521	PH414	PI510	PK46	PL44	
PA121	PM213	PM328	PA217	PB25	PB420	PC57	PD513	PE518	PF522	PH415	PI511	PK48	PL45	
PA122	PM214	PM329	PA218	PB26	PB421	PC58	PD514	PE519	PF523	PH416	PI512	PK49	PL46	
PA123	PM215	PM330	PA219	PB27	PB422	PC59	PD515	PE520	PG41	PH417	PI513	PK410	PL47	
PB14	PM216	PM331	PA220	PB28	PB423	PC510	PD516	PE521	PG42	PH418	PI514	PK411	PL48	

4.5.1.3 Optimizing locations for materials that are required to be located in high racks (R3)

Sets:

K = Location number of high racks

G = Perm high materials

H = Color high materials

Parameters:

$DistPH_k$ = Distance from perm production to location k

$DistCH_k$ = Distance from color production to location k

FreqPermHigh= Average picking frequency per location of perm high materials

FreqColorHigh= Average picking frequency per location of color high materials

Decision variable:

$PermHigh_{gk}$ = 1 if perm high material g is in location k; 0 otherwise

$ColorHigh_{hk}$ = 1 if color high material h is in location k; 0 otherwise

Objective Function:

Minimize total picking distance = $\sum_{k \in K} \sum_{g \in G} \left(PermHigh_{gk} \times DistPH_k \times 2 \times FreqPermHigh \right) + \sum_{k \in K} \sum_{h \in H} (ColorHigh_{hk} \times DistCH_k \times 2 \times FreqColorHigh)$

(16)

Constraints:

$$\sum_{g \in G} PermHigh_{gk} + \sum_{h \in H} ColorHigh_{hk} \leq 1, \qquad \forall_{k \in K} \qquad (17)$$

$$\sum_{k \in K} PermHigh_{gk} = 1, \qquad \forall_{g \in G} \qquad (18)$$

$$\sum_{k \in K} ColorHigh_{hk} = 1, \qquad \forall_{h \in H} \qquad (19)$$

Objective function is demonstrated in Eq. (16). Three constraints are included in the optimization model. For the first constraint as presented in Eq. (17), each k location can be used to store one material at most. In Eq. (18) and Eq. (19), each material in each group must be assigned in one location.

Results:

Total picking distance of materials located in high racks is 39,597,368.20 cm or 395.97 km. Final locations for perm high materials and color high materials are shown in Table 40 and Table 41.

Table 40. Final locations for perm high materials

Final Locations for Perm High Materials														
CB61	RD78	RI76	RJ63	RK513	RL53	RM415	WA47	RS41	WB67	RT61	WD511	WE56	PA719	PC78
CB62	RD79	RI77	RJ64	RK514	RL54	RM416	WA48	RS42	WB68	RT62	WD512	WE57	PA720	PC79
CB63	RD710	RI78	RJ65	RK515	RL55	RM417	WA49	RS43	WB69	RT63	WD513	WE58	PA721	PC710
CB64	RD711	RI79	RJ66	RK516	RL56	RM418	WA410	RS44	WB610	RT64	WD514	WE59	PA722	PC711
CB65	RE71	RI710	RJ67	RK517	RL57	RQ51	WA411	WB41	WB611	WC61	WD515	WE510	PA723	PC713
CB66	RE72	RI711	RJ68	RK518	RL58	RQ52	WA412	WB42	WB612	WC62	WD516	WE511	PB73	PC714
CB67	RE73	RN41	RJ69	RO61	RL59	RM51	WA413	WB43	WB613	WC63	RU61	RV61	PB74	PC715
CB68	RE74	RN42	RJ610	RO62	RL510	RM52	WA414	WB44	WB614	WC64	RU62	RV62	PB75	PC716
CB69	RE75	RJ41	RJ611	RK61	RL511	RM53	WA415	WB45	WB615	WC65	RU63	RV63	PB76	PC717
CB610	RE76	RJ42	RJ612	RK62	RL512	RM54	WA416	WB46	WB616	WC66	RU64	RV64	PB77	PC718
RA71	RE77	RJ43	RJ613	RK63	RL513	RM55	RR51	WB47	RT41	WC67	WD61	RV65	PB78	PC719
RA72	RE78	RJ44	RJ614	RK64	RL514	RM56	RR52	WB48	RT42	WC68	WD62	WE61	PB79	PC720
RA73	RE79	RJ45	RJ615	RK65	RL515	RM57	RR53	WB49	RT43	WC69	WD63	WE62	PB710	PC721
RA74	RE710	RJ46	RJ616	RK66	RL516	RM510	RR54	WB410	RT44	WC610	WD64	WE63	PB711	PE65
RA75	RE711	RJ47	RJ617	RK67	RL517	RM511	WA51	WB411	WC41	WC611	WD65	WE64	PB712	
RA76	RF71	RJ48	RJ618	RK68	RL518	RM512	WA52	WB412	WC42	WC612	WD68	WE65	PB713	
RA77	RF72	RJ49	RO41	RK69	RP61	RM513	WA53	WB413	WC43	WC613	WD69	WE66	PB714	
RA78	RF73	RJ410	RO42	RK610	RP62	RM514	WA54	WB414	WC44	WC614	WD610	WE67	PB715	
RA79	RF74	RJ411	RK41	RK611	RL61	RM515	WA55	WB415	WC45	WC615	WD611	WE68	PB716	
RA710	RF75	RJ412	RK42	RK612	RL62	RM516	WA56	WB416	WC46	WC616	WD612	WE69	PB717	
RA711	RF76	RJ413	RK43	RK613	RL63	RM517	WA57	RS51	WC47	RU41	WD613	WE610	PB718	
RB71	RF77	RJ414	RK44	RK614	RL64	RM518	WA58	RS52	WC48	RU42	WD614	WE611	PB719	
RB72	RF78	RJ415	RK45	RK615	RL65	RQ61	WA59	RS53	WC49	RU43	WD615	PM526	PB720	
RB73	RG71	RJ416	RK46	RK616	RL66	RQ62	WA510	RS54	WC410	RU44	WD616	PM527	PB721	
RB74	RG72	RJ417	RK47	RK617	RL67	RM61	WA511	WB51	WC411	WD41	RV41	PM528	PB722	
RB75	RG73	RJ418	RK48	RK618	RL68	RM62	WA512	WB52	WC412	WD42	RV42	PM529	PC61	
RB76	RG74	RN51	RK49	RP41	RL69	RM63	WA513	WB53	WC413	WD43	RV43	PM530	PC62	
RB77	RG75	RN52	RK410	RP42	RL610	RM64	WA514	WB54	WC414	WD44	RV44	PM531	PC63	
RB78	RG76	RJ51	RK411	RL41	RL611	RM65	WA515	WB55	WC415	WD45	RV45	PM532	PC64	
RB79	RG77	RJ52	RK412	RL42	RL612	RM66	WA516	WB56	WC416	WD48	WE41	PM533	PC65	
RB710	RG78	RJ53	RK413	RL43	RL613	RM67	RR61	WB57	RT51	WD49	WE42	PM534	PC66	
RB711	RG79	RJ54	RK414	RL44	RL614	RM610	RR62	WB58	RT52	WD410	WE43	PM535	PC67	
RC71	RG710	RJ55	RK415	RL45	RL615	RM611	RR63	WB59	RT53	WD411	WE44	PA71	PC68	
RC72	RG711	RJ56	RK416	RL46	RL616	RM612	RR64	WB510	RT54	WD412	WE45	PA72	PC69	
RC73	RH71	RJ57	RK417	RL47	RL617	RM613	WA61	WB511	WC51	WD413	WE46	PA73	PC610	
RC74	RH72	RJ58	RK418	RL48	RL618	RM614	WA62	WB512	WC52	WD414	WE47	PA74	PC611	
RC75	RH73	RJ59	RO51	RL49	RQ41	RM615	WA63	WB513	WC53	WD415	WE48	PA75	PC613	
RC76	RH74	RJ510	RO52	RL410	RQ42	RM616	WA64	WB514	WC54	WD416	WE49	PA76	PC614	
RC77	RH75	RJ511	RK51	RL411	RM41	RM617	WA65	WB515	WC55	RU51	WE410	PA77	PC615	
RC78	RH76	RJ512	RK52	RL412	RM42	RM618	WA66	WB516	WC56	RU52	WE411	PA78	PC616	
RC79	RH77	RJ513	RK53	RL413	RM43	RR41	WA67	RS61	WC57	RU53	RV51	PA79	PC617	
RC710	RH78	RJ514	RK54	RL414	RM44	RR42	WA68	RS62	WC58	RU54	RV52	PA710	PC618	
RC711	RH79	RJ515	RK55	RL415	RM45	RR43	WA69	RS63	WC59	WD51	RV53	PA711	PC619	
RD71	RH710	RJ516	RK56	RL416	RM46	RR44	WA610	RS64	WC510	WD52	RV54	PA712	PC620	
RD72	RH711	RJ517	RK57	RL417	RM47	WA41	WA611	WB61	WC511	WD53	RV55	PA713	PC72	
RD73	RI71	RJ518	RK58	RL418	RM410	WA42	WA612	WB62	WC512	WD54	WE51	PA714	PC73	
RD74	RI72	RN61	RK59	RP51	RM411	WA43	WA613	WB63	WC513	WD55	WE52	PA715	PC74	
RD75	RI73	RN62	RK510	RP52	RM412	WA44	WA614	WB64	WC514	WD58	WE53	PA716	PC75	
RD76	RI74	RJ61	RK511	RL51	RM413	WA45	WA615	WB65	WC515	WD59	WE54	PA717	PC76	
RD77	RI75	RJ62	RK512	RL52	RM414	WA46	WA616	WB66	WC516	WD510	WE55	PA718	PC77	

Table 41. Final locations for color high materials

Final Locations for Color High Materials														
PM51	PM525	PD622	PE611	PE718	PF619	PF721	PG75	PH612	PH718	PI76	PJ612	PJ718	PK78	PL614
PM52	PB723	PD623	PE612	PE719	PF620	PF722	PG76	PH613	PI61	PI77	PJ613	PK61	PK79	PL615
PM53	PC621	PD77	PE613	PE720	PF621	PF723	PG78	PH614	PI62	PI78	PJ614	PK62	PK710	PL616
PM54	PC622	PD78	PE614	PE721	PF622	PG61	PG79	PH615	PI63	PI79	PJ615	PK63	PK711	PL617
PM55	PC623	PD79	PE615	PE722	PF623	PG62	PG710	PH616	PI64	PI710	PJ616	PK64	PK712	PL618
PM56	PC722	PD710	PE616	PE723	PF72	PG63	PG711	PH617	PI65	PI711	PJ617	PK65	PK713	PL71
PM57	PC723	PD711	PE617	PF61	PF73	PG64	PG712	PH618	PI66	PI712	PJ618	PK66	PK714	PL72
PM58	PD65	PD712	PE618	PF62	PF74	PG65	PG713	PH71	PI67	PI713	PJ71	PK68	PK715	PL73
PM59	PD66	PD713	PE619	PF63	PF75	PG66	PG714	PH72	PI68	PI714	PJ72	PK69	PK716	PL74
PM510	PD67	PD714	PE620	PF64	PF76	PG68	PG715	PH73	PI69	PI715	PJ73	PK610	PK717	PL75
PM511	PD68	PD715	PE621	PF65	PF77	PG69	PG716	PH74	PI610	PI716	PJ74	PK611	PK718	PL76
PM512	PD69	PD716	PE622	PF66	PF78	PG610	PG717	PH75	PI611	PI717	PJ75	PK612	PL61	PL77
PM513	PD610	PD717	PE623	PF67	PF79	PG611	PG718	PH76	PI612	PI718	PJ76	PK613	PL62	PL78
PM514	PD611	PD718	PE77	PF68	PF710	PG612	PH61	PH77	PI613	PJ61	PJ77	PK614	PL63	PL79
PM515	PD612	PD719	PE78	PF69	PF711	PG613	PH62	PH78	PI614	PJ62	PJ78	PK615	PL64	PL710
PM516	PD613	PD720	PE79	PF610	PF712	PG614	PH63	PH79	PI615	PJ63	PJ79	PK616	PL65	PL711
PM517	PD614	PD721	PE710	PF611	PF713	PG615	PH64	PH710	PI616	PJ64	PJ710	PK617	PL66	PL712
PM518	PD615	PD722	PE711	PF612	PF714	PG616	PH65	PH711	PI617	PJ65	PJ711	PK618	PL67	PL713
PM519	PD616	PD723	PE712	PF613	PF715	PG617	PH66	PH712	PI618	PJ66	PJ712	PK71	PL68	PL714
PM520	PD617	PE66	PE713	PF614	PF716	PG618	PH67	PH713	PI71	PJ67	PJ713	PK72	PL69	PL715
PM521	PD618	PE67	PE714	PF615	PF717	PG71	PH68	PH714	PI72	PJ68	PJ714	PK73	PL610	PL716
PM522	PD619	PE68	PE715	PF616	PF718	PG72	PH69	PH715	PI73	PJ69	PJ715	PK74	PL611	PL717
PM523	PD620	PE69	PE716	PF617	PF719	PG73	PH610	PH716	PI74	PJ610	PJ716	PK75	PL612	PL718
PM524	PD621	PE610	PE717	PF618	PF720	PG74	PH611	PH717	PI75	PJ611	PJ717	PK76	PL613	

Total picking distance of perm pack materials with huge volume:

For perm pack materials with huge volume, they are assigned to be located in drive-in-rack row WLB with totally 160 locations. Total picking distance of perm pack materials with huge volume can be calculated by average distance from each of 160 locations to perm production times with total picking frequency of perm pack materials with huge volume multiplied by 2 (for traveling back and forth to each location). The detail calculation is shown below.

Average distance from each of 160 locations to perm production = 1,630 cm

Total picking frequency of perm pack materials with huge volume = 2,275

So, the total picking distance of perm pack materials with huge volume = 1,630 cm*2,275*2 = 7,416,500 cm or 74.17 km

Total picking distance of color pack materials with huge volume:

For color pack materials with huge volume, they are assigned to be located in drive-in-rack row JIT with totally 240 locations. Total picking distance of color pack materials with huge column can be calculated by average distance from each of 240 locations to color production times with total picking frequency of color pack materials with huge volume multiplied by 2 (for traveling back and forth to each location). The detail calculation is shown below.

Average distance from each of 240 locations to color production = 2,632 cm

Total picking frequency of color pack materials with huge volume = 3,487

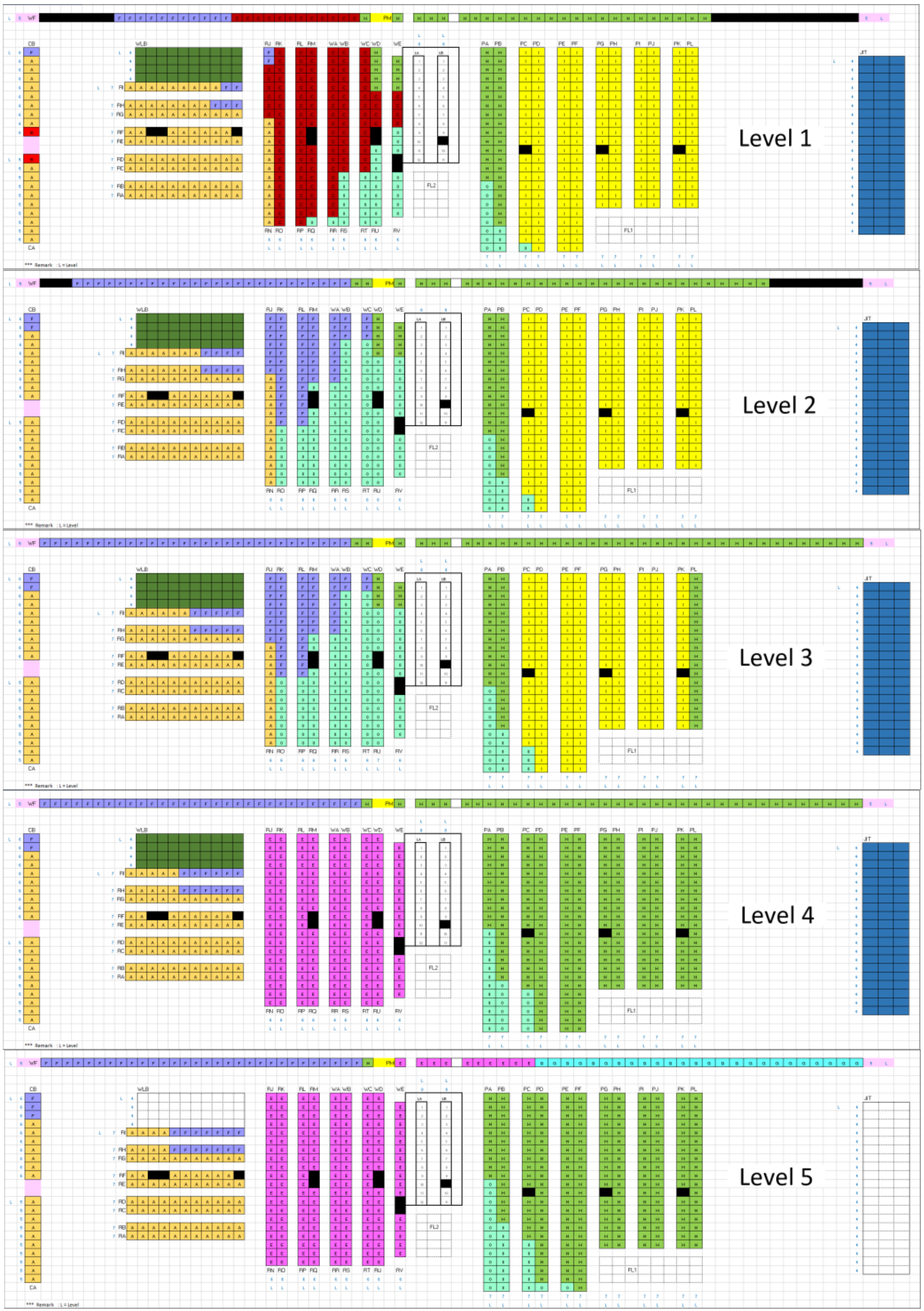
So, the total picking distance of color pack materials with huge volume = 2,632 cm*3,487 *2= 18,355,568 cm or 183.56 km

After all groups of materials under grouping level 1 are assigned locations in the raw materials warehouse, the total picking distances from January to December 2019 can be calculated as summarized in Table 42. In addition, Figure 29 illustrates the assigned locations for each group of materials in the raw materials warehouse.

Table 42. Total picking distances of grouping level 1 from January to December, 2019

Rack Types	Picking Distance (cm)
Low Rack	9,097,107.60
Medium Rack	55,711,383.80
High Rack	39,597,368.20
Drive-in-rack row WLB	7,416,500.00
Drive-in-rack row JIT	18,355,568.00
Total Picking Distance (cm)	**130,177,927.60**
Total Picking Distance (km)	**1,301.78**

(colour swatch)	General Raw Materials
(colour swatch)	Combustible Raw Materials
(colour swatch)	Bulk Materials
(colour swatch)	Perm High Materials
(colour swatch)	Perm Medium Materials
(colour swatch)	Color High Materials
(colour swatch)	Color Medium Materials
(colour swatch)	Color Low Materials
(colour swatch)	Drive-in-rack row WLB
(colour swatch)	Drive-in-rack row JIT
(colour swatch)	Free Locations



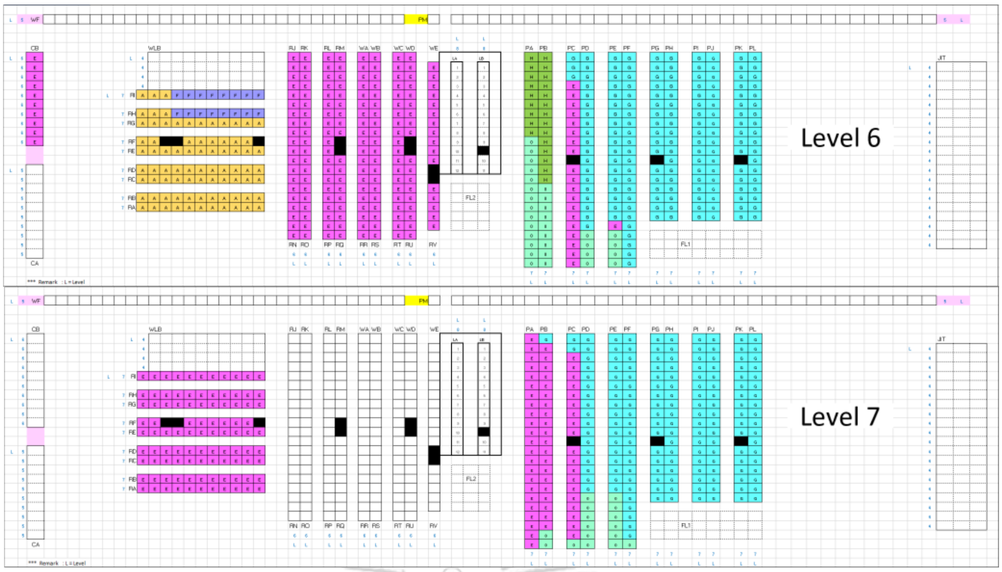


Figure 29. Final assigned locations for each group of raw materials under grouping level 1 in raw materials warehouse

From figure 29, it clearly demonstrates that each group of materials is assigned to be located closing to its usage area as designed. For example, materials that are used in making production are assigned to be located next to making production door. While materials that are used in perm and color productions are also assigned to be located next to perm production door and color production door, respectively. As a result, picking distance during picking process can be minimized as materials are located in the appropriate locations.

4.5.2. Optimization models for grouping level 2

For the shorter running time, optimizing locations for materials that are suitable to locate in different types of racks are run separately.

4.5.2.1. Optimizing locations for materials that are required to be located in low racks (R1)

Sets:

I = Location number of low racks

A = Color low materials class A

B = Color low materials class B

C = Color low materials class C

Parameters:

$DistCL_i$= Distance from color production to location i

FreqColorLowA = Average picking frequency per location of color low materials class A

FreqColorLowB = Average picking frequency per location of color low materials class B

FreqColorLowC = Average picking frequency per location of color low materials class C

Decision variable:

$ColorLowA_{ai}$ = 1 if color low material class A a is in location i; 0 otherwise

$ColorLowB_{bi}$ = 1 if color low material class B b is in location i; 0 otherwise

$ColorLowC_{ci}$ = 1 if color low material class C c is in location i; 0 otherwise

Objective Function:

Minimize total picking distance = $\sum_{i\in I}\sum_{a\in A}(ColorLowA_{ai} \times DistCL_i \times 2 \times FreqColorLowA) + \sum_{i\in I}\sum_{b\in B}(ColorLowB_{bi} \times DistCL_i \times 2 \times FreqColorLowB) + \sum_{i\in I}\sum_{c\in C}(ColorLowC_{ci} \times DistCL_i \times 2 \times FreqColorLowC)$ (20)

Constraints:

$$\sum_{a\in A} ColorLowA_{ai} + \sum_{b\in B} ColorLowB_{bi} + \sum_{c\in C} ColorLowC_{ci} \leq 1,\ \forall_{i\in I} \quad (21)$$

$$\sum_{i\in I} ColorLowA_{ai} = 1, \qquad \forall_{a\in A} \quad (22)$$

$$\sum_{i\in I} ColorLowB_{bi} = 1, \qquad \forall_{b\in B} \quad (23)$$

$$\sum_{i\in I} ColorLowC_{ci} = 1, \qquad \forall_{c\in C} \quad (24)$$

Objective function is presented in Eq. (20). Four constraints are included in the optimization model. For the first constraint as shown in Eq. (21), each i location can be used to store one material at most. From Eq. (22) to Eq. (24), each material in each group must be assigned in one location.

Results:

Total picking distance of all materials located in low racks is 7,410,864 cm or 74.11 km. Final locations for color low materials class A, color low materials class B, and color low materials class C are shown in Table 43 to Table 45.

Table 43. Final locations for color low materials class A

Final Locations for Color Low Class A Materials											
PD120	PF121	PG116	PH111	PH310	PI28	PJ11	PJ27	PJ313	PK22	PK311	PL116
PD121	PF122	PG117	PH112	PH311	PI29	PJ12	PJ28	PJ314	PK23	PK312	PL117
PD122	PF123	PG118	PH113	PH312	PI210	PJ13	PJ29	PJ315	PK24	PK313	PL118
PD123	PF216	PG211	PH114	PH313	PI211	PJ14	PJ210	PJ316	PK25	PK314	PL21
PD221	PF217	PG212	PH115	PH314	PI212	PJ15	PJ211	PJ317	PK26	PK315	PL22
PD222	PF218	PG213	PH116	PH315	PI213	PJ16	PJ212	PJ318	PK28	PK316	PL23
PD223	PF219	PG214	PH117	PH316	PI214	PJ17	PJ213	PK11	PK29	PK317	PL24
PD322	PF220	PG215	PH118	PH317	PI215	PJ18	PJ214	PK12	PK210	PK318	PL25
PD323	PF221	PG216	PH27	PH318	PI216	PJ19	PJ215	PK13	PK211	PL11	PL26
PE120	PF222	PG217	PH28	PI16	PI217	PJ110	PJ216	PK14	PK212	PL12	PL27
PE121	PF223	PG218	PH29	PI17	PI218	PJ111	PJ217	PK15	PK213	PL13	PL28
PE122	PF317	PG312	PH210	PI18	PI37	PJ112	PJ218	PK16	PK214	PL14	PL29
PE123	PF318	PG313	PH211	PI19	PI38	PJ113	PJ32	PK18	PK215	PL15	PL210
PE221	PF319	PG314	PH212	PI110	PI39	PJ114	PJ33	PK19	PK216	PL16	PL211
PE222	PF320	PG315	PH213	PI111	PI310	PJ115	PJ34	PK110	PK217	PL17	PL212
PE223	PF321	PG316	PH214	PI112	PI311	PJ116	PJ35	PK111	PK218	PL18	PL213
PE322	PF322	PG317	PH215	PI113	PI312	PJ117	PJ36	PK112	PK33	PL19	PL214
PE323	PF323	PG318	PH216	PI114	PI313	PJ118	PJ37	PK113	PK34	PL110	PL215
PF116	PG111	PH16	PH217	PI115	PI314	PJ22	PJ38	PK114	PK35	PL111	PL216
PF117	PG112	PH17	PH218	PI116	PI315	PJ23	PJ39	PK115	PK36	PL112	PL217
PF118	PG113	PH18	PH37	PI117	PI316	PJ24	PJ310	PK116	PK38	PL113	PL218
PF119	PG114	PH19	PH38	PI118	PI317	PJ25	PJ311	PK117	PK39	PL114	
PF120	PG115	PH110	PH39	PI27	PI318	PJ26	PJ312	PK118	PK310	PL115	

Table 44. Final locations for color low materials class B

Final Locations for Color Low Class B Materials											
PC117	PC318	PD119	PD318	PE214	PE320	PF211	PG12	PG29	PH15	PI11	PI33
PC118	PC319	PD213	PD319	PE215	PE321	PF212	PG13	PG210	PH21	PI12	PI34
PC119	PC320	PD214	PD320	PE216	PF18	PF213	PG14	PG34	PH22	PI13	PI35
PC120	PC321	PD215	PD321	PE217	PF19	PF214	PG15	PG35	PH23	PI14	PI36
PC121	PC322	PD216	PE112	PE218	PF110	PF215	PG16	PG36	PH24	PI15	PJ21
PC122	PC323	PD217	PE113	PE219	PF111	PF39	PG18	PG38	PH25	PI21	PJ31
PC123	PD112	PD218	PE114	PE220	PF112	PF310	PG19	PG39	PH26	PI22	PK21
PC218	PD113	PD219	PE115	PE314	PF113	PF311	PG110	PG310	PH31	PI23	PK31
PC219	PD114	PD220	PE116	PE315	PF114	PF312	PG23	PG311	PH32	PI24	PK32
PC220	PD115	PD314	PE117	PE316	PF115	PF313	PG24	PH11	PH33	PI25	
PC221	PD116	PD315	PE118	PE317	PF28	PF314	PG25	PH12	PH34	PI26	
PC222	PD117	PD316	PE119	PE318	PF29	PF315	PG26	PH13	PH35	PI31	
PC223	PD118	PD317	PE213	PE319	PF210	PF316	PG28	PH14	PH36	PI32	

Table 45. Final locations for color low materials class C

Final Locations for Color Low Class C Materials											
PC11	PC115	PC214	PC311	PD18	PD210	PD311	PE111	PE31	PF11	PF27	PG32
PC12	PC116	PC215	PC313	PD19	PD211	PD312	PE21	PE32	PF12	PF31	PG33
PC13	PC22	PC216	PC314	PD110	PD212	PD313	PE22	PE33	PF13	PF32	
PC14	PC23	PC217	PC315	PD111	PD31	PE11	PE23	PE34	PF14	PF33	
PC15	PC24	PC32	PC316	PD21	PD32	PE12	PE24	PE35	PF15	PF34	
PC16	PC25	PC33	PC317	PD22	PD33	PE13	PE25	PE36	PF16	PF35	
PC17	PC26	PC34	PD11	PD23	PD34	PE14	PE26	PE37	PF17	PF36	
PC18	PC27	PC35	PD12	PD24	PD35	PE15	PE27	PE38	PF21	PF37	
PC19	PC28	PC36	PD13	PD25	PD36	PE16	PE28	PE39	PF22	PF38	
PC110	PC29	PC37	PD14	PD26	PD37	PE17	PE29	PE310	PF23	PG11	
PC111	PC210	PC38	PD15	PD27	PD38	PE18	PE210	PE311	PF24	PG21	
PC113	PC211	PC39	PD16	PD28	PD39	PE19	PE211	PE312	PF25	PG22	
PC114	PC213	PC310	PD17	PD29	PD310	PE110	PE212	PE313	PF26	PG31	

4.5.2.2. Optimizing locations for materials that are required to be located in medium racks (R2)

Sets:

J = Location number of medium racks

D = General raw materials class A

E = General raw materials class B

F = General raw materials class C

G = Combustible raw materials

H = Bulk materials

L = Perm medium materials class A

M = Perm medium materials class B

N = Perm medium materials class C

O = Color medium materials class A

P = Color medium materials class B

Q = Color medium materials class C

Parameters:

$DistMM_j$ = Distance from making production to location j

$DistPM_j$ = Distance from perm production to location j

$DistCM_j$ = Distance from color production to location j

FreqGRMA= Average picking frequency per location of general raw materials class A

FreqGRMB= Average picking frequency per location of general raw materials class B

FreqGRMC= Average picking frequency per location of general raw materials class C

FreqCRM= Average picking frequency per location of combustible raw materials

FreqBulk= Average picking frequency per location of bulk materials

FreqPermMedA= Average picking frequency per location of perm medium materials class A

FreqPermMedB= Average picking frequency per location of perm medium materials class B

FreqPermMedC= Average picking frequency per location of perm medium materials class C

FreqColorMedA= Average picking frequency per location of color medium materials class A

FreqColorMedB= Average picking frequency per location of color medium materials class B

FreqColorMedC= Average picking frequency per location of color medium materials class C

Decision variable:

$GRMA_{dj}$ = 1 if general raw material class A d is in location j; 0 otherwise

$GRMB_{ej}$ = 1 if general raw material class B e is in location j; 0 otherwise

$GRMC_{fj}$ = 1 if general raw material class C f is in location j; 0 otherwise

CRM_{gj} = 1 if combustible material g is in location j; 0 otherwise

$Bulk_{hj}$ = 1 if bulk material h is in location j; 0 otherwise

$PermMedA_{lj}$ = 1 if perm medium material class A l is in location j; 0 otherwise

$PermMedB_{mj}$ = 1 if perm medium material class B m is in location j; 0 otherwise

$PermMedC_{nj}$ = 1 if perm medium material class C n is in location j; 0 otherwise

$ColorMedA_{oj}$ = 1 if color medium material class A o is in location j; 0 otherwise

$ColorMedB_{pj}$ = 1 if color medium material class B p is in location j; 0 otherwise

$ColorMedC_{qj}$ = 1 if color medium material class C q is in location j; 0 otherwise

Objective Function:

Minimize total picking distance = $\sum_{j\in J}\sum_{d\in D}\left(GRMA_{dj} \times DistMM_j \times 2 \times FreqGRMA\right) + \sum_{j\in J}\sum_{e\in E}\left(GRMB_{ej} \times DistMM_j \times 2 \times FreqGRMB\right) + \sum_{j\in J}\sum_{f\in F}\left(GRMC_{fj} \times DistMM_j \times 2 \times FreqGRMC\right) + \sum_{j\in J}\sum_{g\in G}\left(CRM_{gj} \times DistMM_j \times 2 \times FreqCRM\right) + \sum_{j\in J}\sum_{h\in H}(Bulk_{hj} \times DistPM_j \times 2 \times FreqBulk) + \sum_{j\in J}\sum_{l\in L}(PermMedA_{lj} \times DistPM_j \times 2 \times FreqPermMedA) + \sum_{j\in J}\sum_{m\in M}(PermMedB_{mj} \times DistPM_j \times 2 \times FreqPermMedB) + \sum_{j\in J}\sum_{n\in N}(PermMedC_{nj} \times DistPM_j \times 2 \times FreqPermMedC) + \sum_{j\in J}\sum_{o\in O}\left(ColorMedA_{oj} \times DistCM_j \times 2 \times FreqColorMedA\right) + \sum_{j\in J}\sum_{p\in P}\left(ColorMedB_{pj} \times DistCM_j \times 2 \times FreqColorMedB\right) + \sum_{j\in J}\sum_{q\in Q}(ColorMedC_{qj} \times DistCM_j \times 2 \times FreqColorMedC)$ (25)

Constraints:

$\sum_{d\in D} GRMA_{dj} + \sum_{e\in E} GRMB_{ej} + \sum_{f\in F} GRMC_{fj} + \sum_{g\in G} CRM_{gj} + \sum_{h\in H} Bulk_{hj} + \sum_{l\in L} PermMedA_{lj} + \sum_{m\in M} PermMedB_{mj} + \sum_{n\in N} PermMedC_{nj} + \sum_{o\in O} ColorMedA_{oj} + \sum_{p\in P} ColorMedB_{pj} + \sum_{q\in Q} ColorMedC_{qj} \leq 1, \quad \forall_{j\in J}$ (26)

$$\sum_{j\in J} GRMA_{dj} = 1, \qquad \forall_{d\in D} \tag{27}$$

$$\sum_{j\in J} GRMB_{ej} = 1, \qquad \forall_{e\in E} \tag{28}$$

$$\sum_{j\in J} GRMC_{fj} = 1, \qquad \forall_{f\in F} \tag{29}$$

$$\sum_{j\in J} CRM_{gj} = 1, \qquad \forall_{g\in G} \tag{30}$$

$$\sum_{j\in J} Bulk_{hj} = 1, \qquad \forall_{h\in H} \tag{31}$$

$$\sum_{j\in J} PermMedA_{lj} = 1, \qquad \forall_{l\in L} \tag{32}$$

$$\sum_{j\in J} PermMedB_{mj} = 1, \qquad \forall_{m\in M} \tag{33}$$

$$\sum_{j\in J} PermMedC_{nj} = 1, \qquad \forall_{n\in N} \tag{34}$$

$$\sum_{j\in J} ColorMedA_{oj} = 1, \qquad \forall_{o\in O} \tag{35}$$

$$\sum_{j\in J} ColorMedB_{pj} = 1, \qquad \forall_{p\in P} \tag{36}$$

$$\sum_{j\in J} ColorMedC_{qj} = 1, \qquad \forall_{q\in Q} \tag{37}$$

$$\sum_{j=1}^{266} \sum_{h\in H} Bulk_{hj} = 130 \tag{38}$$

Objective function is presented in Eq. (25). Thirteen constraints are included in the optimization model. For the first constraint as shown in Eq. (26), each j location can be used to store one material at most. From Eq. (27) to Eq. (37), each material in each group must be assigned in one location. For the last constraint as presented in Eq. (38), bulk materials can be stored only on the first floor of the warehouse which includes locations j from 1 to 266.

Results:

Total picking distance of all materials assigned in medium racks is 44,349,835.40 cm or 443.50 km. Final locations for general raw materials class A, general raw materials class B, general raw materials class C, combustible raw material, bulk materials, perm medium materials class A, perm medium materials class B, perm medium materials class C, color medium materials class A, color medium materials class B, and color medium materials class C are shown in Table 46 to Table 56.

Table 46. Final locations for general raw materials class A

Final Locations for General Raw Materials Class A												
CA12	CA36	CB13	CB51	RB311	RC39	RD23	RD49	RE19	RE43	RF13	RF57	RG35
CA13	CA37	CB14	CB52	RB48	RC310	RD24	RD410	RE110	RE44	RF14	RF58	RG36
CA14	CA38	CB15	CB53	RB49	RC311	RD25	RD411	RE111	RE45	RF15	RF67	RG37
CA15	CA39	CB16	CB54	RB410	RC48	RD26	RD55	RE21	RE46	RF16	RF68	RG38
CA16	CA310	CB17	CB55	RB411	RC49	RD27	RD56	RE22	RE47	RF17	RG12	RG39
CA17	CA41	CB21	CB56	RB59	RC410	RD28	RD57	RE23	RE48	RF18	RG13	RG310
CA18	CA42	CB22	RA111	RB510	RC411	RD29	RD58	RE24	RE49	RF22	RG14	RG311
CA19	CA43	CB23	RB15	RB511	RC59	RD210	RD59	RE25	RE410	RF23	RG15	RG46
CA110	CA44	CB24	RB16	RB611	RC510	RD211	RD510	RE26	RE411	RF24	RG16	RG47
CA21	CA45	CB25	RB17	RC15	RC511	RD32	RD511	RE27	RE55	RF25	RG17	RG48
CA22	CA46	CB26	RB18	RC16	RC611	RD33	RD66	RE28	RE56	RF26	RG18	RG49
CA23	CA47	CB27	RB19	RC17	RD11	RD34	RD67	RE29	RE57	RF27	RG19	RG410
CA24	CA48	CB31	RB110	RC18	RD12	RD35	RD68	RE210	RE58	RF28	RG110	RG411
CA25	CA49	CB32	RB111	RC19	RD13	RD36	RD69	RE211	RE59	RF33	RG111	RG57
CA26	CA410	CB33	RB26	RC110	RD14	RD37	RD610	RE32	RE510	RF34	RG23	RG58
CA27	CA51	CB34	RB27	RC111	RD15	RD38	RD611	RE33	RE511	RF35	RG24	RG59
CA28	CA52	CB35	RB28	RC26	RD16	RD39	RE11	RE34	RE66	RF36	RG25	RG510
CA29	CA53	CB36	RB29	RC27	RD17	RD310	RE12	RE35	RE67	RF37	RG26	RG511
CA210	CA54	CB41	RB210	RC28	RD18	RD311	RE13	RE36	RE68	RF38	RG27	RG68
CA31	CA55	CB42	RB211	RC29	RD19	RD44	RE14	RE37	RE69	RF45	RG28	RG69
CA32	CA56	CB43	RB37	RC210	RD110	RD45	RE15	RE38	RE610	RF46	RG29	RG610
CA33	CA57	CB44	RB38	RC211	RD111	RD46	RE16	RE39	RE611	RF47	RG210	RG611
CA34	CA58	CB45	RB39	RC37	RD21	RD47	RE17	RE310	RF11	RF48	RG211	RH111
CA35	CB12	CB46	RB310	RC38	RD22	RD48	RE18	RE311	RF12	RF56	RG34	RI111

Table 47. Final locations for general raw materials class B

Final Locations for General Raw Materials Class B												
RJ13	RA29	RA611	RB41	RB66	RC33	RC57	RD54	RE64	RF63	RG52	RH23	RI33
RJ14	RA210	RB11	RB42	RB67	RC34	RC58	RD61	RE65	RF64	RG53	RH32	RI34
RJ15	RA211	RB12	RB43	RB68	RC35	RC64	RD62	RF21	RF65	RG54	RH33	RI44
RJ16	RA37	RB13	RB44	RB69	RC36	RC65	RD63	RF31	RF66	RG55	RH34	RI45
RJ17	RA38	RB14	RB45	RB610	RC41	RC66	RD64	RF32	RG11	RG56	RH43	RI55
CA59	RA39	RB21	RB46	RC11	RC42	RC67	RD65	RF41	RG21	RG61	RH44	RI56
CA510	RA310	RB22	RB47	RC12	RC43	RC68	RE31	RF42	RG22	RG62	RH45	RI66
RA15	RA311	RB23	RB52	RC13	RC44	RC69	RE41	RF43	RG31	RG63	RH55	RI67
RA16	RA48	RB24	RB53	RC14	RC45	RC610	RE42	RF44	RG32	RG64	RH56	RJ24
RA17	RA49	RB25	RB54	RC21	RC46	RD31	RE51	RF51	RG33	RG65	RH66	RJ25
RA18	RA410	RB31	RB55	RC22	RC47	RD41	RE52	RF52	RG41	RG66	RH67	RJ26
RA19	RA411	RB32	RB56	RC23	RC52	RD42	RE53	RF53	RG42	RG67	RI11	RJ27
RA110	RA59	RB33	RB57	RC24	RC53	RD43	RE54	RF54	RG43	RH11	RI21	RJ28
RA26	RA510	RB34	RB58	RC25	RC54	RD51	RE61	RF55	RG44	RH12	RI22	RJ35
RA27	RA511	RB35	RB64	RC31	RC55	RD52	RE62	RF61	RG45	RH21	RI23	RJ36
RA28	RA610	RB36	RB65	RC32	RC56	RD53	RE63	RF62	RG51	RH22	RI32	RJ37

Table 48. Final locations for general raw materials class C

Final Locations for General Raw Materials Class C												
RN11	RR11	RA25	RA45	RA61	RB62	RH53	RI51	RJ21	RJ31	RO21	RP21	RQ21
RN12	RR12	RA31	RA46	RA62	RB63	RH54	RI52	RJ22	RJ32	RO22	RP22	RQ22
RJ11	RR13	RA32	RA47	RA63	RC51	RH61	RI53	RJ23	RJ33	RK21	RL21	RR21
RJ12	RA11	RA33	RA51	RA64	RC61	RH62	RI54	RJ29	RJ34	RK22	RL22	
RO11	RA12	RA34	RA52	RA65	RC62	RH63	RI61	RJ210	RJ38	RK23	RL23	
RO12	RA13	RA35	RA53	RA66	RC63	RH64	RI62	RJ211	RJ39	RK24	RL24	
RP11	RA14	RA36	RA54	RA67	RH31	RH65	RI63	RJ212	RJ310	RO31	RP31	
RP12	RA21	RA41	RA55	RA68	RH41	RI31	RI64	RJ213	RJ311	RO32	RP32	
RQ11	RA22	RA42	RA56	RA69	RH42	RI41	RI65	RJ214	RJ312	RK31	RL31	
RQ12	RA23	RA43	RA57	RB51	RH51	RI42	RN21	RN31	RJ313	RK32	RL32	
RM11	RA24	RA44	RA58	RB61	RH52	RI43	RN22	RN32	RJ314	RK33	RL33	

Table 49. Final locations for combustible raw materials

Final Locations for Combustible Raw Materials
CA11
CB11

Table 50. Final locations for bulk materials

Final Locations for Bulk Materials												
RJ18	RJ118	RK110	RL12	RL112	RM17	WA11	WA111	WB110	WC19	WD114	WF14	WF114
RJ19	RK11	RK111	RL13	RL113	RM110	WA12	WA112	WB111	WC110	WD115	WF15	WF115
RJ110	RK12	RK112	RL14	RL114	RM111	WA13	WA113	WB112	WC111	WD116	WF16	WF116
RJ111	RK13	RK113	RL15	RL115	RM112	WA14	WA114	WB113	WC112	WE18	WF17	WF117
RJ112	RK14	RK114	RL16	RL116	RM113	WA15	WA115	WB114	WC113	WE19	WF18	WF118
RJ113	RK15	RK115	RL17	RL117	RM114	WA16	WA116	WB115	WC114	WE110	WF19	WF119
RJ114	RK16	RK116	RL18	RL118	RM115	WA17	WB16	WB116	WC115	WE111	WF110	WF120
RJ115	RK17	RK117	RL19	RM14	RM116	WA18	WB17	WC16	WC116	WF11	WF111	WF121
RJ116	RK18	RK118	RL110	RM15	RM117	WA19	WB18	WC17	WD112	WF12	WF112	WF122
RJ117	RK19	RL11	RL111	RM16	RM118	WA110	WB19	WC18	WD113	WF13	WF113	PM135

Table 51. Final locations for perm medium materials class A

Final Locations for Perm Medium Materials Class A												
WF123	CB47	RH17	RH35	RH411	RI14	RI29	RI48	RI611	WF227	WF327	WF425	WF525
WF124	CB48	RH18	RH36	RH57	RI15	RI210	RI49	WF216	WF228	WF328	WF426	WF526
CB18	CB49	RH19	RH37	RH58	RI16	RI211	RI410	WF217	WF317	WF329	WF427	WF527
CB19	CB410	RH110	RH38	RH59	RI17	RI35	RI411	WF218	WF318	WF330	WF428	WF528
CB110	CB57	RH24	RH39	RH510	RI18	RI36	RI57	WF219	WF319	WF331	WF429	WF529
CB28	CB58	RH25	RH310	RH511	RI19	RI37	RI58	WF220	WF320	WF418	WF430	WF530
CB29	CB59	RH26	RH311	RH68	RI110	RI38	RI59	WF221	WF321	WF419	WF431	WF531
CB210	CB510	RH27	RH46	RH69	RI24	RI39	RI510	WF222	WF322	WF420	WF520	
CB37	RH13	RH28	RH47	RH610	RI25	RI310	RI511	WF223	WF323	WF421	WF521	
CB38	RH14	RH29	RH48	RH611	RI26	RI311	RI68	WF224	WF324	WF422	WF522	
CB39	RH15	RH210	RH49	RI12	RI27	RI46	RI69	WF225	WF325	WF423	WF523	
CB310	RH16	RH211	RH410	RI13	RI28	RI47	RI610	WF226	WF326	WF424	WF524	

Table 52. Final locations for perm medium materials class B

Final Locations for Perm Medium Materials Class B											
RJ215	RK212	RK314	RL215	RL317	WA216	WF29	WF35	WF313	WF49	WF417	WF513
RJ216	RK213	RK315	RL216	RL318	WA316	WF210	WF36	WF314	WF410	WF56	WF514
RJ217	RK214	RK316	RL217	RM216	WF23	WF211	WF37	WF315	WF411	WF57	WF515
RJ218	RK215	RK317	RL218	RM217	WF24	WF212	WF38	WF316	WF412	WF58	WF516
RJ315	RK216	RK318	RL313	RM218	WF25	WF213	WF39	WF45	WF413	WF59	WF517
RJ316	RK217	RL212	RL314	RM318	WF26	WF214	WF310	WF46	WF414	WF510	WF518
RJ317	RK218	RL213	RL315	WA214	WF27	WF215	WF311	WF47	WF415	WF511	WF519
RJ318	RK313	RL214	RL316	WA215	WF28	WF34	WF312	WF48	WF416	WF512	

Table 53. Final locations for perm medium materials class C

Final Locations for Perm Medium Materials Class C												
RK25	RK211	RK312	RL210	RL311	RM214	RM315	WA211	WA312	WB215	WC214	WF22	WF52
RK26	RK37	RL25	RL211	RL312	RM215	RM316	WA212	WA313	WB216	WC215	WF32	WF53
RK27	RK38	RL26	RL37	RM210	RM311	RM317	WA213	WA314	WB314	WC216	WF33	WF54
RK28	RK39	RL27	RL38	RM211	RM312	WA28	WA39	WA315	WB315	WC314	WF42	WF55
RK29	RK310	RL28	RL39	RM212	RM313	WA29	WA310	WB213	WB316	WC315	WF43	
RK210	RK311	RL29	RL310	RM213	RM314	WA210	WA311	WB214	WC213	WC316	WF44	

Table 54. Final locations for color medium materials class A

Final Locations for Color Medium Materials Class A												
PM112	PM215	PM313	PM412	PE521	PG414	PH417	PI416	PJ410	PJ517	PK58	PL314	PL52
PM113	PM216	PM314	PM413	PE522	PG415	PH418	PI417	PJ411	PJ518	PK59	PL315	PL53
PM114	PM217	PM315	PM414	PE523	PG416	PH57	PI418	PJ412	PK41	PK510	PL316	PL54
PM115	PM218	PM316	PM415	PF415	PG417	PH58	PI57	PJ413	PK42	PK511	PL317	PL55
PM116	PM219	PM317	PM416	PF416	PG418	PH59	PI58	PJ414	PK43	PK512	PL318	PL56
PM117	PM220	PM318	PM417	PF417	PG511	PH510	PI59	PJ415	PK44	PK513	PL41	PL57
PM118	PM221	PM319	PM418	PF418	PG512	PH511	PI510	PJ416	PK45	PK514	PL42	PL58
PM119	PM222	PM320	PM419	PF419	PG513	PH512	PI511	PJ417	PK46	PK515	PL43	PL59
PM120	PM223	PM321	PM420	PF420	PG514	PH513	PI512	PJ418	PK48	PK516	PL44	PL510
PM121	PM224	PM322	PM421	PF421	PG515	PH514	PI513	PJ52	PK49	PK517	PL45	PL511
PM122	PM225	PM323	PM422	PF422	PG516	PH515	PI514	PJ53	PK410	PK518	PL46	PL512
PM123	PM226	PM324	PM423	PF423	PG517	PH516	PI515	PJ54	PK411	PL31	PL47	PL513
PM124	PM31	PM325	PM424	PF516	PG518	PH517	PI516	PJ55	PK412	PL32	PL48	PL514
PM125	PM32	PM41	PD420	PF517	PH46	PH518	PI517	PJ56	PK413	PL33	PL49	PL515
PM126	PM33	PM42	PD421	PF518	PH47	PI46	PI518	PJ57	PK414	PL34	PL410	PL516
PM127	PM34	PM43	PD422	PF519	PH48	PI47	PJ41	PJ58	PK415	PL35	PL411	PL517
PB123	PM35	PM44	PD423	PF520	PH49	PI48	PJ42	PJ59	PK416	PL36	PL412	PL518
PM28	PM36	PM45	PD521	PF521	PH410	PI49	PJ43	PJ510	PK417	PL37	PL413	
PM29	PM37	PM46	PD522	PF522	PH411	PI410	PJ44	PJ511	PK418	PL38	PL414	
PM210	PM38	PM47	PD523	PF523	PH412	PI411	PJ45	PJ512	PK52	PL39	PL415	
PM211	PM39	PM48	PE420	PG410	PH413	PI412	PJ46	PJ513	PK53	PL310	PL416	
PM212	PM310	PM49	PE421	PG411	PH414	PI413	PJ47	PJ514	PK54	PL311	PL417	
PM213	PM311	PM410	PE422	PG412	PH415	PI414	PJ48	PJ515	PK55	PL312	PL418	
PM214	PM312	PM411	PE423	PG413	PH416	PI415	PJ49	PJ516	PK56	PL313	PL51	

Table 55. Final locations for color medium materials class B

Final Locations for Color Medium Materials Class B												
PM128	PB117	PM235	PM430	PB221	PB422	PC419	PD414	PE412	PE519	PF512	PG56	PH56
PM129	PB118	PM326	PM431	PB222	PB423	PC420	PD415	PE413	PE520	PF513	PG58	PI41
PM130	PB119	PM327	PM432	PB223	PB519	PC421	PD416	PE414	PF47	PF514	PG59	PI42
PM131	PB120	PM328	PA221	PB317	PB520	PC422	PD417	PE415	PF48	PF515	PG510	PI43
PM132	PB121	PM329	PA222	PB318	PB521	PC423	PD418	PE416	PF49	PG42	PH41	PI44
PM133	PB122	PM330	PA223	PB319	PB522	PC517	PD419	PE417	PF410	PG43	PH42	PI45
PM134	PM227	PM331	PA322	PB320	PB523	PC518	PD513	PE418	PF411	PG44	PH43	PI51
PA120	PM228	PM332	PA323	PB321	PB620	PC519	PD514	PE419	PF412	PG45	PH44	PI52
PA121	PM229	PM333	PA423	PB322	PB621	PC520	PD515	PE513	PF413	PG46	PH45	PI53
PA122	PM230	PM425	PB216	PB323	PB622	PC521	PD516	PE514	PF414	PG48	PH51	PI54
PA123	PM231	PM426	PB217	PB418	PB623	PC522	PD517	PE515	PF58	PG49	PH52	PI55
PB114	PM232	PM427	PB218	PB419	PC416	PC523	PD518	PE516	PF59	PG53	PH53	PI56
PB115	PM233	PM428	PB219	PB420	PC417	PD412	PD519	PE517	PF510	PG54	PH54	PJ51
PB116	PM234	PM429	PB220	PB421	PC418	PD413	PD520	PE518	PF511	PG55	PH55	PK51

Table 56. Final locations for color medium materials class C

Final Locations for Color Medium Materials Class C												
WD110	PB16	WE27	PA212	PA321	PA520	PB29	PB48	PB517	PC411	PD46	PE43	PE512
WD111	PB17	WE28	PA213	PA412	PA521	PB210	PB49	PB518	PC413	PD47	PE44	PF41
WE16	PB18	WE29	PA214	PA413	PA522	PB211	PB410	PB69	PC414	PD48	PE45	PF42
WE17	PB19	WE210	PA215	PA414	PA523	PB212	PB411	PB610	PC415	PD49	PE46	PF43
PA18	PB110	WE211	PA216	PA415	PA614	PB213	PB412	PB611	PC56	PD410	PE47	PF44
PA19	PB111	WE39	PA217	PA416	PA615	PB214	PB413	PB612	PC57	PD411	PE48	PF45
PA110	PB112	WE310	PA218	PA417	PA616	PB215	PB414	PB613	PC58	PD52	PE49	PF46
PA111	PB113	WE311	PA219	PA418	PA617	PB36	PB415	PB614	PC59	PD53	PE410	PF51
PA112	WD211	WF21	PA220	PA419	PA618	PB37	PB416	PB615	PC510	PD54	PE411	PF52
PA113	WD212	WF31	PA311	PA420	PA619	PB38	PB417	PB616	PC511	PD55	PE52	PF53
PA114	WD213	WF41	PA312	PA421	PA620	PB39	PB58	PB617	PC513	PD56	PE53	PF54
PA115	WD214	WF51	PA313	PA422	PA621	PB310	PB59	PB618	PC514	PD57	PE54	PF55
PA116	WD215	PM334	PA314	PA513	PA622	PB311	PB510	PB619	PC515	PD58	PE55	PF56
PA117	WD216	PM335	PA315	PA514	PA623	PB312	PB511	PC45	PC516	PD59	PE56	PF57
PA118	WD312	PM433	PA316	PA515	PB24	PB313	PB512	PC46	PD41	PD510	PE57	PG41
PA119	WD313	PM434	PA317	PA516	PB25	PB314	PB513	PC47	PD42	PD511	PE58	PG51
PB13	WD314	PM435	PA318	PA517	PB26	PB315	PB514	PC48	PD43	PD512	PE59	PG52
PB14	WD315	PA210	PA319	PA518	PB27	PB316	PB515	PC49	PD44	PE41	PE510	
PB15	WD316	PA211	PA320	PA519	PB28	PB47	PB516	PC410	PD45	PE42	PE511	

4.5.2.3. Optimizing locations for materials that are required to be located in high racks (R3)

Sets:

k = Location number of high racks

R = Perm high materials class A

S = Perm high materials class B

T = Perm high materials class C

U = Color high materials class A

V = Color high materials class B

W = Color high materials class C

Parameters:

$DistPH_k$ = Distance from perm production to location k

$DistCH_k$ = Distance from color production to location k

FreqPermHighA= Average picking frequency per location of perm high materials class A

FreqPermHighB= Average picking frequency per location of perm high materials class B

FreqPermHighC= Average picking frequency per location of perm high materials class C

FreqColorHighA= Average picking frequency per location of color high materials class A

FreqColorHighB= Average picking frequency per location of color high materials class B

FreqColorHighC= Average picking frequency per location of color high materials class C

Decision variable:

$PermHighA_{rk}$ = 1 if perm high material class A r is in location k; 0 otherwise

$PermHighB_{sk}$ = 1 if perm high material class B s is in location k; 0 otherwise

$PermHighC_{tk}$ = 1 if perm high material class C t is in location k; 0 otherwise

$ColorHighA_{uk}$ = 1 if color high material class A u is in location k; 0 otherwise

$ColorHighB_{vk}$ = 1 if color high material class B v is in location k; 0 otherwise

$ColorHighC_{wk}$ = 1 if color high material class C w is in location k; 0 otherwise

Objective Function:

Minimize total picking distance = $\sum_{k\in K}\sum_{r\in R}(PermHighA_{rk}\times DistPH_k\times 2\times FreqPermHighA)+\sum_{k\in K}\sum_{s\in S}(PermHighB_{sk}\times DistPH_k\times 2\times FreqPermHighB)+\sum_{k\in K}\sum_{t\in T}(PermHighC_{tk}\times DistPH_k\times 2\times FreqPermHighC)+\sum_{k\in K}\sum_{u\in U}(ColorHighA_{uk}\times DistCH_k\times 2\times FreqColorHighA)+\sum_{k\in K}\sum_{v\in V}(ColorHighB_{vk}\times DistCH_k\times 2\times FreqColorHighB)+\sum_{k\in K}\sum_{w\in W}(ColorHighC_{wk}\times DistCH_k\times 2\times FreqColorHighC)$ (39)

Constraints:

$$\sum_{r\in R} PermHighA_{rk}+\sum_{s\in S} PermHighB_{sk}+\sum_{t\in T} PermHighC_{tk}+\sum_{u\in U} ColorHighA_{uk}+\sum_{v\in V} ColorHighB_{vk}+\sum_{w\in W} ColorHighC_{wk}\leq 1,\ \forall_{k\in K} \quad (40)$$

$$\sum_{k\in K} PermHighA_{rk}=1,\quad \forall_{r\in R} \quad (41)$$

$$\sum_{k\in K} PermHighB_{sk}=1,\quad \forall_{s\in S} \quad (42)$$

$$\sum_{k\in K} PermHighC_{tk}=1,\quad \forall_{t\in T} \quad (43)$$

$$\sum_{k\in K} ColorHighA_{uk}=1,\quad \forall_{u\in U} \quad (44)$$

$$\sum_{k\in K} ColorHighB_{vk}=1,\quad \forall_{v\in V} \quad (45)$$

$$\sum_{k\in K} ColorHighC_{wk}=1,\quad \forall_{w\in W} \quad (46)$$

Objective function is presented in Eq. (39). Seven constraints are included in the optimization model. For the first constraint as shown in Eq. (40), each k location can be used to store one material at most. From Eq. (41) to Eq. (46), each material in each group must be assigned in one location.

Results:

Total picking distance of materials located in high racks is 32,712,686.60 cm or 327.13 km. Final locations for perm high materials class A, perm high materials class B, perm high materials class C, color high materials class A, color high materials class B, and color high materials class C are shown in Table 57 to Table 62.

Table 57. Final locations for perm high materials class A

Final Locations for Perm High Materials Class A												
CB61	RB78	RD78	RF78	RH711	RJ410	RJ514	RK47	RK517	RL416	RL616	RM618	WB414
CB62	RB79	RD79	RG71	RI71	RJ411	RJ515	RK48	RK518	RL417	RL617	WA49	WB415
CB63	RB710	RD710	RG72	RI72	RJ412	RJ516	RK49	RK69	RL418	RL618	WA410	WB416
CB64	RB711	RD711	RG73	RI73	RJ413	RJ517	RK410	RK610	RL57	RM411	WA411	WB515
CB65	RC71	RE71	RG74	RI74	RJ414	RJ518	RK411	RK611	RL58	RM412	WA412	WB516
CB66	RC72	RE72	RG75	RI75	RJ415	RJ63	RK412	RK612	RL59	RM413	WA413	WC413
CB67	RC73	RE73	RG76	RI76	RJ416	RJ64	RK413	RK613	RL510	RM414	WA414	WC414
CB68	RC74	RE74	RG77	RI77	RJ417	RJ65	RK414	RK614	RL511	RM415	WA415	WC415
CB69	RC75	RE75	RG78	RI78	RJ418	RJ66	RK415	RK615	RL512	RM416	WA416	WC416
CB610	RC76	RE76	RG79	RI79	RJ51	RJ67	RK416	RK616	RL513	RM417	WA510	WC515
RA77	RC77	RE77	RG710	RI710	RJ52	RJ68	RK417	RK617	RL514	RM418	WA511	WC516
RA78	RC78	RE78	RG711	RI711	RJ53	RJ69	RK418	RK618	RL515	RM512	WA512	
RA79	RC79	RE79	RH71	RN42	RJ54	RJ610	RK57	RL46	RL516	RM513	WA513	
RA710	RC710	RE710	RH72	RJ41	RJ55	RJ611	RK58	RL47	RL517	RM514	WA514	
RA711	RC711	RE711	RH73	RJ42	RJ56	RJ612	RK59	RL48	RL518	RM515	WA515	
RB71	RD71	RF71	RH74	RJ43	RJ57	RJ613	RK510	RL49	RL69	RM516	WA516	
RB72	RD72	RF72	RH75	RJ44	RJ58	RJ614	RK511	RL410	RL610	RM517	WA612	
RB73	RD73	RF73	RH76	RJ45	RJ59	RJ615	RK512	RL411	RL611	RM518	WA613	
RB74	RD74	RF74	RH77	RJ46	RJ510	RJ616	RK513	RL412	RL612	RM614	WA614	
RB75	RD75	RF75	RH78	RJ47	RJ511	RJ617	RK514	RL413	RL613	RM615	WA615	
RB76	RD76	RF76	RH79	RJ48	RJ512	RJ618	RK515	RL414	RL614	RM616	WA616	
RB77	RD77	RF77	RH710	RJ49	RJ513	RK46	RK516	RL415	RL615	RM617	WB413	

Table 58. Final locations for perm high materials class B

Final Locations for Perm High Materials Class B												
RA71	RK43	RK66	RL56	RM410	WA41	WA63	WB412	WB614	WC511	WD412	WE46	PM530
RA72	RK44	RK67	RP62	RM53	WA42	WA64	WB56	WB615	WC512	WD413	WE47	PM531
RA73	RK45	RK68	RL61	RM54	WA43	WA65	WB57	WB616	WC513	WD414	WE48	PM532
RA74	RO51	RP41	RL62	RM55	WA44	WA66	WB58	WC44	WC514	WD415	WE49	PM533
RA75	RO52	RP42	RL63	RM56	WA45	WA67	WB59	WC45	WC67	WD416	WE410	PM534
RA76	RK51	RL41	RL64	RM57	WA46	WA68	WB510	WC46	WC68	WD511	WE411	PM535
RN41	RK52	RL42	RL65	RM510	WA47	WA69	WB511	WC47	WC69	WD512	WE57	
RN51	RK53	RL43	RL66	RM511	WA48	WA610	WB512	WC48	WC610	WD513	WE58	
RN52	RK54	RL44	RL67	RM65	WA51	WA611	WB513	WC49	WC611	WD514	WE59	
RN61	RK55	RL45	RL68	RM66	WA52	WB44	WB514	WC410	WC612	WD515	WE510	
RN62	RK56	RP51	RM41	RM67	WA53	WB45	WB67	WC411	WC613	WD516	WE511	
RJ61	RO62	RP52	RM42	RM610	WA54	WB46	WB68	WC412	WC614	WD612	WE68	
RJ62	RK61	RL51	RM43	RM611	WA55	WB47	WB69	WC56	WC615	WD613	WE69	
RO41	RK62	RL52	RM44	RM612	WA56	WB48	WB610	WC57	WC616	WD614	WE610	
RO42	RK63	RL53	RM45	RM613	WA57	WB49	WB611	WC58	WD49	WD615	WE611	
RK41	RK64	RL54	RM46	RR43	WA58	WB410	WB612	WC59	WD410	WD616	PM528	
RK42	RK65	RL55	RM47	RR44	WA59	WB411	WB613	WC510	WD411	WE45	PM529	

Table 59. Final locations for perm high materials class C

Final Locations for Perm High Materials Class C												
RO61	RR53	RS54	RT43	WC61	RU53	WD65	RV55	WE67	PA718	PB714	PC614	PC716
RP61	RR54	WB51	RT44	WC62	RU54	WD68	WE51	PA71	PA719	PB715	PC615	PC717
RQ41	RR61	WB52	WC41	WC63	WD51	WD69	WE52	PA72	PA720	PB716	PC616	PC718
RQ42	RR62	WB53	WC42	WC64	WD52	WD610	WE53	PA73	PA721	PB717	PC617	PC719
RQ51	RR63	WB54	WC43	WC65	WD53	WD611	WE54	PA74	PA722	PB718	PC71	PD64
RQ52	RR64	WB55	RT51	WC66	WD54	RV41	WE55	PA75	PA723	PB719	PC72	PD65
RM51	WA61	RS61	RT52	RU41	WD55	RV42	WE56	PA76	PB72	PC61	PC73	PD66
RM52	WA62	RS62	RT53	RU42	WD58	RV43	RV61	PA77	PB73	PC62	PC74	PD76
RQ61	RS41	RS63	RT54	RU43	WD59	RV44	RV62	PA78	PB74	PC63	PC75	PD77
RQ62	RS42	RS64	WC51	RU44	WD510	RV45	RV63	PA79	PB75	PC64	PC76	PD78
RM61	RS43	WB61	WC52	WD41	RU61	WE41	RV64	PA710	PB76	PC65	PC77	PE64
RM62	RS44	WB62	WC53	WD42	RU62	WE42	RV65	PA711	PB77	PC66	PC78	PE65
RM63	WB41	WB63	WC54	WD43	RU63	WE43	WE61	PA712	PB78	PC67	PC79	PE66
RM64	WB42	WB64	WC55	WD44	RU64	WE44	WE62	PA713	PB79	PC68	PC710	PE75
RR41	WB43	WB65	RT61	WD45	WD61	RV51	WE63	PA714	PB710	PC69	PC711	PE76
RR42	RS51	WB66	RT62	WD48	WD62	RV52	WE64	PA715	PB711	PC610	PC713	PE77
RR51	RS52	RT41	RT63	RU51	WD63	RV53	WE65	PA716	PB712	PC611	PC714	PE78
RR52	RS53	RT42	RT64	RU52	WD64	RV54	WE66	PA717	PB713	PC613	PC715	

Table 60. Final locations for color high materials class A

Final Locations for Color High Materials Class A												
PM51	PM517	PF618	PG616	PH614	PI67	PI712	PJ611	PJ712	PK612	PK714	PL612	PL710
PM52	PM518	PF619	PG617	PH615	PI68	PI713	PJ612	PJ713	PK613	PK715	PL613	PL711
PM53	PM519	PF620	PG618	PH616	PI69	PI714	PJ613	PJ714	PK614	PK716	PL614	PL712
PM54	PM520	PF621	PG713	PH617	PI610	PI715	PJ614	PJ715	PK615	PK717	PL615	PL713
PM55	PM521	PF622	PG714	PH618	PI611	PI716	PJ615	PJ716	PK616	PK718	PL616	PL714
PM56	PM522	PF623	PG715	PH78	PI612	PI717	PJ616	PJ717	PK617	PL61	PL617	PL715
PM57	PM523	PF718	PG716	PH79	PI613	PI718	PJ617	PJ718	PK618	PL62	PL618	PL716
PM58	PD621	PF719	PG717	PH710	PI614	PJ62	PJ618	PK62	PK74	PL63	PL71	PL717
PM59	PD622	PF720	PG718	PH711	PI615	PJ63	PJ74	PK63	PK75	PL64	PL72	PL718
PM510	PD623	PF721	PH67	PH712	PI616	PJ64	PJ75	PK64	PK76	PL65	PL73	
PM511	PD723	PF722	PH68	PH713	PI617	PJ65	PJ76	PK65	PK78	PL66	PL74	
PM512	PE621	PF723	PH69	PH714	PI618	PJ66	PJ77	PK66	PK79	PL67	PL75	
PM513	PE622	PG612	PH610	PH715	PI78	PJ67	PJ78	PK68	PK710	PL68	PL76	
PM514	PE623	PG613	PH611	PH716	PI79	PJ68	PJ79	PK69	PK711	PL69	PL77	
PM515	PE723	PG614	PH612	PH717	PI710	PJ69	PJ710	PK610	PK712	PL610	PL78	
PM516	PF617	PG615	PH613	PH718	PI711	PJ610	PJ711	PK611	PK713	PL611	PL79	

Table 61. Final locations for color high materials class B

Final Locations for Color High Materials Class B											
PM524	PC623	PD718	PE617	PE720	PF615	PF717	PG79	PH64	PH77	PI74	PJ72
PM525	PC723	PD719	PE618	PE721	PF616	PG68	PG710	PH65	PI62	PI75	PJ73
PM526	PD617	PD720	PE619	PE722	PF713	PG69	PG711	PH66	PI63	PI76	PK61
PM527	PD618	PD721	PE620	PF612	PF714	PG610	PG712	PH74	PI64	PI77	PK71
PC621	PD619	PD722	PE718	PF613	PF715	PG611	PH62	PH75	PI65	PJ61	PK72
PC622	PD620	PE616	PE719	PF614	PF716	PG78	PH63	PH76	PI66	PJ71	PK73

Table 62. Final locations for color high materials class C

Final Locations for Color High Materials Class C												
PB720	PC720	PD611	PD710	PD717	PE613	PE713	PF63	PF610	PF78	PG63	PG74	PI61
PB721	PC721	PD612	PD711	PE67	PE614	PE714	PF64	PF611	PF79	PG64	PG75	PI71
PB722	PC722	PD613	PD712	PE68	PE615	PE715	PF65	PF73	PF710	PG65	PG76	PI72
PB723	PD67	PD614	PD713	PE69	PE79	PE716	PF66	PF74	PF711	PG66	PH61	PI73
PC618	PD68	PD615	PD714	PE610	PE710	PE717	PF67	PF75	PF712	PG71	PH71	
PC619	PD69	PD616	PD715	PE611	PE711	PF61	PF68	PF76	PG61	PG72	PH72	
PC620	PD610	PD79	PD716	PE612	PE712	PF62	PF69	PF77	PG62	PG73	PH73	

Total picking distance of perm and color pack materials with huge volume:

Total picking distances of perm and color pack materials with huge volume that are located in drive-in-rack rows WLB and JIT, respectively for grouping level 2 are the same with grouping level 1 as presented in Table 63.

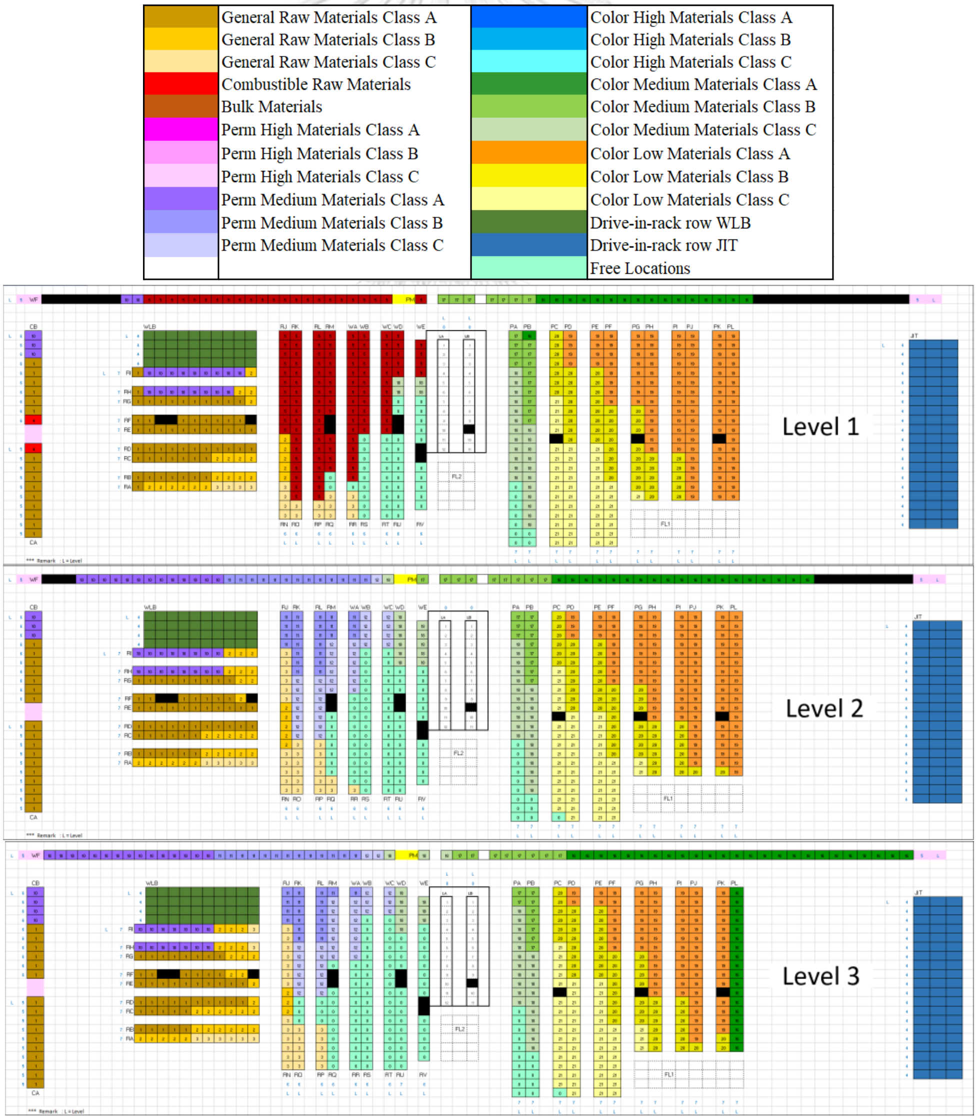
Table 63. Picking distance of perm and color pack materials with huge volume

Pack Materials in Drive-In-Rack Areas	Picking Distance (cm)
Perm pack materials with huge volume	7,416,500.00
Color pack materials with huge volume	18,355,568.00

After all groups of materials under grouping level 2 are assigned locations in the raw materials warehouse, the total picking distances from January to December 2019 can be calculated as summarized in Table 64. In addition, Figure 30 illustrates the assigned locations for each group of materials under grouping level 2 in the raw materials warehouse.

Table 64. Total picking distances of grouping level 2 from January to December, 2019

Rack Types	Picking Distance (cm)
Low Rack	7,410,864.00
Medium Rack	44,349,835.40
High Rack	32,712,686.60
Drive-in-rack row WLB	7,416,500.00
Drive-in-rack row JIT	18,355,568.00
Total Picking Distance (cm)	**110,245,454.00**
Total Picking Distance (km)	**1,102.45**



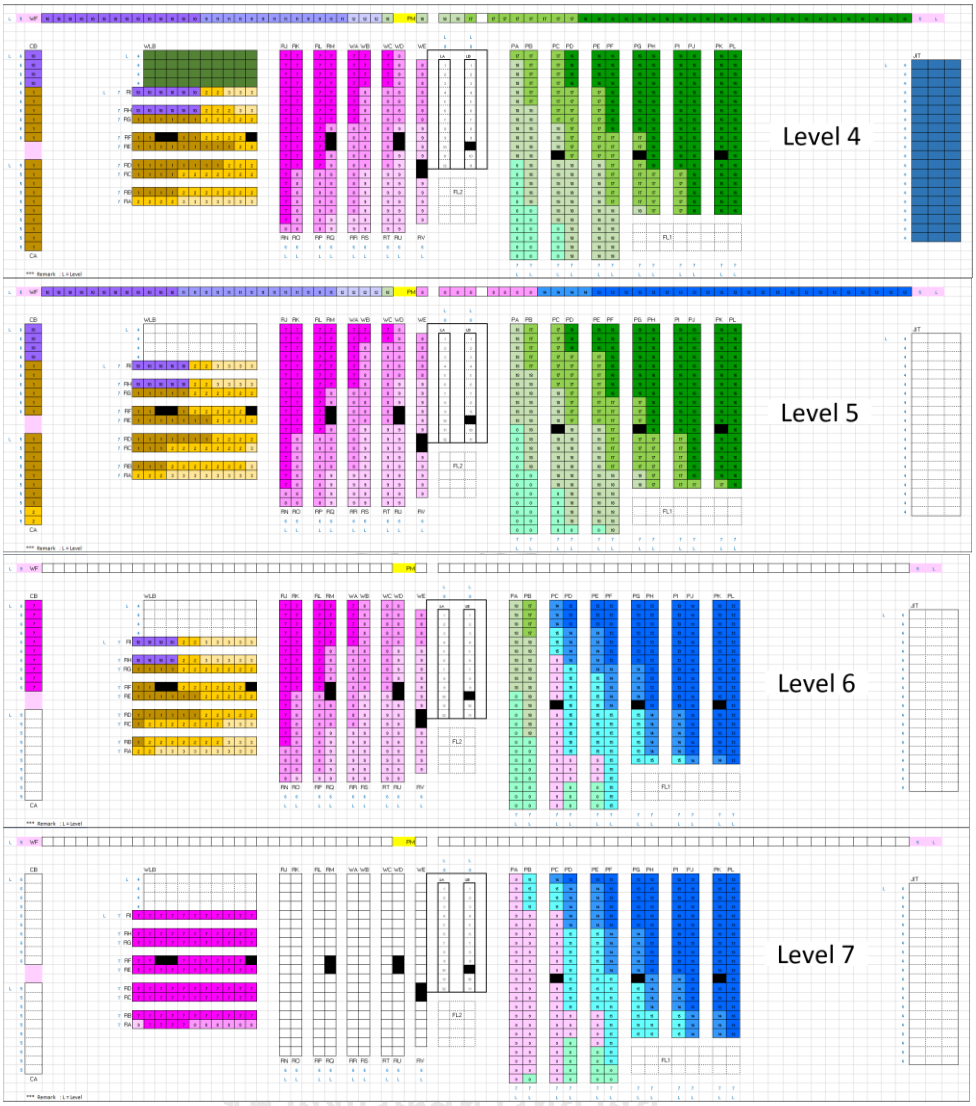


Figure 30. Final assigned locations for each group of raw materials under grouping level 2 in raw materials warehouse

From figure 30, it clearly demonstrates that each group of materials is assigned to be located closing to its usage area. In addition, materials that have higher turnover rate (higher picking frequency) are assigned to be located closer to their usage area than materials that have lower turnover rate (lower picking frequency). This is a result from the optimization model that is trying to minimize the total picking distance during the picking process.

4.6. Finalize grouping of materials in raw materials warehouse

As mentions in part 4.2, grouping level 1 and grouping level 2 will be compared in terms of space required and the total picking distance. The grouping that requires lower space and results in shorter picking distance will be selected for implementation in the raw materials warehouse. The comparison of required space and the total picking distance between grouping level 1 and grouping level 2 is shown in Table 65.

Table 65. Compare the total required space and the picking distance between grouping level 1 and grouping level 2

	Grouping Level 1	**Grouping Level 2**	**Differences**
Total Required Space (#Locations)	3,844	3,891	1.2%
Total Picking Distance (km)	1,301.78	1,102.45	15.3%

Grouping level 2 requires more locations than grouping level 1 by 47 locations or 1.2%. This number can be converted to opportunity saving cost of 128,662.5 THB per year (47 locations × 7.5 THB/day/location × 365 days/year) that grouping level 1 can gain over grouping level 2. However, the total picking distance of grouping level 2 is shorter than grouping level 1 by 199.32 km or 15.3%. This number can be converted to opportunity saving cost of 137,802.1 THB per year (199.32 km/1301.78 km × 25,000 THB/operator/month × 3 operators × 12 months/year) that grouping level 2 can gain over grouping level 1. Based on these comparisons, grouping level 2 is more attractive for implementation than grouping level 1. So, grouping level 2 is selected to be implemented in the raw materials warehouse.

By choosing grouping level 2 for implementation in the raw materials warehouse, the available locations after reallocating space for raw materials are 326 locations including low racks 2 locations, medium racks 306 locations, and high racks 18 locations. Rack types that can be used for storing finished products are medium racks and high racks which are accounted for 324 locations. In the next part, some finished products are chosen to be stored at the raw materials warehouse.

4.7. Selecting the most suitable finished products to be stored at raw materials warehouse

As discussed with the warehouse team of the case study company, there are three possible groups of finished products that can be stored in the raw materials warehouse. The first option is to store damaged, expired, obsolete finished products at the raw materials warehouse. Currently, these groups of finished products occupy 320 locations at the external warehouse. However, the warehouse manager has plan to review and move these product groups out from the external warehouse by quarter. In average, damaged, expired and obsolete finished products are 35 pallets per month. Hence, the required space in the warehouse for locating these product groups is 35*3 = 105 locations. The saving from storing these product groups in the raw materials warehouse is (35pallets*7.5THB/pallet/day*90days/month+35pallets*7.5THB/pallet/day*60days/month+35pallets*7.5THB/pallet/day*30days)/3 = 15,750 THB per month. For the cost involved, these products have to be transported back from the external warehouse to the raw materials warehouse which this process costs 2,150 THB per month. So, the net benefit is 13,600 THB per month or 163,200 THB per year.

The second option is to store fresh finished products after production at the raw materials warehouse for two days. Recently, finished products are directly shipped to be stored at the external warehouse on the same day of production while testing results do not come out which normally take three days on average. As a result, the recall to transport finished products back to the manufacturing plant is required in case that finished products are out of specification. With this option, it can help to reduce risks from recalling finished products back. However, storing finished products for three days is not possible as minimum locations required are 480 locations (normally finished products are produced 160 pallets/day*3 days) but the available locations in the raw materials warehouse are only 324 locations. By storing finished products for two days at the raw materials warehouse, it cannot help to reduce recalling risk but it can help to save storing cost at the external warehouse for two days which is about 72,000 THB per month (320locations*7.5 THB/location/day*30 days/month). On the other hand, two more operators are needed to support this process which costs 50,000 THB per month. Thus, the net benefit is 22,000 THB per month or 264,000 THB per year.

The last option is to store Japan retail products at the raw materials warehouse and directly ship them from the raw materials warehouse to seaport. Japan retail product is the only possible group of finished products to be stored at the raw materials warehouse because Japan retail products are usually shipped in full pallets while other finished products are sold in cartons and many SKUs of products can be mixed in one pallet. However, it is not possible to store all 53 SKUs of Japan retail products in the raw materials warehouse. The selected SKUs are SKUs that sum of inventories are not over 324 pallets and weekly shipment can fully utilize truck's space (40 pallets per truck). SKUs that are aligned with these requirements are SKUs number 99240015867 and 99240015855. Cost saving from this option comes from storage cost saving at the external warehouse which is about 72,900 THB per month (324 locations*7.5 THB/location/day*30 days/month) and cheaper shipping cost by 8,000 THB per month as distance from manufacturing plant to seaport is closer than distance from the external warehouse to the seaport. Nevertheless, this option requires an additional three operators to operate which costs 75,000 THB per month and requires one additional push-pull equipment used in the loading process which costs 1,417 THB per month. The net benefit is 4,483.33 per month or 53,800 THB per year.

All benefits and costs of each option are summarized in Table 66. The most attractive option is the second option which is storing fresh finished products at raw materials warehouse for two days before shipping them to the external warehouse. So, this option is selected for implementation in the raw materials warehouse.

Table 66. Options for storing finished products at raw materials warehouse

Options	Details	Pros	Benefits (THB per month)	Cons	Costs (THB per month)	Net Benefit (THB per month)	Net Benefit (THB per year)
1	Storing damage, expired, stop-ship-date (SSD), and obsolete materials at raw materials warehouse - Currently 320 locations in DHL warehouse - Plan: Physical write-off once a quarter - Average damage and SSD per month = 35 pallets - Hence, require storage space is 35*3 = 105 locations in raw materials warehouse	- Save storing cost at DHL warehouse (Saving cost for each quarter = (35 pallets*7.5THB/pallet day*90 days+35*7.5*60+35*7.5*30) = 47,250 THB)	15,750.00	- Transportation cost to transport these products from DHL warehouse back to plant is required. (One time a month = 2,150 THB (35 pallet per truck))	2,150.00	13,600.00	163,200.00
2	Storing fresh finished goods after produced at raw materials warehouse for 2 days before shipping to DHL warehouse - Normally we ship 4 trucks a day = 4 trucks*40 pallets per truck =160 pallets a day - Hence, require storage space is 160*2 = 320 locations in raw materials warehouse	- Save storing cost at DHL warehouse for 2 days as available locations for finished products at raw materials warehouse is 324 locations	72,000.00	- Double touch in operation is involved and this process requires additional two workers to support storing finished products for 2 days at raw materials warehouse - Available locations in raw materials are not enough to store finished products for 3 days (require 480 locations). So, the company loses the opportunity to prevent risk in recalling finished products back.	50,000.00	22,000.00	264,000.00
3	Storing Japan retail products at raw materials warehouse and direct ship from manufacturing plant to sea port	- Save storing cost at DHL warehouse for 324 locations	72,900.00	- Required additional 3 headcounts at manufacturing plant to manage pick, pack, and loading finished products to trucks	75,000.00	4,483.33	53,800.00
		- Cheaper on shipping cost as distance from manufacturing plant to sea port is closer than distance from DHL to sea port	8,000.00	- Required 1 additional equipment (push-pull machine) for loading finished products into trucks	1,416.67		

4.8. Summary results from raw materials warehouse improvement

In this part, results from raw materials warehouse improvement under this research are presented by comparing with the current situation and the current layout in the raw materials warehouse. The overall results linked to each implementation plan are summarized in Figure 31.

Actions	RESULTS			
	Capacity Enhancement	Utilization Improvement	Picking Distance Reduction	Cost Saving
Removing obsolete materials from raw materials warehouse	✓			
Regrouping and reallocating space for each group of materials		✓		
Adjusting beam height	✓			
Reassigning locations for each group of materials			✓	
Storing some finished products at raw materials warehouse				✓

Figure 31. The overall results linked to each implementation plan

4.8.1. Capacity enhancement

In terms of capacity enhancement, capacity in the raw materials warehouse is improved under this research based on two actions, namely removing obsolete products from the raw materials warehouse and adjusting beam height to match the actual size of materials.

From the first action which is clearing obsolete products from the raw materials warehouse, free space is increased by 9.04 % or 368 locations. From the second action which is adjusting beam height to match the actual size of materials, the total rack locations in raw materials is increased by 3.61% or 147 locations.

Overall, the capacity in the raw materials warehouse is improved by 12.65% or 515 locations.

4.8.2. Utilization improvement

Based on current space allocation in the raw materials warehouse, the space allocated to each group of materials is not appropriate as it does not match the actual inventory of each material group. As a result, some groups of materials are overflow to other areas in which the overflow process requires additional human effort to manually assign locations for materials. In addition, the overflow process results in longer picking distance as materials are not located in proper locations. In this research, space for each group of materials is reallocated based on maximum inventory levels to avoid the overflow of materials to non-assigned locations. The average utilization before and after improvement is present in Figure 32. In addition, monthly utilization of the raw materials warehouse before and after improvement is presented in Table 67 and Table 68, respectively.

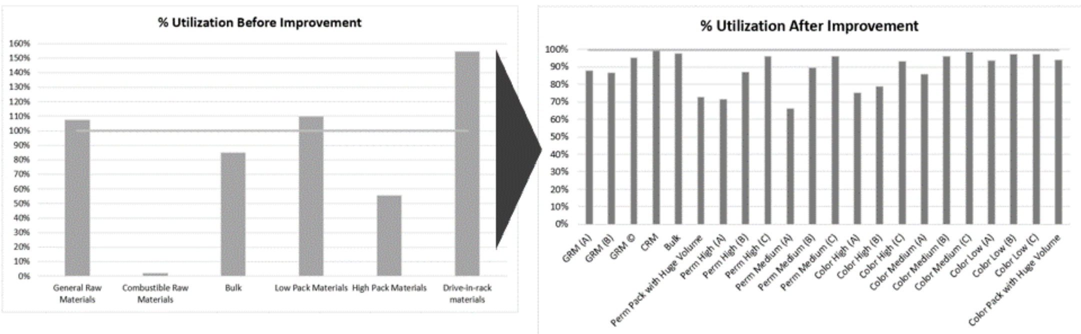


Figure 32. Average utilization of each material group before and after improvement

Table 67. Monthly utilization before improvement

Material Groups	Utilization Before Improvement											
	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
General Raw Materials	93.6%	101.6%	115.2%	117.0%	112.8%	109.0%	109.0%	109.7%	105.3%	105.5%	110.6%	98.2%
Combustible Raw Materials	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%
Bulk	87.1%	83.2%	149.5%	128.2%	108.9%	93.6%	62.4%	60.9%	60.4%	61.4%	61.4%	60.4%
Low Pack Materials (Height < 1.8 m)	115.7%	117.9%	113.3%	111.1%	112.4%	107.3%	109.4%	108.4%	106.4%	105.3%	106.2%	104.6%
High Pack Materials (Height > 1.8 m)	43.5%	50.5%	55.8%	66.4%	57.7%	52.3%	60.5%	57.3%	50.9%	57.0%	58.4%	53.3%
Drive-in-rack materials	170.3%	191.0%	133.5%	157.5%	175.0%	144.0%	145.5%	140.8%	160.5%	172.5%	120.3%	145.0%
Overall utilization	**91.0%**	**96.9%**	**96.3%**	**100.3%**	**98.3%**	**90.4%**	**92.3%**	**90.5%**	**89.1%**	**91.8%**	**88.2%**	**86.7%**

Table 68. Monthly utilization after improvement

Groups	Material Groups	Utilization After Improvement											
		Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
Group 1	General raw materials (A)	79.8%	85.9%	100.0%	95.2%	91.7%	84.6%	89.7%	91.7%	83.3%	87.5%	93.9%	72.1%
Group 2	General raw materials (B)	74.0%	78.8%	92.3%	100.0%	93.8%	93.3%	86.1%	84.1%	86.5%	81.3%	84.6%	84.1%
Group 3	General raw materials (C)	77.8%	88.9%	90.4%	97.0%	97.8%	99.3%	98.5%	100.0%	97.8%	97.0%	97.8%	98.5%
Group 4	Combustible raw materials	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 5	Bulk	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	96.9%	94.6%	93.8%	95.4%	95.4%	93.8%
Group 6	Perm Pack Material with Huge Volume	75.6%	126.3%	7.5%	73.8%	109.4%	20.6%	41.9%	68.8%	101.3%	140.6%	27.5%	77.5%
Group 7	Perm High (A)	44.0%	40.4%	64.7%	100.0%	94.9%	97.5%	85.8%	59.3%	74.2%	61.1%	67.6%	66.2%
Group 8	Perm High (B)	100.0%	97.1%	94.3%	100.0%	91.0%	86.2%	84.8%	79.0%	81.4%	78.1%	80.0%	73.8%
Group 9	Perm High (C)	98.3%	100.0%	97.4%	98.3%	96.1%	97.0%	94.4%	94.4%	95.3%	95.3%	94.0%	93.6%
Group 10	Perm Medium (A)	100.0%	96.0%	71.5%	67.5%	55.6%	63.6%	66.9%	60.3%	58.9%	49.0%	53.6%	49.0%
Group 11	Perm Medium (B)	86.3%	93.7%	98.9%	100.0%	97.9%	94.7%	93.7%	87.4%	78.9%	80.0%	78.9%	81.1%
Group 12	Perm Medium (C)	96.1%	97.4%	94.7%	93.4%	93.4%	92.1%	92.1%	96.1%	98.7%	98.7%	100.0%	100.0%
Group 13	Color High (A)	65.7%	74.6%	100.0%	76.6%	77.6%	71.6%	60.7%	67.7%	56.2%	87.1%	87.1%	77.1%
Group 14	Color High (B)	90.3%	95.8%	100.0%	93.1%	80.6%	68.1%	66.7%	73.6%	66.7%	69.4%	66.7%	73.6%
Group 15	Color High (C)	100.0%	100.0%	97.7%	95.5%	95.5%	94.3%	92.0%	94.3%	88.6%	87.5%	85.2%	86.4%
Group 16	Color Medium (A)	96.4%	100.0%	93.8%	86.6%	99.0%	70.5%	82.0%	78.4%	84.9%	75.1%	84.6%	76.7%
Group 17	Color Medium (B)	95.6%	100.0%	97.3%	97.3%	98.9%	95.6%	95.1%	92.3%	93.4%	97.8%	94.0%	92.9%
Group 18	Color Medium (C)	95.9%	98.4%	97.1%	97.6%	98.0%	99.2%	99.2%	98.4%	99.2%	100.0%	99.2%	99.2%
Group 19	Color Low (A)	100.0%	99.3%	95.3%	95.3%	94.5%	95.6%	93.8%	99.3%	85.4%	90.1%	86.5%	89.1%
Group 20	Color Low (B)	97.4%	98.7%	100.0%	97.4%	97.4%	97.4%	97.4%	97.4%	94.7%	96.7%	96.1%	95.4%
Group 21	Color Low (C)	96.6%	100.0%	100.0%	97.9%	97.9%	97.9%	97.9%	97.9%	95.2%	95.2%	94.5%	94.5%
Group 22	Color Pack Material with Huge Volume	75.0%	109.2%	76.3%	104.2%	82.5%	70.8%	130.0%	114.2%	85.0%	102.9%	92.5%	86.3%
	Overall Utilization	**86.3%**	**92.7%**	**88.6%**	**93.9%**	**92.8%**	**85.3%**	**88.8%**	**86.9%**	**85.5%**	**88.3%**	**84.5%**	**82.9%**

From the above tables, they clearly demonstrate that the utilization of each material group after improvement is more balanced than the utilization of each material group before improvement. The average utilization of each material group is lower than 100%. Thus, there are few materials overflowing across the assigned locations. There are only two groups of materials after improvement that utilization over 100% which are perm pack materials with huge volume and color pack materials with huge volume. However, these two groups of materials are allowed to be located in perm high and color high areas in case that their assigned space is not enough.

4.8.3. Picking distance reduction

Based on new assigned locations for each group of materials in the raw materials warehouse, overall picking distance is expected to be reduced significantly as materials are located in proper locations and assigned based on ABC class-based storage. Detail calculation of the total picking distance before improvement is shown in Table 69 and the comparison of the total picking distance before and after improvement is shown in Table 70.

Table 69. Total picking distance before improvement

Material Groups	Before Improvement		
	Total Picking Frequency	Average Distance (cm)	Total Picking Distance (cm)
General Raw Materials	3,292	2,233.48	14,705,232.32
Combustible Raw Materials	12	1,522.82	36,547.68
Bulk Materials	260	5,102.34	2,653,216.80
Low Pack Materials (Height < 1.8 m)	6,016	6,596.39	79,367,764.48
High Pack Materials (Height > 1.8 m)	6,120	7,021.07	85,937,896.80
Drive-in-rack materials	3,699	6,279.00	46,452,042.00
Total Distance (cm)			**229,152,700.08**
Total Distance (km)			**2,291.53**

Table 70. Comparison of total picking distance before and after improvement

	Total Picking Distance (km)
Before Improvement	2,291.53
After Improvement	1,102.45
% Improvement	**51.9%**

From the results, the total picking distance after improvement is reduced by 52%. By reducing the total picking distance, picking time should also reduce and productivity should increase. In other word, operators will have more available time to do other value-added activities in the raw materials warehouse such as training and Kaizen.

4.8.4. Cost reduction

As there are 326 locations available in the raw materials warehouse after reallocating areas for raw materials, 324 locations are planned to be used for storing fresh finished products after production for two days prior to moving to be stored at the external warehouse. The cost saving of 264,000 THB per year is obtained from storage cost reduction at the external warehouse.

Chapter 5

Robustness Analysis

In this chapter, the robustness of the proposed model is analyzed and the contingency plan is developed. As the space for each material group is allocated based on the maximum forecasted month-end inventory, changing in forecast can impact the utilization, total picking distance, and cost saving as presented earlier in part 4.9. For the robustness analysis, forecasted inventory is assumed to be increased by 5% and 10%. Based on the historical data as presented in part 3.1.1, maximum month-end inventory was at 99.1 percentile. Hence, 10% increasing in forecasted inventory could be used to represent the worst-case scenario that can occur in the raw materials warehouse. Then, utilization is measured based on the space allocation in part 4.3. In case that utilization is over 100%, the contingency plan developed under this research is applied for assigning the overflow materials to other available locations and the additional picking travel distance is reported.

5.1. Scenario 1: 5% increasing in forecasted inventory

By assuming that forecasted inventory of all SKUs is increased by 5%, utilization over 100% is expected to occur as previously the allocated space is based on the maximum month-end inventory. Figure 33 illustrates average utilization and Table 71 presents monthly utilization for scenario 1 that forecasted inventory is increased by 5%.

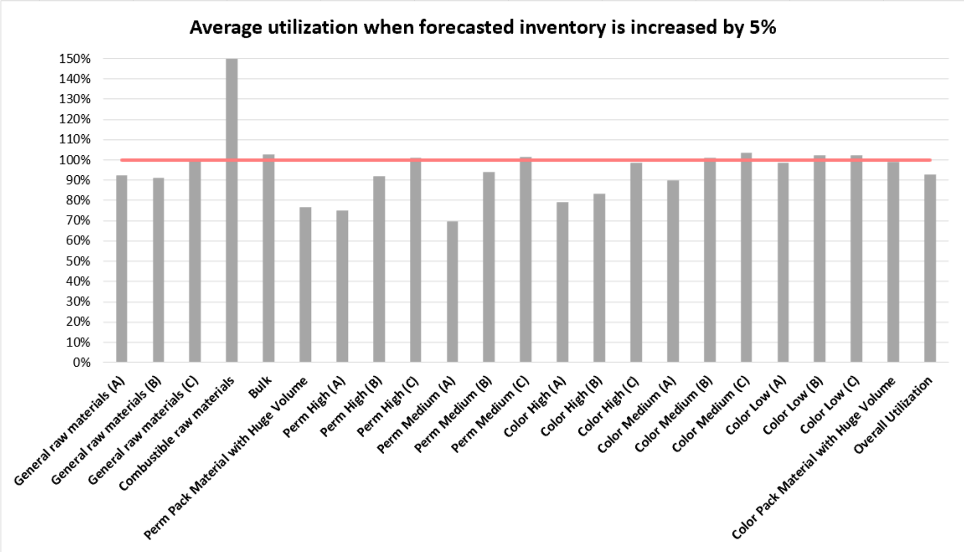


Figure 33. Average utilization of scenario 1 that forecasted inventory is increased by 5%

Table 71. Monthly utilization of scenario 1 that forecasted inventory is increased by 5%

Groups	Material Groups	Utilization when forecasted inventory is increased by 5%											
		Jan-19	**Feb-19**	**Mar-19**	**Apr-19**	**May-19**	**Jun-19**	**Jul-19**	**Aug-19**	**Sep-19**	**Oct-19**	**Nov-19**	**Dec-19**
Group 1	General raw materials (A)	84.0%	90.4%	105.1%	100.0%	96.5%	89.1%	94.2%	96.5%	87.5%	92.0%	98.7%	76.0%
Group 2	General raw materials (B)	77.9%	83.2%	97.1%	105.3%	98.6%	98.1%	90.4%	88.5%	90.9%	85.6%	88.9%	88.5%
Group 3	General raw materials (C)	82.2%	93.3%	95.6%	102.2%	103.0%	104.4%	103.7%	105.2%	103.0%	102.2%	103.0%	103.7%
Group 4	Combustible raw materials	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%
Group 5	Bulk	105.4%	105.4%	105.4%	105.4%	105.4%	105.4%	102.3%	100.0%	99.2%	100.8%	100.8%	99.2%
Group 6	Perm Pack Material with Huge Volume	80.0%	133.1%	8.1%	77.5%	115.0%	21.9%	44.4%	72.5%	106.9%	148.1%	29.4%	81.9%
Group 7	Perm High (A)	46.5%	42.5%	68.0%	105.1%	100.0%	102.5%	90.2%	62.5%	78.2%	64.4%	71.3%	69.8%
Group 8	Perm High (B)	105.2%	102.4%	99.0%	105.2%	95.7%	91.0%	89.0%	83.3%	85.7%	82.4%	84.3%	77.6%
Group 9	Perm High (C)	103.4%	105.2%	102.6%	103.4%	101.3%	102.1%	99.1%	99.1%	100.4%	100.4%	98.7%	98.3%
Group 10	Perm Medium (A)	105.3%	101.3%	75.5%	71.5%	58.9%	66.9%	70.9%	63.6%	62.3%	51.7%	57.0%	51.7%
Group 11	Perm Medium (B)	91.6%	98.9%	104.2%	105.3%	103.2%	100.0%	98.9%	92.6%	83.2%	84.2%	83.2%	85.3%
Group 12	Perm Medium (C)	101.3%	102.6%	100.0%	98.7%	98.7%	97.4%	97.4%	101.3%	103.9%	103.9%	105.3%	105.3%
Group 13	Color High (A)	69.2%	78.6%	105.5%	80.6%	81.6%	75.6%	64.2%	71.1%	59.2%	91.5%	91.5%	81.1%
Group 14	Color High (B)	95.8%	101.4%	105.6%	98.6%	84.7%	72.2%	70.8%	77.8%	70.8%	73.6%	70.8%	77.8%
Group 15	Color High (C)	105.7%	105.7%	103.4%	101.1%	101.1%	100.0%	97.7%	100.0%	93.2%	92.0%	89.8%	90.9%
Group 16	Color Medium (A)	101.3%	105.2%	98.7%	91.1%	104.3%	74.1%	86.2%	82.3%	89.2%	79.0%	88.9%	80.7%
Group 17	Color Medium (B)	100.5%	105.5%	102.2%	102.2%	103.8%	100.5%	100.0%	97.3%	98.4%	102.7%	98.9%	97.8%
Group 18	Color Medium (C)	100.8%	103.7%	102.0%	102.4%	102.9%	104.5%	104.5%	103.7%	104.5%	105.3%	104.5%	104.5%
Group 19	Color Low (A)	105.1%	104.4%	100.4%	100.4%	99.3%	100.7%	98.5%	104.4%	89.8%	94.9%	90.9%	93.8%
Group 20	Color Low (B)	102.6%	103.9%	105.3%	102.6%	102.6%	102.6%	102.6%	102.6%	100.0%	102.0%	101.3%	100.7%
Group 21	Color Low (C)	101.4%	105.5%	105.5%	103.4%	103.4%	103.4%	103.4%	103.4%	100.0%	100.0%	99.3%	99.3%
Group 22	Color Pack Material with Huge Volume	78.8%	115.0%	80.4%	109.6%	86.7%	74.6%	136.7%	120.0%	89.6%	108.3%	97.5%	90.8%
	Overall Utilization	**90.9%**	**97.7%**	**93.3%**	**98.9%**	**97.7%**	**89.9%**	**93.6%**	**91.6%**	**90.0%**	**93.0%**	**89.0%**	**87.3%**
Grouping by Material Height	Low Materials	103.5%	104.6%	103.0%	101.8%	101.2%	101.9%	100.9%	103.7%	95.1%	98.1%	95.8%	97.0%
	Medium Materials	94.4%	98.5%	99.1%	98.2%	98.1%	92.2%	94.2%	92.5%	91.9%	90.2%	93.3%	87.6%
	High Pack Materials	82.6%	83.5%	93.9%	99.4%	95.1%	93.0%	86.4%	80.2%	81.6%	83.6%	85.0%	81.8%
	DIR + High Pack Materials	81.7%	94.0%	82.4%	98.7%	95.9%	82.3%	90.0%	85.8%	85.7%	94.6%	81.0%	83.3%
Availability of Assigned Rack's Type	Low Racks	-20	-26	-17	-10	-7	-11	-5	-21	28	11	24	17
	Medium Racks	104	28	16	34	35	143	107	138	149	181	123	229
	High Racks	188	178	66	6	53	76	147	214	198	177	162	196
	DIR + High Pack Materials	271	89	260	19	61	262	148	210	212	80	281	247

The data showed in Table 71 demonstrates that utilization over 100% occurring in some group of materials in some months. As the company has the policy to reassign locations for each group of materials once a year, the contingency plan is needed for handling with overflow materials occurring during a year.

Figure 34 reveals the searching strategy for the next locations if assigned locations are full. First, locations of the same group of materials but across classes are searched if the assigned locations are full. If they are not available, the second priority is searching for locations of the same group of materials but different heights followed by searching for locations of materials in the same usage area and locations of materials across usage area, consequently. This logic of searching strategy is input in the SAP system. So, once the assigned locations are full, the SAP system will auto-recommend the next locations based on this logic. However, materials across locations are reviewed by monthly and relocated back to their assign locations if their assigned locations are available in order to minimize materials locating across locations and minimize the total picking distance.

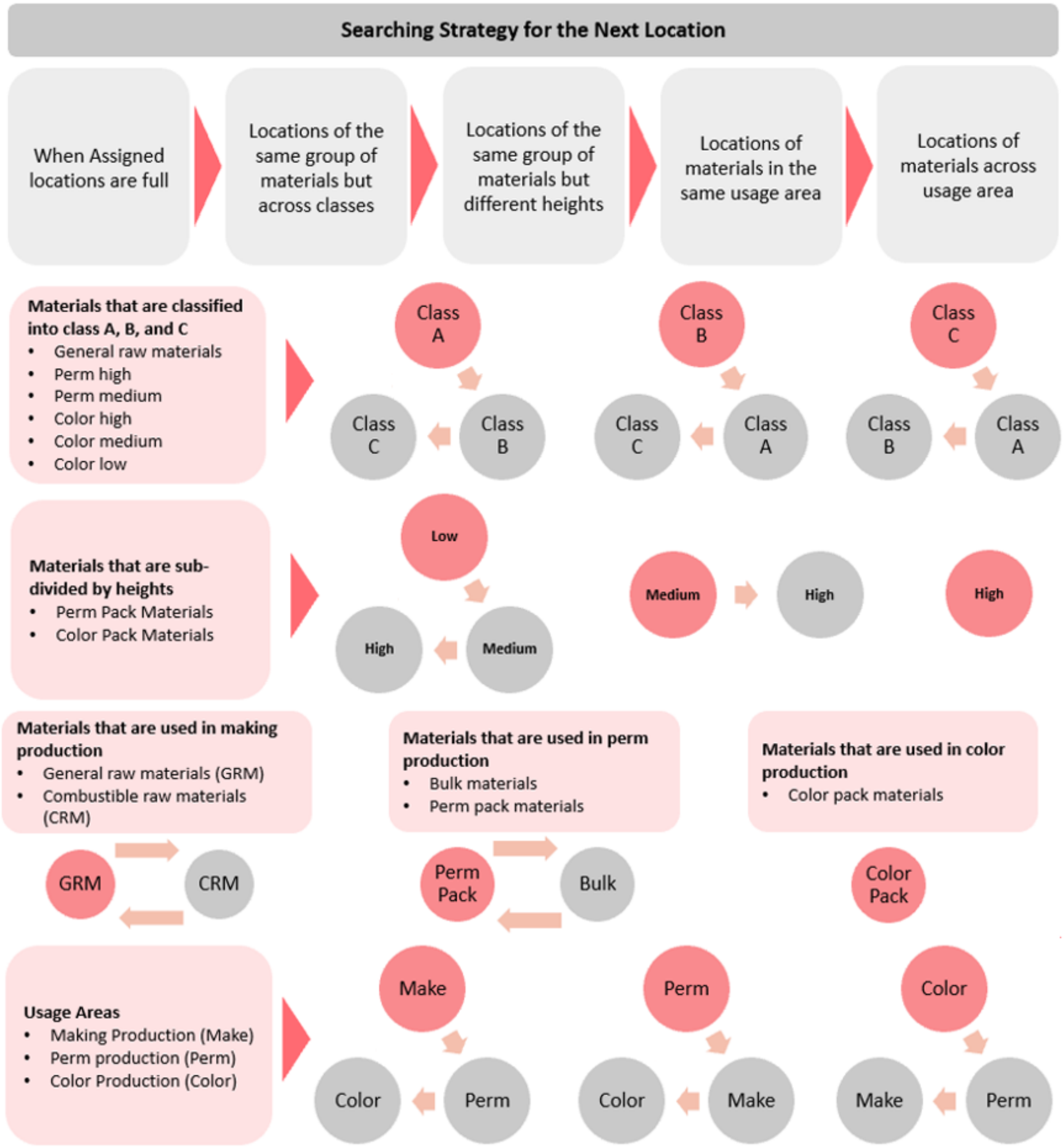


Figure 34. Overall searching strategy for the next locations

Table 72 and Table 73 present the summary of searching strategy for the next locations under material group levels and material class levels, respectively.

Table 72. Searching strategy for the next locations under material group levels

Starting Point	Next 1	Next 2	Next 3	Next 4	Next 5	Next 6	Next 7
General Raw Materials	Combustible Raw Materials	Perm Medium	Bulk	Perm High	Color Medium	Color High	
Combustible Raw Materials	General Raw Materials	Perm Medium	Bulk	Perm High	Color Medium	Color High	
Bulk	Perm Medium	General Raw Materials	Combustible Raw Materials	Color Medium			
Perm Pack Material with Huge Volume	Perm High	Color High	Color Pack Material with Huge Volume				
Perm High	Color High						
Perm Medium	Bulk	Perm High	General Raw Materials	Combustible Raw Materials	Color Medium	Color High	
Color High	Perm High						
Color Medium	Color High	Perm Medium	Bulk	Perm High	General Raw Materials	Combustible Raw Materials	
Color Low	Color Medium	Color High	Perm Medium	Bulk	Perm High	General Raw Materials	Combustible Raw Materials
Color Pack Material with Huge Volume	Color High	Perm High	Perm Pack Material with Huge Volume				

Table 73. Searching strategy for the next locations under material class levels

Starting Point	Next 1	Next 2
Class A	Class B	Class C
Class B	Class A	Class C
Class C	Class A	Class B

Searching strategy is valid as long as the next locations are available for storing materials. On the other hand, the invalid case can occur if there is no suitable rack available after searching for the next locations. In that case, the previous space allocated for finished products is needed to be adjusted by allocating locations back to raw materials.

For the scenario that forecasted inventory is increased by 5%, the only group of racks that are not enough is low racks as utilization of low materials is over 100%. However, low materials are capable to be stored in medium and high racks which are still available. Hence, searching strategy is still valid for this scenario and there is no need to adjust space allocated for finished products.

The impacts from increasing forecasted inventory by 5% are higher travel distance during picking process as some of materials are located in other locations which are not the most suitable locations and higher work effort to relocate materials back to assigned locations once a month. From the analysis as presented in

Table 74, the total picking distance is increased by 2.3% compared to based case scenario and about 81 touches per month are required to locate materials back to their assign locations. The average utilization and monthly utilization after using searching for the next locations strategy are presented in Figure 35 and Table 75, respectively. It is noticeable that utilization of all material groups after using searching for the next locations strategy is not over 100% as the next locations are always available for this scenario.

Table 74. Total picking distance of scenario 1 that forecasted inventory is increased by 5%

	Total Picking Distance (km)
Base case scenario	1,102.45
5% increase in forecasted inventory	1,127.40
% Increase	**2.3%**

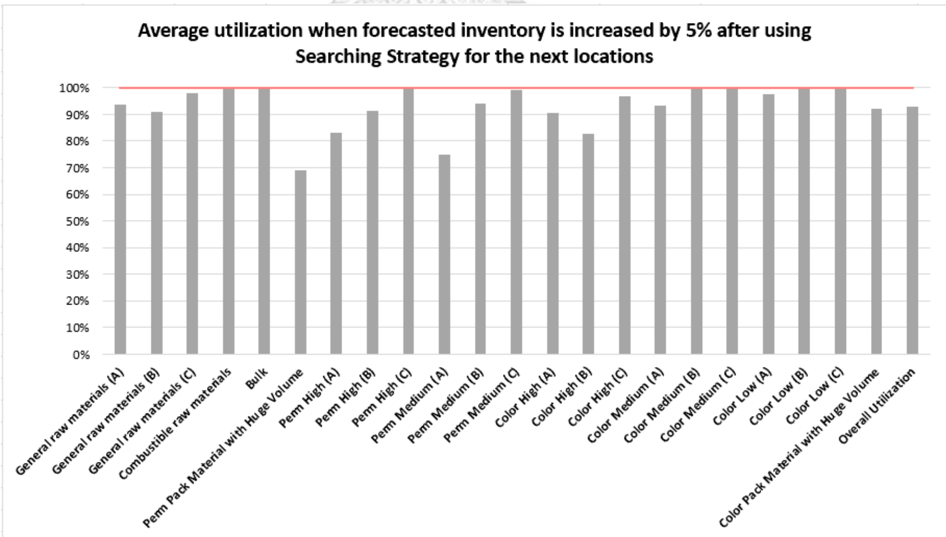


Figure 35. Average utilization of scenario 1 after using searching strategy for the next locations

Table 75. Monthly utilization of scenario 1 after using searching strategy for the next locations

Groups	Material Groups	Utilization when forecasted inventory is increased by 5% after use searching strategy for the next locations											
		Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
Group 1	General raw materials (A)	86.5%	92.9%	100.0%	100.0%	98.1%	91.3%	96.2%	99.0%	89.1%	93.3%	100.0%	77.9%
Group 2	General raw materials (B)	77.9%	83.2%	100.0%	100.0%	98.6%	98.1%	90.4%	88.5%	90.9%	85.6%	89.4%	88.5%
Group 3	General raw materials (C)	82.2%	93.3%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 4	Combustible raw materials	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 5	Bulk	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.2%	100.0%	100.0%	99.2%
Group 6	Perm Pack Material with Huge Volume	80.0%	100.0%	8.1%	91.9%	100.0%	21.9%	44.4%	72.5%	100.0%	100.0%	29.4%	81.9%
Group 7	Perm High (A)	53.8%	90.9%	77.1%	100.0%	100.0%	100.0%	96.0%	62.5%	82.5%	93.8%	71.3%	69.8%
Group 8	Perm High (B)	100.0%	100.0%	99.0%	100.0%	100.0%	96.7%	89.0%	83.3%	85.7%	82.4%	84.3%	77.6%
Group 9	Perm High (C)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.1%	99.1%	100.0%	100.0%	98.7%	98.3%
Group 10	Perm Medium (A)	100.0%	100.0%	100.0%	89.4%	65.6%	71.5%	72.8%	64.2%	64.2%	54.3%	60.3%	54.3%
Group 11	Perm Medium (B)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	98.9%	92.6%	83.2%	84.2%	83.2%	85.3%
Group 12	Perm Medium (C)	100.0%	100.0%	100.0%	98.7%	98.7%	97.4%	97.4%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 13	Color High (A)	85.1%	100.0%	100.0%	97.5%	100.0%	75.6%	100.0%	95.0%	59.2%	100.0%	91.5%	81.1%
Group 14	Color High (B)	95.8%	100.0%	100.0%	98.6%	84.7%	72.2%	70.8%	77.8%	70.8%	73.6%	70.8%	77.8%
Group 15	Color High (C)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	97.7%	100.0%	93.2%	92.0%	89.8%	90.9%
Group 16	Color Medium (A)	100.0%	100.0%	100.0%	97.7%	100.0%	81.6%	91.5%	92.1%	92.8%	84.9%	92.5%	84.3%
Group 17	Color Medium (B)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	97.3%	98.4%	100.0%	98.9%	97.8%
Group 18	Color Medium (C)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 19	Color Low (A)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	89.8%	96.0%	91.6%	94.2%
Group 20	Color Low (B)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 21	Color Low (C)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.3%	99.3%
Group 22	Color Pack Material with Huge Volume	78.8%	100.0%	80.4%	100.0%	93.3%	74.6%	100.0%	100.0%	89.6%	100.0%	97.5%	90.8%
Overall Utilization		**90.9%**	**97.7%**	**93.3%**	**98.9%**	**97.7%**	**89.9%**	**93.6%**	**91.6%**	**90.0%**	**93.0%**	**89.0%**	**87.3%**
Grouping by Material Height	Low Materials	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	95.1%	98.1%	95.8%	97.0%
	Medium Materials	93.9%	96.4%	100.0%	98.7%	96.6%	92.8%	94.5%	93.6%	91.9%	90.2%	93.3%	87.6%
	High Pack Materials	85.2%	97.7%	94.0%	99.4%	99.0%	93.0%	94.5%	84.6%	82.7%	92.6%	85.0%	81.8%
	DIR + High Pack Materials	83.6%	98.3%	82.5%	98.7%	98.2%	82.3%	90.0%	85.8%	85.7%	94.6%	81.0%	83.3%
Availability of Assigned Rack's Type	Low Racks	0	0	0	0	0	0	0	0	28	11	24	17
	Medium Racks	112	66	0	24	62	132	102	117	149	181	123	229
	High Racks	160	25	65	6	11	76	59	166	187	80	162	196
	DIR + High Pack Materials	243	25	259	19	27	262	148	210	212	80	281	247

5.2. Scenario 2: 10% increasing in forecasted inventory

For scenario 2 that forecasted inventory is increased by 10%, overutilization is expected to be more critical than scenario 1 (forecasted inventory is increased by 5%). Figure 36 presents average utilization and Table 76 illustrates monthly utilization for scenario 2 that forecasted inventory overshoots from the base case by 10%.

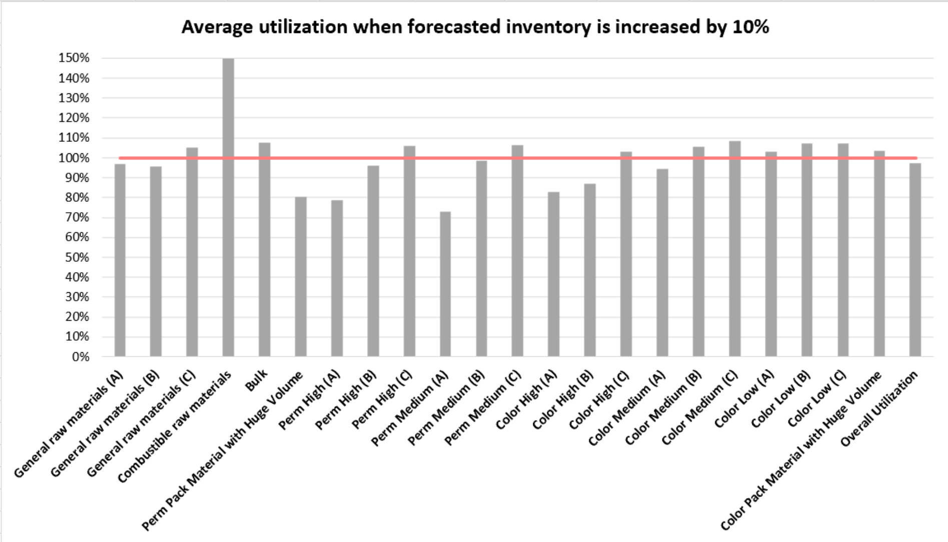


Figure 36. Average utilization of scenario 2 that forecasted inventory is increased by 10%

Table 76. Monthly utilization of scenario 2 that forecasted inventory is increased by 10%

Groups	Material Groups	Utilization when forecasted inventory is increased by 10%											
		Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
Group 1	General raw materials (A)	87.8%	94.6%	110.3%	104.8%	101.0%	93.3%	98.7%	101.0%	91.7%	96.5%	103.5%	79.5%
Group 2	General raw materials (B)	81.7%	87.0%	101.9%	110.1%	103.4%	102.9%	94.7%	92.8%	95.2%	89.4%	93.3%	92.8%
Group 3	General raw materials (C)	85.9%	97.8%	100.0%	107.4%	108.1%	109.6%	108.9%	110.4%	108.1%	107.4%	108.1%	108.9%
Group 4	Combustible raw materials	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%	150.0%
Group 5	Bulk	110.0%	110.0%	110.0%	110.0%	110.0%	110.0%	106.9%	104.6%	103.8%	105.4%	105.4%	103.8%
Group 6	Perm Pack Material with Huge Volume	83.8%	139.4%	8.8%	81.3%	120.6%	23.1%	46.3%	75.6%	111.9%	155.0%	30.6%	85.6%
Group 7	Perm High (A)	48.7%	44.7%	71.3%	110.2%	104.7%	107.3%	94.5%	65.5%	81.8%	67.3%	74.5%	73.1%
Group 8	Perm High (B)	110.0%	107.1%	103.8%	110.0%	100.5%	95.2%	93.3%	87.1%	90.0%	86.2%	88.1%	81.4%
Group 9	Perm High (C)	108.2%	110.3%	107.3%	108.2%	106.0%	106.9%	103.9%	103.9%	105.2%	105.2%	103.4%	103.0%
Group 10	Perm Medium (A)	110.6%	106.0%	78.8%	74.8%	61.6%	70.2%	74.2%	66.9%	64.9%	54.3%	59.6%	54.3%
Group 11	Perm Medium (B)	95.8%	103.2%	109.5%	110.5%	108.4%	104.2%	103.2%	96.8%	87.4%	88.4%	87.4%	89.5%
Group 12	Perm Medium (C)	106.6%	107.9%	105.3%	103.9%	103.9%	101.3%	101.3%	106.6%	109.2%	109.2%	110.5%	110.5%
Group 13	Color High (A)	72.6%	82.1%	110.4%	84.6%	85.6%	79.1%	67.2%	74.6%	62.2%	96.0%	96.0%	85.1%
Group 14	Color High (B)	100.0%	105.6%	111.1%	102.8%	88.9%	75.0%	73.6%	81.9%	73.6%	76.4%	73.6%	81.9%
Group 15	Color High (C)	110.2%	110.2%	108.0%	105.7%	105.7%	104.5%	102.3%	104.5%	97.7%	96.6%	94.3%	95.5%
Group 16	Color Medium (A)	106.2%	110.2%	103.3%	95.4%	109.2%	77.7%	90.2%	86.2%	93.4%	82.6%	93.1%	84.6%
Group 17	Color Medium (B)	105.5%	110.4%	107.1%	107.1%	108.8%	105.5%	104.9%	101.6%	102.7%	107.7%	103.8%	102.2%
Group 18	Color Medium (C)	105.7%	108.6%	106.9%	107.3%	107.8%	109.4%	109.4%	108.6%	109.4%	110.2%	109.4%	109.4%
Group 19	Color Low (A)	110.2%	109.5%	105.1%	105.1%	104.0%	105.5%	103.3%	109.5%	94.2%	99.3%	95.3%	98.2%
Group 20	Color Low (B)	107.2%	108.6%	110.5%	107.2%	107.2%	107.2%	107.2%	107.2%	104.6%	106.6%	105.9%	105.3%
Group 21	Color Low (C)	106.2%	110.3%	110.3%	108.3%	108.3%	108.3%	108.3%	108.3%	104.8%	104.8%	104.1%	104.1%
Group 22	Color Pack Material with Huge Volume	82.5%	120.4%	84.2%	114.6%	90.8%	77.9%	143.3%	125.8%	93.8%	113.3%	102.1%	95.0%
	Overall Utilization	**95.2%**	**102.2%**	**97.8%**	**103.5%**	**102.4%**	**94.1%**	**98.0%**	**95.9%**	**94.3%**	**97.4%**	**93.2%**	**91.5%**
Grouping by Material Height	Low Materials	108.4%	109.5%	107.9%	106.5%	106.0%	106.7%	105.6%	108.6%	99.6%	102.6%	100.4%	101.6%
	Medium Materials	98.9%	103.0%	103.9%	102.8%	102.8%	96.6%	98.6%	96.9%	96.3%	94.5%	97.8%	91.7%
	High Pack Materials	86.4%	87.4%	98.3%	104.1%	99.6%	97.2%	90.5%	84.0%	85.5%	87.5%	89.0%	85.8%
	DIR + High Pack Materials	85.5%	98.4%	86.3%	103.3%	100.5%	86.1%	94.3%	89.9%	89.7%	99.0%	84.8%	87.3%
Availability of Assigned Rack's Type	Low Racks	-48	-54	-45	-37	-34	-38	-32	-49	2	-15	-2	-9
	Medium Racks	21	-56	-71	-52	-51	63	26	57	69	102	40	152
	High Racks	147	136	18	-44	4	30	103	173	156	135	119	153
	DIR + High Pack Materials	215	24	202	-49	-7	206	85	150	152	15	225	188

The same searching strategy for the next locations as introduced in the previous part is also applied in this scenario. However, the searching strategy is found to be invalid in some months including February, March, April, and May as there are not enough suitable racks for locating a certain type of materials. In this case, some of the assigned locations for finished products are needed to allocate back to materials as summarized in Table 77.

Table 77. Number locations of finished products that are allocated to overflow materials and the remaining locations available for finished products

Rack Types	Location available for Finished Products	Locations of Finished Products that are allocated back to materials				Remaining locations for Finished Products			
		Feb'19	Mar'19	Apr'19	May'19	Feb'19	Mar'19	Apr'19	May'19
Low racks	2	54	45	37	34	0	0	0	0
Medium racks	306	32	53	52	51	222	210	157	223
High racks	18	0	0	49	7	18	18	0	11
Total	326	86	98	138	92	240	228	157	234

As the remaining locations for finished products are less than the base case scenario, this directly impacts cost saving that is claimed in part 4.9. To store fresh finished products at the raw materials warehouse, the minimum space required is 320 locations to be still profitable. Thus, fresh finished products should not be stored at the raw materials warehouse in February, March, April, and May as the remaining space for finished products is less than the minimum requirement. Instead of gaining storage saving for 264,000 THB, only 176,000 THB is obtained.

From using searching for the next locations strategy, some materials in some months are not located in the most suitable locations. As a result, picking distance is increased around 5.2% compared to the base case as presented in Table 78. In addition, the additional working effort required to allocate materials back to their assigned locations is estimated to be 182 touches per month.

Table 78. Total picking distance for scenario 2 that forecasted inventory is increased by 10%

	Total Picking Distance (km)
Base case scenario	1,102.45
10% increase in forecasted inventory	1,159.91
% Increase	**5.2%**

After using searching for the next location strategy and allocating some space of finished products to overflow materials, Figure 37 and Table 79 show an updated average utilization and monthly utilization in the raw materials warehouse, consecutively.

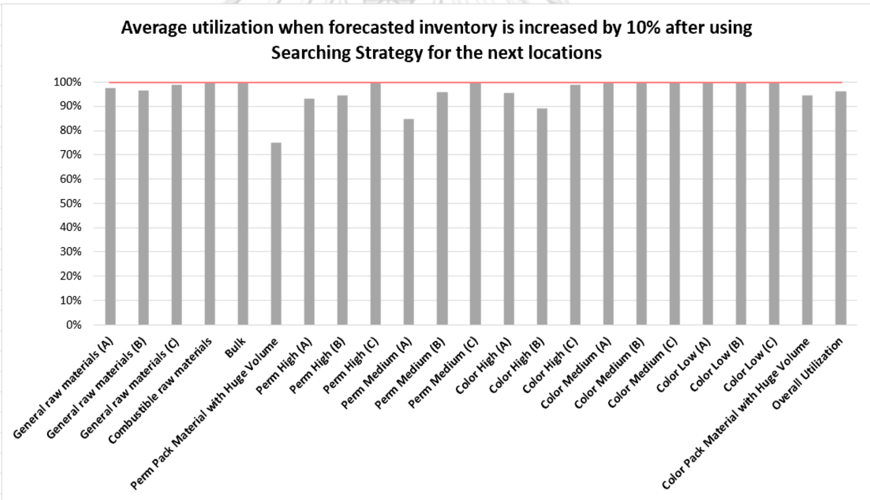


Figure 37. Average utilization of scenario 2 after using the searching strategy for the next locations and allocating some space of finished products to overflow materials

Table 79. Monthly utilization of scenario 2 after using the searching strategy for the next locations and allocating some space of finished products to overflow materials

Groups	Material Groups	Utilization when forecasted inventory is increased by 10% after use searching strategy for the next locations											
		Jan-19	**Feb-19**	**Mar-19**	**Apr-19**	**May-19**	**Jun-19**	**Jul-19**	**Aug-19**	**Sep-19**	**Oct-19**	**Nov-19**	**Dec-19**
Group 1	General raw materials (A)	92.3%	100.0%	100.0%	100.0%	100.0%	99.7%	100.0%	100.0%	95.5%	100.0%	100.0%	83.7%
Group 2	General raw materials (B)	81.7%	100.0%	100.0%	100.0%	100.0%	100.0%	99.0%	100.0%	95.2%	89.4%	100.0%	92.8%
Group 3	General raw materials (C)	85.9%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 4	Combustible raw materials	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 5	Bulk	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 6	Perm Pack Material with Huge Volume	83.8%	100.0%	8.8%	100.0%	100.0%	23.1%	92.5%	75.6%	100.0%	100.0%	30.6%	85.6%
Group 7	Perm High (A)	85.8%	100.0%	100.0%	100.0%	100.0%	100.0%	97.8%	85.5%	93.1%	100.0%	77.5%	75.6%
Group 8	Perm High (B)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	93.3%	87.1%	90.0%	93.3%	88.1%	81.4%
Group 9	Perm High (C)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 10	Perm Medium (A)	100.0%	100.0%	100.0%	100.0%	100.0%	82.1%	82.8%	76.2%	72.8%	63.6%	75.5%	62.9%
Group 11	Perm Medium (B)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	96.8%	87.4%	88.4%	87.4%	89.5%
Group 12	Perm Medium (C)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 13	Color High (A)	100.0%	100.0%	100.0%	100.0%	100.0%	95.5%	100.0%	100.0%	66.2%	100.0%	100.0%	85.1%
Group 14	Color High (B)	100.0%	100.0%	100.0%	100.0%	100.0%	75.0%	73.6%	81.9%	73.6%	100.0%	84.7%	81.9%
Group 15	Color High (C)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	97.7%	100.0%	94.3%	95.5%
Group 16	Color Medium (A)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	96.4%
Group 17	Color Medium (B)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 18	Color Medium (C)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 19	Color Low (A)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.3%	100.0%	100.0%	100.0%
Group 20	Color Low (B)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 21	Color Low (C)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Group 22	Color Pack Material with Huge Volume	82.5%	100.0%	84.2%	100.0%	100.0%	77.9%	100.0%	100.0%	93.8%	100.0%	100.0%	95.0%
	Overall Utilization	**95.2%**	**100.0%**	**95.3%**	**100.0%**	**100.0%**	**94.1%**	**98.0%**	**95.9%**	**94.3%**	**97.4%**	**93.2%**	**91.5%**
Grouping by Material Height	Low Materials	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.6%	100.0%	100.0%	100.0%
	Medium Materials	95.6%	100.0%	100.0%	100.0%	100.0%	98.5%	98.5%	97.9%	95.8%	95.2%	97.3%	92.2%
	High Pack Materials	96.4%	100.0%	100.0%	100.0%	100.0%	97.5%	96.4%	92.6%	88.0%	98.7%	90.5%	85.8%
	DIR + High Pack Materials	92.8%	100.0%	87.6%	100.0%	100.0%	86.3%	96.6%	92.0%	90.3%	99.1%	85.5%	87.3%
Availability of Assigned Rack's Type	Low Racks	0	0	0	0	0	0	0	0	2	0	0	0
	Medium Racks	81	0	0	0	0	28	28	39	77	88	49	143
	High Racks	39	0	0	0	0	27	39	80	129	14	103	153
	DIR + High Pack Materials	107	0	184	0	0	203	51	119	144	14	214	188

Chapter 6
Implementation Plan

In this chapter, the implementation plan is developed in order to guide the case study company on how to implement the improving plans step by step. These plans are already verified with the warehouse management team of the case study company. In the latter part of this chapter, tools that are established under this research for improving raw materials warehouse are also introduced.

6.1. Implementation plan for the case study company

6.1.1. Implementation plan for removing obsolete materials from raw materials warehouse

Processes and expected time of each process to remove obsolete materials from the raw materials warehouse are described in Table 80. Total expected time required for implementation this process is 11 days.

Table 80. Implementing steps for removing obsolete materials from raw materials warehouse

Steps	Tasks	Expected Time (Days)
1	Move write-off materials in SAP system from release status to block status	1
2	Physically count write-off materials and cross-check with amounts in SAP system. In case that amounts in SAP system do not align with actual quantities, adjusting amounts in SAP system is needed.	3
3	Move physical write-off materials from locations in raw materials warehouse to tent locations. At the same time, tracking location number for each product is required.	3
4	Appoint third party to remove write-off materials from manufacturing plant for destroying process	1
5	Physically remove materials from manufacturing plant	3

6.1.2. Implementation plan for adjusting rack height and moving materials to assigned locations

Rack height adjustment should be implemented prior to moving materials to assigned locations. All processes and expected time to implement each process are summarized in Table 81. Total expected time required is 22 days. In each step, it has to work during the downtime of the raw materials warehouse as the SAP system is needed to be frozen or there should be no transaction occurring during the changing process.

Table 81. Processes and expected time for adjusting rack height and moving materials into new assigned locations in raw materials warehouse

Steps	Tasks	Expected Time (Days)
1	Change rule for material triggering process from prioritizing by zoning to prioritizing by GR (good receive) date by SAP owner	1
2	In this step, it is divided into 5 waves and 3 actions are required for each wave. **Actions for each wave:** - Adjust physical rack height by third party - Create new rack locations in SAP system by SAP owner - Delete removed rack locations in SAP system by SAP owner	
	Wave 1: Adjusting physical rack height for zone RJ, RK, RL, and RM	1
	Wave 2: Adjusting physical rack height for zone WA, WB, WC, WD, and WE	1
	Wave 3: Adjusting physical rack height for zone PA, PB, PC, and PD	1
	Wave 4: Adjusting physical rack height for zone PE, PF, PG, and PH	1
	Wave 5: Adjusting physical rack height for zone PI, PJ, PK, and PL	1
	Total Lead Time	**5**
3	In this step, it is divided into 16 waves and 4 actions are required for each wave. **Actions for each wave:** - Revise storage type and rack type for each location in SAP system - Revise material type and required rack type for each material in SAP system - Change rules for auto recommending locations for each group of materials - Physically change locations for each group of materials	
	Wave 1: General raw mateials class A (312 locations)	1
	Wave 2: General raw materials class B (208 locations) + Combustible raw materials (2 locations)	1
	Wave 3: General raw mateials class C (135 locations) + Bulk materials (130 locations)	1
	Wave 4: Perm medium class A (151 locations), class B (95 locations), and class C (76 locations)	1
	Wave 5: Color medium class A (305 locations)	1
	Wave 6: Color medium class B (182 locations)	1
	Wave 7: Color medium class C (245 locations)	1
	Wave 8: Color low class A (274 locations)	1
	Wave 9: Color low class B (152 locations) and class C (145 locations)	1
	Wave 10: Perm high class A (275 locations)	1
	Wave 11: Perm high class B (210 locations)	1
	Wave 12: Perm high class C (233 locations)	1
	Wave 13: Color high class A (201 locations) and class B (72 locations)	1
	Wave 14: Color high class C (88 locations)	1
	Wave 15: Drive-in-rack row WLB (160 locations)	1
	Wave 16: Drive-in-rack row JIT (240 locations)	1
	Total Lead Time	**16**

In the first step, the current rule or conflict set in the SAP system on material triggering process has to be changed. Materials are changed to be triggered by GR or good receive date instead of triggered by material zoning in the raw materials warehouse. This helps to prevent first-in, first-out (FIFO) problem as materials that are received first are triggered to be used first.

In the second step, it is the step to do physical rack height adjustment in the raw materials warehouse as the current layout of the warehouse is proposed to be changed according to part 4.4. This task is implemented by the third party. In parallel, the SAP owner has to create new rack locations and delete removed rack locations in the SAP system.

The last step is moving materials to be stored in the assigned locations. The material can be stored in a certain location if material type and height of material match the storage type and storage height. As both materials and rack locations are changed in both type and height, material and bin master in the SAP system have to be changed. To revise storage type and rack type for each location, the material has to be moved from the current location to the overflow location which is dummy location in the SAP system first. After new storage types and heights are created in the SAP system, materials that are also changed in type and height are moved from the overflow location to be stored at the new assigned locations. In addition, rules or conflicts for auto recommending locations during put-away and return processes have to be revised.

6.1.3. Implementation plan for storing finished products at raw materials warehouse

Currently, fresh finished products are directly moved from the productions to be located at FL2 area which is an area for preparing loading finished products into trucks in order to transport to the external warehouse. In this research, this process is proposed to be changed. Fresh finished products are instead moved from the productions to be stored at the prepared rack locations in the raw materials warehouse for two days prior to unloading to FL2 area and transporting to the external warehouse. The processes and expected time to implement these changes are presented in Table 82.

Table 82. Processes and expected time for storing finished products at raw materials warehouse

Steps	Tasks	Expected Time (Days)
1	Create rules in SAP system that fresh finished products produced from productions have to locate at assigned locations (324 locations) in raw materials warehouse though auto put-away function in SAP system	1
2	Create excel tracking file to record storing periods of finished products in raw materials warehouse. After storing finished products for two days, finished products are unloaded from rack locations to locate at FL2 locations which are locations for loading finished products into trucks.	1
3	Train operators to use excel file for daily tracking status of finished products in raw materials warehouse	1

6.2. Tools used for improving raw materials warehouse

Assigning each group of materials into an appropriate location is difficult to do by manually for this raw materials warehouse as there are many slot locations (4,217 locations) with variety SKUs of raw materials (1,611 SKUs: not including label and tank farm materials) located in this raw materials warehouse. Hence, the optimization program is a tool for helping the warehouse manager to locate each group of materials into the most suitable location that results in the lowest total picking distance required during the picking process. Another tool created in this research is a mapping diagram. It is a tool used for visualizing the locations for each group of materials in the raw materials warehouse which can help the warehouse manager to recheck whether the locations are already appropriate or still required additional adjustment.

6.2.1. Optimization tool

Three optimization models are used for identifying the most appropriate location for each group of materials. Three models are divided into the model for materials located in the row rack (R1), the model for materials located in the medium rack (R2), and the model for materials located in the high rack (R3). All models are friendly designed for the users. Inputs needed for each model are the total space available for each rack type, the space required for each raw material, the distance from each location to usage area, and the average picking frequency per location for each group of materials. Users can directly input these requirements in the OPL program (marked in red) as shown in Figure 38 to Figure 40.

Model File

```
//Sets
range I = 1..573;
range A = 1..274;
range B = 1..152;
range C = 1..145;

//Parameters
float DistCL[I]=...;
float FreqColorLowA=3.4;
float FreqColorLowB=1.2;
float FreqColorLowC=0.4;

//Decision variables
dvar boolean ColorLowA[A][I];
dvar boolean ColorLowB[B][I];
dvar boolean ColorLowC[C][I];

//Objective function
dexpr float objective = sum(i in I,a in A)ColorLowA[a][i]*DistCL[i]*2*FreqColorLowA+sum(i in I,b
in B)ColorLowB[b][i]*DistCL[i]*2*FreqColorLowB+sum(i in I,c in
C)ColorLowC[c][i]*DistCL[i]*2*FreqColorLowC;
minimize objective;

//Constraints
subject to{

forall (i in I)
  sum(a in A)ColorLowA[a][i]+sum(b in B)ColorLowB[b][i]+sum(c in C)ColorLowC[c][i]<=1;

forall (a in A)
  sum(i in I)ColorLowA[a][i]==1;

forall (b in B)
  sum(i in I)ColorLowB[b][i]==1;

forall (c in C)
  sum(i in I)ColorLowC[c][i]==1;

}
```


Figure 38. Inputs required for row racks model in OPL program

Model File

```
//Sets
range I = 1..2147;
range A = 1..312;
range B = 1..208;
range C = 1..135;
range D = 1..2;
range E = 1..130;
range F = 1..151;
range G = 1..95;
range H = 1..76;
range J = 1..305;
range K = 1..182;
range L = 1..245;

//Parameters
float DistMM[I]=...;
float DistPM[I]=...;
float DistCM[I]=...;
float FreqGRMA=8.5;
float FreqGRMB=2.4;
float FreqGRMC=1.1;
float FreqCRM=11;
float FreqBulk=2;
float FreqPermMedA=5;
float FreqPermMedB=1.5;
float FreqPermMedC=0.6;
float FreqColorMedA=10.3;
float FreqColorMedB=3.2;
float FreqColorMedC=0.7;

//Decision variables
dvar boolean GRMA[A][I];
dvar boolean GRMB[B][I];
dvar boolean GRMC[C][I];
dvar boolean CRM[D][I];
dvar boolean Bulk[E][I];
dvar boolean PermMedA[F][I];
dvar boolean PermMedB[G][I];
dvar boolean PermMedC[H][I];
dvar boolean ColorMedA[J][I];
dvar boolean ColorMedB[K][I];
dvar boolean ColorMedC[L][I];
```

```
//Objective function

dexpr float objective = sum(i in I,a in A)GRMA[a][i]*DistMM[i]*2*FreqGRMA+sum(i in I,b in
B)GRMB[b][i]*DistMM[i]*2*FreqGRMB+sum(i in I,c in C)GRMC[c][i]*DistMM[i]*2*FreqGRMC+sum(i in I,d in
D)CRM[d][i]*DistMM[i]*2*FreqCRM+sum(i in I,e in E)Bulk[e][i]*DistPM[i]*2*FreqBulk+sum(i in I,f in
F)PermMedA[f][i]*DistPM[i]*2*FreqPermMedA+sum(i in I,g in G)PermMedB[g][i]*DistPM[i]*2*FreqPermMedB+sum(i in I,h in
H)PermMedC[h][i]*DistPM[i]*2*FreqPermMedC+sum(i in I,j in J)ColorMedA[j][i]*DistCM[i]*2*FreqColorMedA+sum(i in I,k in
K)ColorMedB[k][i]*DistCM[i]*2*FreqColorMedB+sum(i in I,l in L)ColorMedC[l][i]*DistCM[i]*2*FreqColorMedC;
minimize objective;

//Constraints
subject to{

sum (e in E, i in 1..266)Bulk[e][i]==130;

forall (i in I)
sum(a in A)GRMA[a][i]+sum(b in B)GRMB[b][i]+sum(c in C)GRMC[c][i]+sum(d in D)CRM[d][i]+sum(e in E)Bulk[e][i]+sum(f in
F)PermMedA[f][i]+sum(g in G)PermMedB[g][i]+sum(h in H)PermMedC[h][i]+sum(j in J)ColorMedA[j][i]+sum(k in
K)ColorMedB[k][i]+sum(l in L)ColorMedC[l][i]<=1;

forall (a in A)
  sum(i in I)GRMA[a][i]==1;

forall (b in B)
  sum(i in I)GRMB[b][i]==1;

forall (c in C)
  sum(i in I)GRMC[c][i]==1;

forall (d in D)
  sum(i in I)CRM[d][i]==1;

forall (e in E)
  sum(i in I)Bulk[e][i]==1;

forall (f in F)
  sum(i in I)PermMedA[f][i]==1;

forall (g in G)
  sum(i in I)PermMedB[g][i]==1;

forall (h in H)
  sum(i in I)PermMedC[h][i]==1;

forall (j in J)
  sum(i in I)ColorMedA[j][i]==1;

forall (k in K)
  sum(i in I)ColorMedB[k][i]==1;

forall (l in L)
  sum(i in I)ColorMedC[l][i]==1;

}
```


Figure 39. Inputs required for medium racks model in OPL program

Model File

```
//Sets
range I = 1..1097;
range A = 1..275;
range B = 1..210;
range C = 1..233;
range D = 1..201;
range E = 1..72;
range F = 1..88;

//Parameters
float DistPH[I]=...;
float DistCH[I]=...;

float FreqPermHighA=6.0;
float FreqPermHighB=1.5;
float FreqPermHighC=0.4;
float FreqColorHighA=8.0;
float FreqColorHighB=4.2;
float FreqColorHighC=1.0;

//Decision variables
dvar boolean PermHighA[A][I];
dvar boolean PermHighB[B][I];
dvar boolean PermHighC[C][I];
dvar boolean ColorHighA[D][I];
dvar boolean ColorHighB[E][I];
dvar boolean ColorHighC[F][I];
```

```
//Objective function
dexpr float objective = sum(i in I,a in A)PermHighA[a][i]*DistPH[i]*2*FreqPermHighA+sum(i in I,b in
B)PermHighB[b][i]*DistPH[i]*2*FreqPermHighB+sum(i in I,c in
C)PermHighC[c][i]*DistPH[i]*2*FreqPermHighC+sum(i in I,d in
D)ColorHighA[d][i]*DistCH[i]*2*FreqColorHighA+sum(i in I,e in
minimize objective;

//Constraints
subject to{

forall (i in I)
  sum(a in A)PermHighA[a][i]+sum(b in B)PermHighB[b][i]+sum(c in C)PermHighC[c][i]+sum(d in
D)ColorHighA[d][i]+sum(e in E)ColorHighB[e][i]+sum(f in F)ColorHighC[f][i]<=1;

forall (a in A)
  sum(i in I)PermHighA[a][i]==1;

forall (b in B)
  sum(i in I)PermHighB[b][i]==1;

forall (c in C)
  sum(i in I)PermHighC[c][i]==1;

forall (d in D)
  sum(i in I)ColorHighA[d][i]==1;

forall (e in E)
  sum(i in I)ColorHighB[e][i]==1;

forall (f in F)
  sum(i in I)ColorHighC[f][i]==1;
}
```

Figure 40. Inputs required for high racks model in OPL program

After users input these parameter values in the OPL program and start run configuration, the final locations for each group of materials are directly linked to excel file and the total picking distance is also reported as shown in Table 83.

Table 83. Example of optimized locations for row lack model run from OPL program

No	Row	Level	Column	Combine	Location for ColorLowA	Location for ColorLowB	Location for ColorLowC	FreqColorLowA	FreqColorLowB	FreqColorLowC	Total Distance
2439	PC	1	1	PC11	0	0	1	3.4	1.2	0.4	5240
2440	PC	1	2	PC12	0	0	1	3.4	1.2	0.4	5144
2441	PC	1	3	PC13	0	0	1	3.4	1.2	0.4	5048
2442	PC	1	4	PC14	0	0	1	3.4	1.2	0.4	4952
2443	PC	1	5	PC15	0	0	1	3.4	1.2	0.4	4856
2444	PC	1	6	PC16	0	0	1	3.4	1.2	0.4	4760
2445	PC	1	7	PC17	0	0	1	3.4	1.2	0.4	4664
2446	PC	1	8	PC18	0	0	1	3.4	1.2	0.4	4568
2447	PC	1	9	PC19	0	0	1	3.4	1.2	0.4	4472
2448	PC	1	10	PC110	0	0	1	3.4	1.2	0.4	4376
2449	PC	1	11	PC111	0	0	1	3.4	1.2	0.4	4280
2450	PC	1	13	PC113	0	0	1	3.4	1.2	0.4	4088
2451	PC	1	14	PC114	0	0	1	3.4	1.2	0.4	3992
2452	PC	1	15	PC115	0	0	1	3.4	1.2	0.4	3896
2453	PC	1	16	PC116	0	0	1	3.4	1.2	0.4	3800
2454	PC	1	17	PC117	0	1	0	3.4	1.2	0.4	11112
2455	PC	1	18	PC118	0	1	0	3.4	1.2	0.4	10824
2456	PC	1	19	PC119	0	1	0	3.4	1.2	0.4	10536
2457	PC	1	20	PC120	0	1	0	3.4	1.2	0.4	10248
2458	PC	1	21	PC121	0	1	0	3.4	1.2	0.4	9960
2459	PC	1	22	PC122	0	1	0	3.4	1.2	0.4	9672
2460	PC	1	23	PC123	0	1	0	3.4	1.2	0.4	9384
										Total	7,410,864.00

From Table 83, numbers “0” and “1” in Location for ColorLowA, Location for ColorLowB, and Location for ColorLowC columns indicate whether or not to use location in each row to locate material type in that column. “0” means not to locate and “1” means to locate. On the rightmost column, it shows the total picking distance from moving materials in each location to the usage area. At the bottom of the rightmost column, it reports the total picking distance for all materials located at low racking type (R1).

6.2.2. Mapping diagram

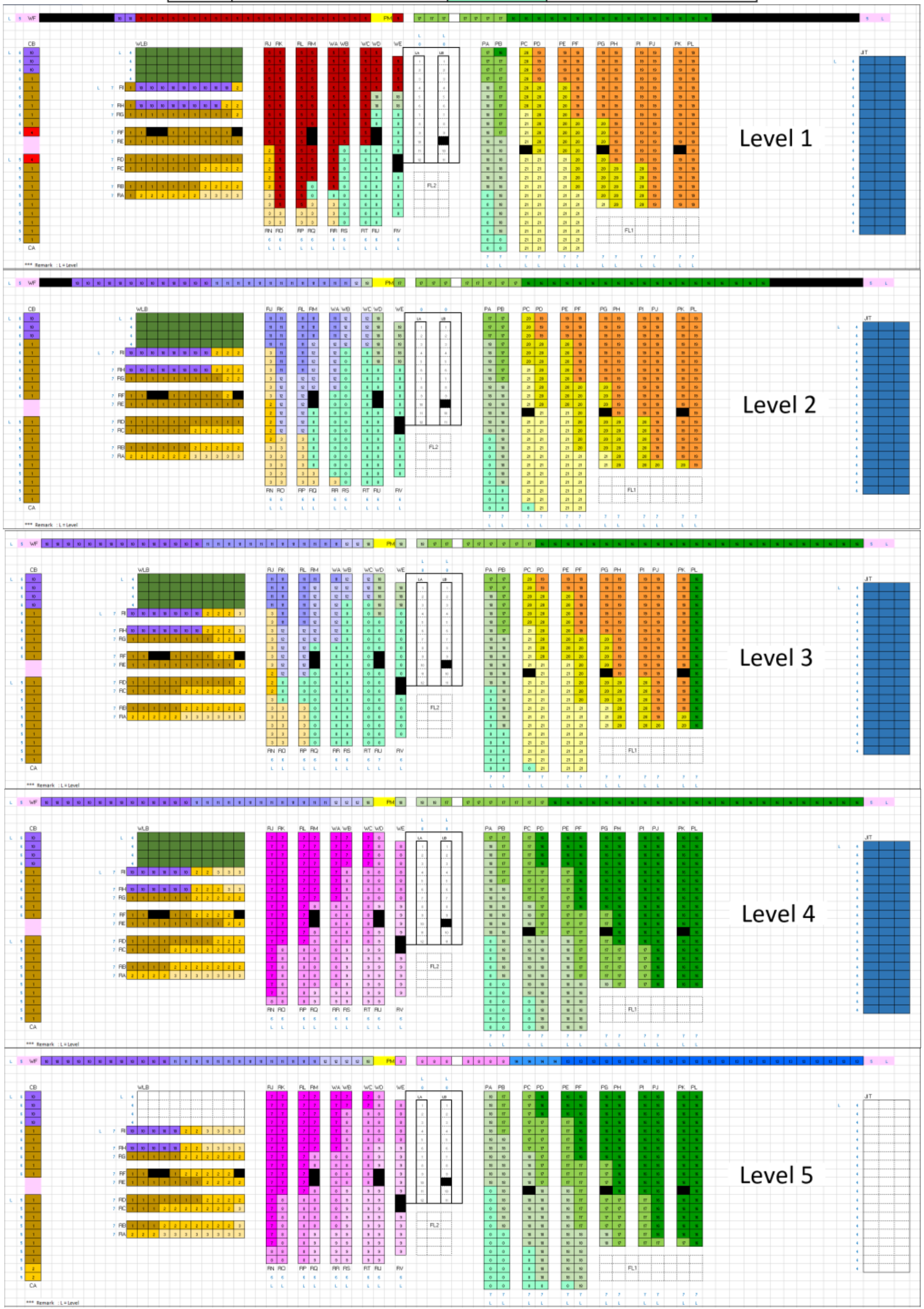
After locations for each group of materials are finalized, they are input in “Mapping Diagram” file, sheet “Distance_Value”, and column “Final groups Link to AutoAssignedLocation” as shown in Table 84. Then, mapping diagram for visualizing final locations for each group of materials is automatically shown in “AutoAssignedLocation” sheet as presented in Figure 41.

Table 84. Inputs of final material groups required in mapping diagram file

No	Row	Level	Column	Combine	Final groups Link to AutoAssignedLocation
1	CA	1	1	CA11	4
2	CA	1	2	CA12	1
3	CA	1	3	CA13	1
4	CA	1	4	CA14	1
5	CA	1	5	CA15	1
6	CA	1	6	CA16	1
7	CA	1	7	CA17	1
8	CA	1	8	CA18	1
9	CA	1	9	CA19	1
10	CA	1	10	CA110	1
11	CA	2	1	CA21	1
12	CA	2	2	CA22	1
13	CA	2	3	CA23	1
14	CA	2	4	CA24	1
15	CA	2	5	CA25	1
16	CA	2	6	CA26	1
17	CA	2	7	CA27	1
18	CA	2	8	CA28	1
19	CA	2	9	CA29	1
20	CA	2	10	CA210	1
21	CA	3	1	CA31	1
22	CA	3	2	CA32	1
23	CA	3	3	CA33	1
24	CA	3	4	CA34	1
25	CA	3	5	CA35	1
26	CA	3	6	CA36	1
27	CA	3	7	CA37	1
28	CA	3	8	CA38	1
29	CA	3	9	CA39	1
30	CA	3	10	CA310	1
31	CA	4	1	CA41	1
32	CA	4	2	CA42	1
33	CA	4	3	CA43	1
34	CA	4	4	CA44	1

In the rightmost column, it is a column that requires users to input the final group of materials that locate in each location. For example, location CA11 is assigned to locate material group 4 which is combustible raw material and location CA12 is assigned to locate material group 1 which is general raw material class A.

General Raw Materials Class A	Color High Materials Class A
General Raw Materials Class B	Color High Materials Class B
General Raw Materials Class C	Color High Materials Class C
Combustible Raw Materials	Color Medium Materials Class A
Bulk Materials	Color Medium Materials Class B
Perm High Materials Class A	Color Medium Materials Class C
Perm High Materials Class B	Color Low Materials Class A
Perm High Materials Class C	Color Low Materials Class B
Perm Medium Materials Class A	Color Low Materials Class C
Perm Medium Materials Class B	Drive-in-rack row WLB
Perm Medium Materials Class C	Drive-in-rack row JIT
	Free Locations



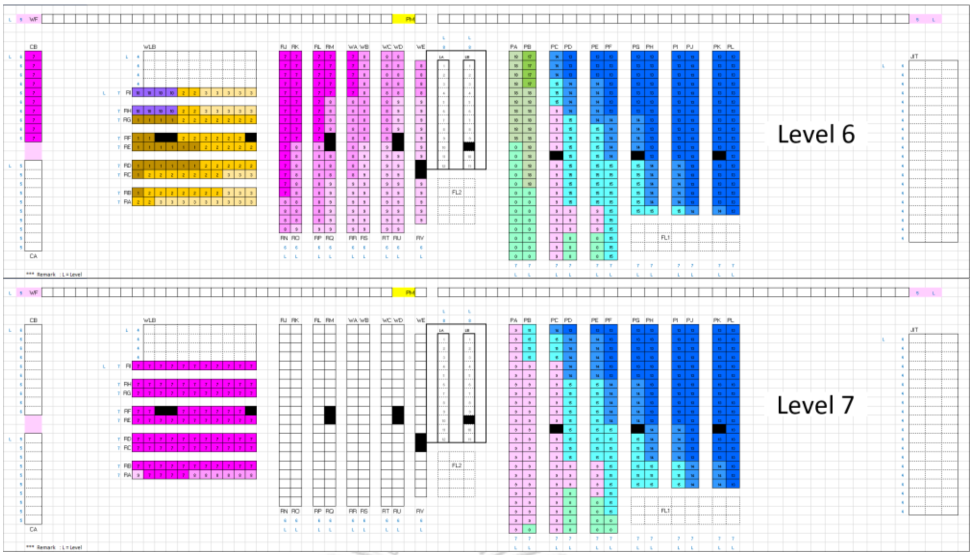


Figure 41. Mapping diagram for visualizing final locations for each group of materials

Chapter 7
Conclusion

7.1. Conclusion

The objective of this research was to save cost from storing finished products at the external public warehouse by utilizing areas at the internal raw materials warehouse. In order to achieve that objective, the current internal raw materials warehouse was firstly improved in terms of capacity, utilization, and efficiency.

The methodology used in this research included firstly, extracting the current inventory and demand in the next 12 months of each SKU from the SAP system. SKUs, that appeared in the inventory but was devoid of demand in the next 12 months, were reviewed by the planning team to assert whether they could be written-off and removed from the raw materials warehouse. The result showed that 283 SKUs with 368 pallets were obsolete materials and can be discarded from the warehouse. Therefore, the available space in the raw materials warehouse was increased by 9.04% by clearing out obsolete materials. Secondly, all SKUs of raw materials in the raw materials warehouse were regrouped according to types, sizes, and turnover rates. Two levels of grouping were developed namely grouping level 1 (considering only material types and sizes) and grouping level 2 (considering material types, sizes, and turnover rates) in order to trade-off among the number of groups, space required, and picking distance in the later part. Each material was assigned into one group under grouping level 1 and grouping level 2. Thirdly, space was allocated to each group of materials based on the maximum month-end inventory for both grouping level 1 and grouping level 2. After the total required space for each group of materials was revealed, the total required locations for each type of racks were also disclosed and the beam height adjustment was considered for matching up the actual requirement in the fourth step. Since the current raw materials warehouse had more high racks than necessary, reducing the beam height resulted in capacity enhancement by 3.6%. In the fifth step, the location of each group of materials under grouping level 1 and grouping level 2 in the raw materials warehouse was assigned. An optimization model was used to identify the most appropriate locations for each group of materials with an objective function to minimize the total picking distance. After locations for each group of materials were identified, the total picking distance for grouping level 1 and grouping level 2 can be calculated. In the sixth step, grouping level 1 and grouping level 2 were compared in terms of the total required space and total picking distance.

The results demonstrated that grouping level 2 required more space than grouping level 1 by 1.2%. On the other hand, the total picking distance of grouping level 2 was less than grouping level 1 by 15.3%. Overall, grouping level 2 was more attractive than grouping level 1. Therefore, it was chosen to be implemented in the raw materials warehouse. Compared to the current situation in the raw materials warehouse, the total capacity was increased by 12.65% through clearing obsolete products and adjusting the beam height. In addition, utilization was more balanced throughout the warehouse and there was fewer materials overflow across assigned locations. These measures helped to reduce human effort in manually reassigning locations for overflow materials. In addition, the picking distance was expected to be reduced about 52%.

After the current internal raw materials warehouse was improved and 324 locations were available for storing finished products, the next step was choosing some finished products to be stored at the raw materials warehouse. Three options were developed and compared in terms of costs and benefits, and it was found out that option 2 delivered the highest net benefit and was selected for implementation. This option stored fresh finished products at the raw materials warehouse for two days prior to shipping for storage at the external warehouse. By implementing this option, it can generate cost saving by 264,000 THB per year.

In the latter part of this research, the robustness of the proposed model was analyzed. Two scenarios were considered: that the forecasted inventory was increased by 5% and by 10%. The impacts of these changes on utilization, picking distance, and cost saving were analyzed. In case that utilization was over 100%, the contingency plan developed under this research could be used to manage the overflow materials. For the first scenario that the forecasted inventory was expanded by 5%, overutilization was observed in some groups of materials in some months. Searching for the next locations strategy was developed in order to handle the overflow materials. Based on this scenario, the total picking distance was increased by about 2.3% as some materials were improperly located across assigned locations. Nevertheless, searching for the next locations strategy was always valid in this scenario since there were always suitable racks available during searching for the next locations. Therefore, it was not necessary to allocate some space of finished products to overflow materials and cost saving from locating some finished products at the raw materials warehouse was still the same. For the second scenario, forecasted inventory was boosted up by 10%. In this scenario, the searching strategy for the next locations was invalid in some months due to inadequate suitable racks for locating certain types of materials. Hence, some assigned locations for finished products were allocated to overflow materials which directly impacted on cost saving obtained from storing some finished products at the raw materials warehouse. The cost-saving remained 176,000 THB per year and the total picking distance rose by 5.2% compared to the base case scenario.

The implementation plans and tools created for the case study company were presented in the last part of this thesis. There were three implementation plans in total, namely an implementation plan for removing obsolete materials from the raw materials warehouse, a plan for adjusting the rack height and relocating materials into new assigned locations, and another plan for storing finished products at the raw materials warehouse. Expected times involved in implementing these three plans were 11 days, 22 days, and 3 days, respectively. Two tools were delivered to the case study company which were an optimization tool for identifying the most appropriate locations for each product's group and mapping diagram for visualizing the final locations of each product's group in the raw materials warehouse.

7.2. Recommendation

In this study, materials returned from productions were assigned to be located at the assigned locations with the beam height matching the received quantities. In the current practice, materials returned from productions were usually stored in pallet with less height than the received height. For further study, separating locations for returned materials and assigning lower beam height than normal locations are interesting since it can help to enhance capacity, utilization, and efficiency of the raw materials warehouse.

In addition, warehouse reshuffling can also be studied due to large size of the raw materials warehouse with a variety SKUs number. The optimized strategy for warehouse reshuffling can help to reduce reshuffling cost and increase the benefits gained from reassigning locations for each group of materials.

REFERENCES

1. Tompkins, J.A. and J.D. Smith, *The warehouse management handbook*. 1st ed. 1988, USA: McGraw-Hill.
2. Emmett, S., *Excellence in warehouse management: How to minimize costs and maximize value*. 1st ed. 2005, Great Britain: John Wiley & Sons, Ltd.
3. Richards, G., *Warehouse management: A complete guide to improving efficiency and minimizing costs in the modern warehouse*. 1st ed. 2011, Great Britain and the United States: Kogan Page Limited.
4. Quader, S. and K.K. Castillo-Villar, *Design of an enhanced multi-aisle order-picking system considering storage assignments and routing heuristics.* Robotics and Computer–Integrated Manufacturing, 2018. **50**: p. 13-29.
5. Bentz, K.T., *Warehouse layout optimization*, in *International Business*. 2017, Arcada University: Finland.
6. Bartholdi, J.J. and S.T. Hackman, *Warehouse & distribution science release 0.96* 2014.
7. Yongprasert, B., *Design of storage location and order picking for fast-moving items in automotive assembly plant*, in *Industrial Engineering*. 2013, Chulalongkorn University: Thailand.
8. Markmul, K., *Developing work processes in an exporting spare-part warehouse of an agriculture machinery manufacturer*, in *Industrial Engineering*. 2012, Chulalongkorn University: Thailand.
9. Chan, F.T.S. and H.K. Chan, *Improving the productivity of order picking of a manual-pick and multi-level rack distribution warehouse through the implementation of class-based storage.* Expert systems with applications, 2011. **38**: p. 2686-2700.
10. Gu, J., M. Goetschalckx, and L.F. McGinnis, *Research on warehouse operation: A comprehensive review.* European journal of operational research, 2006. **177**: p. 1-21.
11. Ren-Qian, Z., W. Meng, and P. Xing, *New model of the storage location*

assignment problem considering demand correlation pattern. Computers & Industrial Engineering, 2019. **129**: p. 210-219.

12. Zhang, Y., *Correlated storage assignment strategy to reduce travel distance in order picking.* IFAC-PapersOnLine, 2016: p. 030-035.

13. Frazelle, E., *World Class Warehousing and Material Handling*. international ed. 2002, Singapore: McGraw Hill.

14. Can Den Berg, J.P. and W.H.M. Zijim, *Models for warehouse management: Classification and examples.* International Journal of Production Research, 1999. **59**: p. 519-528.

15. Guo, X., Y. Yu, and R.B.M. De Koster, *Impact of required storage space on storage policy performance in a unit-load warehouse.* International journal of production research, 2016. **54**(8): p. 2405-2418.

16. Phumchusri, N. and P. Kitpipit, *Warehouse Layout Design for an Automotive Raw Materials Supplier.* Engineering Journal, 2017. **21**(7): p. 361-387.

17. Battista, C., et al., *Storage location assignment problem: Implementation in a warehouse design optimization tool*, in *Proceeding of the Conference Breaking down the Barriers between Research and Industry*. 2011: Italy.

18. Tippayawong, K.Y., A. Sopadang, and P. Patitad, *Improving warehouse layout design of a chicken slaughterhouse using combined ABC class based and optimized allocation techniques*, in *Proceedings of the world congress on engineering*. 2013: London, U.K.

19. Pazour, J.A. and H.J. Carlo, *Warehouse reshuffling: Insights and Optimization.* Transportation Research Part E, 2015. **73**: p. 207-226.

20. Wutthisirisart, P., M.Y. Sir, and J.S. Nobel, *The two-warehouse material location selection problem.* Int. J. Production Economics, 2015. **170**: p. 780-789.

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