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Article

Optimal Storage Locations for Warehouse Efficiency Improvement in a Haircare Manufacturer

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Abstract. This study aimed to enhance efficiency of a raw materials warehouse in a case study haircare manufacturer in Thailand by identifying the optimal storage locations for materials locating at this warehouse. At the same time, it was our goal to increase capacity and improve utilization at this warehouse in order to store some finished products here instead of storing all of them at an external public warehouse. As a result, the case study company can save storage cost of finished products at the external public warehouse. The key methodologies used to improve current raw materials warehouse were removing obsolete materials from warehouse, regrouping materials according to types, sizes, and turnover rate, reallocating space for each group of materials, considering beam height adjustment, and reassigning locations for each group of materials using optimization model. The results showed that capacity of the studied warehouse was enhanced by 12.65%, picking distance was reduced by 51.9% compared to current situation, utilization was more balanced throughout warehouse and annual cost saving of 874,800 THB was obtained from locating some finished products at the internal raw materials warehouse. In addition, robustness of the proposed model was analyzed and contingency plan was developed for handling with over flow materials when over utilization occurs.

Keywords: Optimal storage location, warehouse improvement, storage location assignment, picking distance reduction.

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1. Introduction

Manufacturing plant of a case study company is used to produce haircare products. The internal raw materials warehouse at this manufacturing plant is used to store raw materials and pack materials. For finished products, they are shipped to store at an external public warehouse. As customer demand is growing, the current contract on required space at the external public warehouse is not enough for storing all finished products. In fact, the case study company can ask for more space at external public warehouse but this option comes with higher rental operating cost of the company. Hence, warehouse manager is looking for an opportunity to store some finished products at the internal raw materials warehouse in order to save cost at external public warehouse. At the same time, warehouse manager would like to use this opportunity to improve capacity, space utilization, and efficiency at this warehouse.

Size of the internal raw materials warehouse is 10×40.5×101 m³ (Height×Depth×Width) with 4,070 storage locations in total. Warehouse layout is shown in Fig. 1. Where two alphabets represent name of each row, the number in each excel represent column number and L plus number represent the maximum level in each row.

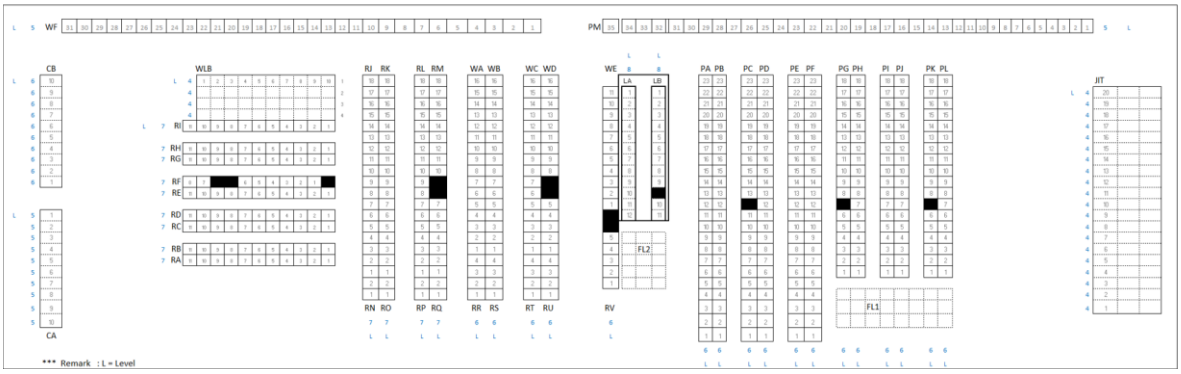

Fig. 1. Layout of the internal raw materials warehouse.

There are two types of storage used in this warehouse: single selective rack and drive-in-rack. The majority of racks is single selective rack which accounts for 3,670 locations. The rest of 400 locations are drive-in-rack. Four sizes of single selective rack are adopted and named R1, R3, R4, and R5. They are different in height but they have the same width and depth. On the other hand, only one size of drive-in-rack is used named JT. Table 1 presents dimension and the number of bins for each storage type.

Table 1. Dimension and the 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
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			**4,070**

Totally 2,109 SKUs of materials are presently stored at raw materials warehouse including 299 SKUs of raw materials, 1,774 SKUs of pack materials, and 36 SKUs of bulk materials. These materials are received from suppliers and stocked at the warehouse until productions order to use these materials in production processes to produce finished products.

Based on current warehouse's layout, areas in warehouse are divided into six storage areas which are storage areas for combustible raw materials, general raw materials, bulk materials, low pack materials, high pack materials, and pack materials with huge volume (drive-in-rack materials). Each material 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 SKU. However, materials can be stored across storage area by 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 warehouse, general and combustible raw materials are assigned to locate closer to making production area, bulk materials are assigned to locate at first level of warehouse due to weight constraint, and drive-in-rack materials are assigned into drive-in-rack areas. For color pack materials and perm pack materials, they are randomly located throughout warehouse with the only constraint that material heights have to match with rack heights. Class-based storage according to material's turnover rate is not applied in this raw materials warehouse.

For flow of materials and warehouse system, materials delivered by suppliers are firstly located at dock area FL1 in order to check the quality and quantity according to invoice before moving to rack locations. For put-away process, SAP system will auto recommend available storage location for operators. Then operators will use reach truck to move materials from dock area to store them at recommended storage locations. These are parts of receiving, put-away, and storing processes. Once there is an order triggered by operation, warehouse operators will look at storage location in SAP system and use forklift to pick products at storage locations to serve at operation area which is a part of picking process. In case that a required material presents in more than one location, SAP system will trigger material according to priorities set in SAP system which are materials in their original location following by materials across location. In addition, materials within the same area are triggered according to expiry date. After finished packing process, finished products are transferred to dock area or FL2 area in order to be prepared loading further to containers which is a part of shipping process to the external public warehouse.

The issue currently found at this internal raw materials warehouse is unsuitable space allocation for each group of materials causing huge work effort to do manual adjustment by workers and larger picking distance required. Figure 2 represents projected utilization of combustible raw materials that has very low utilization as assigned locations are more than actual inventory of this material group. On the other hand, utilization of pack materials with huge volume is always above 100% as assigned locations are not enough for storing inventory of materials in this group.

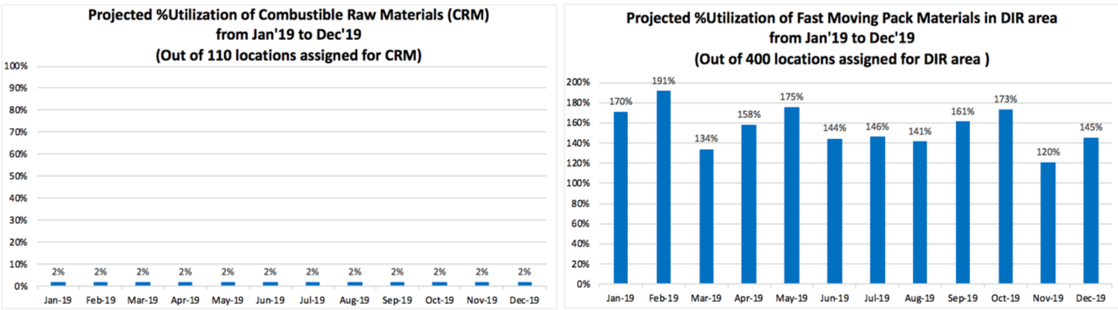

Fig. 2. Projected %Utilization of combustible raw materials and pack materials with huge volume from Jan'19 to Dec'19.

In addition, it is discovered that some materials are located in the raw materials warehouse for a long period of time without any movements (no movement more than 6 months) and also absent of demand triggering in the next 12 months. These materials should be considered to locate in further locations from usage area or remove from warehouse. Table 2 demonstrates example of materials that have inventory in the warehouse but have no demand in the next 12 months.

Table 2. Example of materials that have inventory without demand triggering 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	-

These problems are solved under this research. The scopes for improving space utilization, capacity, and efficiency at the internal raw materials warehouse include reviewing current inventory and identifying obsolete materials that can be removed from the warehouse in order to enhance space available, regrouping materials according to type, sizes, and turnover rate, reallocating space and reassigning locations for each group of materials, and considering beam height adjustment to match with actual sizes of materials. This research is studied based on forecasted inventory, supply, and demand data from January to December, 2019 provided by the company on January 1, 2019. The results are reported in terms of utilization, capacity, and efficiency improvement compared to current situation in this warehouse and cost reduction from storing some finished products at this raw materials warehouse.

2. Literature Review

In this section, the related theories and studies used in this research are discussed.

2.1. Warehouse Overview

There are two main types of warehouse: private warehouse and public warehouse as stated in [1]. Private warehouse is own by company which includes the ownership in land, building, and equipment while 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.

According to [2], four common activities typically occur in warehouse: 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 as stated in [3]. Based on [4], picking process is considered as the costliest activity within warehouse accounting for 50% to 75% of total operating costs. Travel to product location spends longest time during picking process or around 50% of total picking time as revealed by [5].

There are different types of storage equipment used in today's warehouse for instance block stacking, adjustable pallet racking or single selective racking, double-deep racking, narrow aisle racking, drive-in-racking and drive-through racking, flow racking, and push-back racking. Each one is suitable to use in different warehouse layout and operation design [3]. At present, single selective rack and drive-in-rack are used this warehouse. The disadvantage of drive-in-rack is inability to manage materials by FIFO (first-in, first-out). Flow racking is an alternative choice for drive-in-rack that can help to solve FIFO issue. However, storage depth of flow rack is commonly limited to eight pallets due to weight consideration as discussed in [6].

The desirable warehouse layout as recommended by [3] 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 the design phase. For space calculation for each area, using an average inventory level might not be an appropriate number because materials can overflow during peak demand period. Thus, Frazelle [7] 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. Some warehouses are divided storage area into forward area and reserve area as discussed in [8]. 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.

In case that warehouse manager found that current space within warehouse is not enough to store all required materials, the solutions can be expanding warehouse, renting additional space, and creating additional space within current warehouse [3]. Third option is the cheapest option and can be done though reducing inventory level, moving expired, obsolete, damage 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. Markmul [9] increased capacity within current warehouse by removing non-moving stocks from warehouse and changing beam height to match with product's size. As a result, capacity of warehouse was enhanced by 14%.

To store products into two warehouses, Phumchusri and Kitpipit [10] proposed that first priority was to understand company's requirement especially safety and quality requirements and second priority was to consider about distance. Products should be located closer to usage area as much as possible to minimize travel distance. Wutthisirisart, Sir, and Nobel [11] had discussed on location selection problem in case that company had two warehouses. 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. The results demonstrated that shipment level policy had the lowest cost, following by material level policy, material level flexible storage policy, and material level strict storage policy, respectively.

2.2. Storage Location Assignment

Three types of storage assignment: random storage, dedicated storage, and class-based storage are commonly used in many warehouses as discussed in [12]. For random storage, locations in warehouse are shared. So, utilization of this storage type is usually higher than other storage types but it can result in higher picking distance as fast-moving materials may be located in further locations to usage area. In contrast, dedicated storage assigns each material into fixed location resulting in low utilization. However, it is easier to operate as operators become familiar with material locations. The last storage assignment is class-based storage. Materials are divided into classes and each class is assigned to specific area within warehouse. Materials within the same class can share locations together but locations are not shared across different classes. Pareto's method as applied in [9] is usually used for classification materials into classes. This storage type is typically used in many warehouses as it can deliver higher utilization than dedicated storage and shorter picking distance than random storage. Nevertheless, Guo, Yu, and De Koster [13] 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 the number of classes and space required are necessary. In addition to classic storage policy as mentioned earlier, clustering storage is popularly used when multiple items are picked in each tour as discussed in [14]. Some research as revealed in [15] also considered sequence of picking lists after clustering SKUs in order to further minimize travel distance and time. However, clustering storage is not applied in this research as only one item is picked in each tour.

As stated in [16], three criteria typically used to assign products into classes including popularity or picking frequency, maximum inventory, and cube-per-order (COI). After products are assigned into classes, another decision is how to assign locations for each class of materials in warehouse. Quader and Castillo-Villar [4] proposed to use either within-aisle storage or across-aisle storage in single-level rack warehouse while Chan and Chan [17] proposed to use either horizontal or vertical ABC class-based storage in multi-level rack warehouse. In contrast, Battista et al. [18] did not use all above strategies. Instead, weight for each slot in warehouse according to travel time required to reach each slot was computed and products that had similar turnover rate were assigned to locate to same weighted slot. Tippayawong, Sopadang, and Patitad [19] applied ABC class-based storage and mathematical linear programming to identify optimized locations for each commodity. The objective function was to minimize travel distance of products from origins to destinations. The results presented that overall travel distance and total picking time were reduced by 45% and 42%, respectively.

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2.3. Warehouse Reshuffling

An assigned location for each material can be changed over the period of time due to changing in demand profile. Warehouse reshuffling 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. Pazour and Carlo [20] 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 by 6%.

2.4. Storage Space Required for Each Group of Products

From [18], total storage locations required for dedicated and random storage can be calculated using Eq. (1) and Eq. (2) as shown below.

$$M_{Dedicated} = \sum_p \max_t \{M_{pt}\} \quad (1)$$
$$M_{Random} = \max_t \{\sum_p M_{pt}\} \quad (2)$$

where M_{pt} is space required by product p at time t, $M_{Dedicated}$ and M_{Random} are total space required for dedicated and random storage, respectively.

Phumchusri and Kitpipit [10] also calculated the number of spaces required based on maximum inventory in the past one year instead of using an average number.

3. Research Methodology

Overall research methodologies used in this research are summarized in Fig. 3.

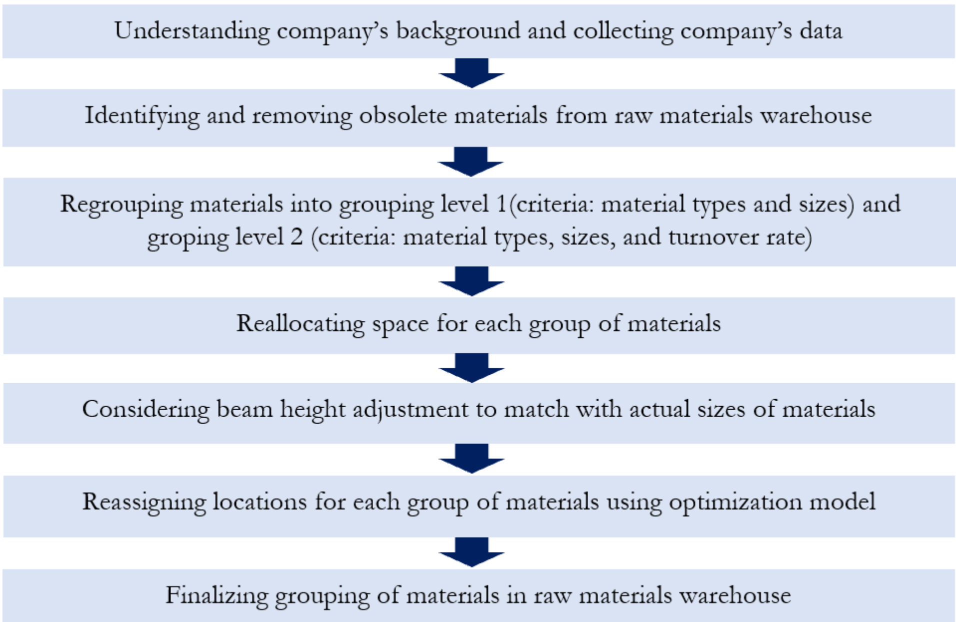

Fig. 3. Overall research methodologies.

3.1. Collecting Company's Data

Company's data required in this research are forecasted month end inventory, demand, and supply data from January to December 2019, material master data including type of materials, the number of pieces or weight per pallet, and received pallet heights, storage locations, and layout of this raw materials warehouse.

3.2. Identifying and Removing Obsolete Materials from Raw Materials Warehouse

In the first step, current inventory and forecasted demand of each SKU in the next 12 months are extracted from SAP system. SKUs that have inventory more than zero but their aggregate demand in the next 12 months are zero are reviewed with planning team whether they can be written-off from the warehouse. After confirmation from planning team is obtained, write-off or obsolete materials are removed from warehouse to temporary tent location in order to process physical write-off further. This process can help to enhance capacity within the warehouse.

3.3. Regrouping Materials into Grouping Level 1 (Criteria: Material's Types and Sizes) and Grouping Level 2 (Criteria: Material's Types, Sizes, and Turnover Rate)

As there are too many SKUs of materials with limited number of locations in the warehouse, it is not appropriate to use dedicated storage policy as it can result in low utilization. On the other hand, using random storage can result in high utilization but it can also result in high average picking distance during picking process. Thus, group-based location is applied. However, group-based location in this research considers not only material's turnover rate but also types and heights of materials. For trading-off among the number of material's groups, storage space required, and total picking distance, two grouping levels are arranged and compared in terms of storage space required and travel distance reduction. Two grouping levels are named grouping level 1 and grouping level 2. For grouping level 1, materials are classified into groups based on type of material and height of material. For grouping level 2, materials are classified into groups based on type of material, height of material and material turnover rate. As Zhang [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. If travel distance reduction is small compared to larger space required, grouping level 1 should be implemented in this warehouse.

Starting from material types, all materials in the warehouse should be divided into seven types which are general raw materials, combustible raw materials, bulk materials, perm pack materials with huge volume, 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 warehouse which are making production, perm production, and color production. Each production area is connected to this warehouse with different entrances. So, materials should be divided into three types according to usage area. For the second criteria which is 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 specific requirement is bulk. 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 bulks. The last criteria is 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 locate in drive-in-rack locations rather than single selective rack locations. Seven types of materials as grouped by these three criteria are summarized in Table 3. Each material is assigned into one type of material.

Table 3. 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 variety 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 used in the warehouse as introduced earlier. From observing 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 warehouse as summarized in Table 4.

Table 4. Proposed rack's type to use in this 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 5 presents final groups of materials under grouping level 1categorized based on material types and sizes. Each material is assigned into one group of materials under grouping level 1.

Table 5. 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)

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 locate closer to 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, 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. 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. Final groups of materials under grouping level 2 are presented in Table 6.

Table 6. 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)

3.4. 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 SAP system. In the second step, month end inventory by SKUs from the first step is converted from their original unit (gram, kilogram, or piece) to pallet unit using unit conversion from material master data. For 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 7 and Table 8.

Table 7. Month end inventory of each material's 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 Inventor
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**

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Table 8. Month end inventory of each material's 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**
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 (C)	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**

The final space allocated for each group of materials is assigned 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. The final space allocated for each group under grouping level 1 and grouping level 2 is demonstrated in Table 9 and Table 10, respectively.

Table 9. 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 10. 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 (C)	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**

3.5. Considering Beam Height Adjustment to Match with Actual Sizes of Materials

After total required space for each material's group is identified, required space for each rack's type can be finalized as shown in Table 11.

Table 11. Current rack available and the 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 current racks availability in 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 considered to match with actual sizes of raw materials and best utilize the area. 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. For the key constraint, beam height of the same row and same level of rack should be the same to avoid confusion during operation. Table 12 demonstrates an updated rack available in the warehouse after applying beam height adjustment.

Table 12. New rack available and the 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**

It is noticeable that the availabilities of each rack's type match with rack requirement for both grouping level 1 and grouping level 2. Furthermore, the excess locations are allocated to medium rack size in order to use for storing finished products.

3.6. Reassigning Locations for Each Group of Materials Using Optimization Model

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

In the first step, all parameters have to be collected which consist of travel distances from each location to each usage area and average picking frequency per location for each group of materials. After all necessary parameters for creating optimization model are collected. The next step is to construct optimization model and use OPL program (IBM ILOG CPLEX Optimization Studio) to generate the optimized results. Two main optimization models are created for grouping level 1 and grouping level 2.

3.6.1. Optimization models for grouping level 1

Sets:
I = Set of location number = {1,2,…,3817}
LR = Set of location number for low racks = {1,2,…,573}, where $LR \in I$
MR = Set of location number for medium racks = {574,575,…,2720}, where $MR \in I$
HR = Set of location number for high racks = {2721,2722,…,3817}, where $HR \in I$
MRF = Set of location number for medium racks that are located at first floor of warehouse = {574,575,…,839}, where $MRF \in I$
J = Set of material number = {1,2,…,3444}
CLM = Set of material number for color low materials = {1,2,…,567}, where $CLM \in J$
CMM = Set of material number for color medium materials = {568,569,…,1295}, where $CMM \in J$
CHM = Set of material number for color high materials = {1296,1297,…,1654}, where $CHM \in J$
GRM = Set of material number for general raw materials = {1655,1656,…,2290}, where $GRM \in J$
CRM = Set of material number for combustible raw materials = {2291,2292}, where $CRM \in J$
BM = Set of material number for bulk materials = {2293,2294,…,2422}, where $BM \in J$
PMM = Set of material number for perm medium materials = {2423,2424,…,2730}, where $PMM \in J$
PHM = Set of material number for perm high materials = {2731,2732,…,3444}, where $PHM \in J$
CP = Set of material number used in color production = {1,2,…,1654}, where $CP \in J$
MP = Set of material number used in making production = {1655,1656,…,2292}, where $MP \in J$
PP = Set of material number used in perm production = {2293,2294,…,3444}, where $PP \in J$
K = Set of usage area = {1,2,3}, where 1 = making area, 2= perm area, and 3 = color area

Parameters:
$Dist_{ik}$ = Distance from location i to usage area k
$Freq_j$ = Picking frequency per location of material j

Decision variable:
x_{ij} = 1 if material j is in location i ; 0 otherwise

Objective function:
Minimize Total Picking Distance =

$$\sum_{j\in MP}\sum_{i\in I}\left(x_{ij}\times Dist_{i1}\times 2\times Freq_j\right)+\sum_{j\in PP}\sum_{i\in I}\left(x_{ij}\times Dist_{i2}\times 2\times Freq_j\right)+\sum_{j\in CP}\sum_{i\in I}\left(x_{ij}\times Dist_{i3}\times 2\times Freq_j\right) \quad (3)$$

Constraints:

$$\sum_{j\in J} x_{ij}\leq 1, \qquad \forall_{i\in I} \quad (4)$$

$$\sum_{i\in I} x_{ij}=1, \qquad \forall_{j\in J} \quad (5)$$

$$\sum_{i\in LR}\sum_{j\in CLM} x_{ij}=567 \quad (6)$$

$$\sum_{i\in MR}\sum_{j\in CMM} x_{ij}=728 \quad (7)$$

$$\sum_{i\in HR}\sum_{j\in CHM} x_{ij}=359 \quad (8)$$

$$\sum_{i\in MR}\sum_{j\in GRM} x_{ij}=636 \quad (9)$$

$$\sum_{i\in MR}\sum_{j\in CRM} x_{ij}=2 \quad (10)$$

$$\sum_{i\in MRF}\sum_{j\in BM} x_{ij}=130 \quad (11)$$

$$\sum_{i\in MR}\sum_{j\in PMM} x_{ij}=308 \quad (12)$$

$$\sum_{i\in HR}\sum_{j\in PHM} x_{ij}=714 \quad (13)$$

Total picking distance as shown in Eq. (3) equals picking distance of materials located in making production (first term) plus picking distance of materials located in perm production (second term) and plus picking distance of materials located in color production (third term). The objective function is subjected to ten constraints as presented in Eq. (4) to Eq. (13). Eq. (4) limits that each i location can be used to store one material at most while Eq. (5) indicates that each material in each group must be assigned in one location. The rest constraints imply that each material has to be assigned to suitable rack's type. Color low materials have to be located at low racks as stated in Eq. (6). Color medium materials, general raw materials, combustible raw materials, and perm medium materials have to be located at medium racks as forced by Eq. (7), Eq. (9), Eq. (10), and Eq. (12), respectively. In Eq. (8) and Eq. (13), color high materials and perm high materials have to be stored at high racks, consecutively. Eq. (11) is for indicating that bulk materials can be stored only on the first floor of warehouse which includes locations i = 574 to 839.

The results from optimization model present final locations for each group of materials under grouping level 1 as illustrated in Fig. 4.

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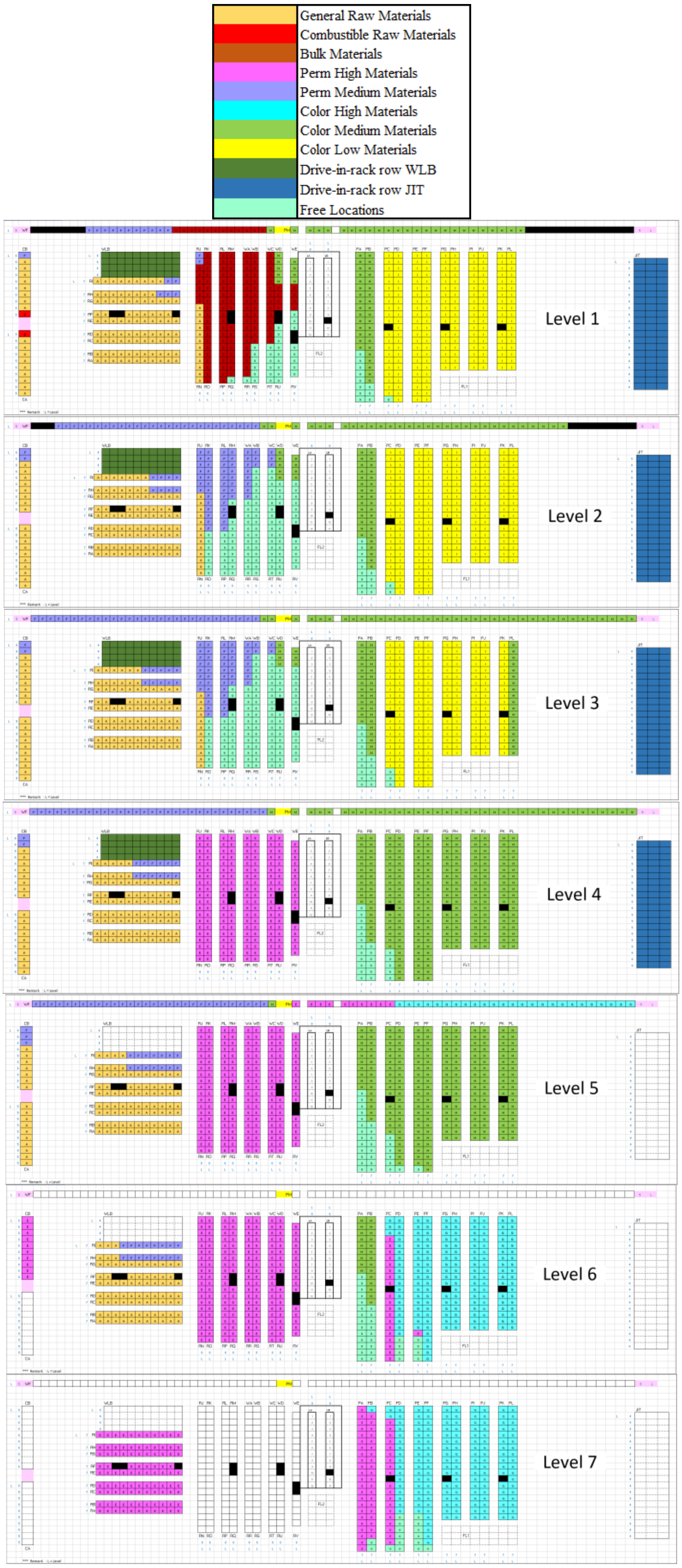

Fig. 4. Final assigned locations for each group of raw materials under grouping level 1 in this warehouse.

Total picking distance calculated based on new assigned locations for each group of materials under grouping level 1 is 1,301.78 km.

3.6.2. Optimization models for grouping level 2

Sets:
I = Set of location number = {1,2,…,3817}
LR = Set of location number for low racks = {1,2,…,573}, where $LR \in I$
MR = Set of location number for medium racks = {574,575,…,2720}, where $MR \in I$
HR = Set of location number for high racks = {2721,2722,…,3817}, where $HR \in I$
MRF = Set of location number for medium racks that are located at first floor of warehouse = {574,575,…,839}, where $MRF \in I$
J = Set of material number = {1,2,…,3491}
CLMA = Set of material number for color low materials class A = {1,2,…,274}, where $CLMA \in J$
CLMB = Set of material number for color low materials class B = {275,276,…,426}, where $CLMB \in J$
CLMC = Set of material number for color low materials class C = {427,428,…,571}, where $CLMC \in J$
CMMA = Set of material number for color medium materials class A = {572,573,…,876}, where $CMMA \in J$
CMMB = Set of material number for color medium materials class B = {877,878,…,1058}, where $CMMB \in J$
CMMC = Set of material number for color medium materials class C = {1059,1060,…,1303}, where $CMMC \in J$
CHMA = Set of material number for color high materials class A = {1304,1305,…,1504}, where $CHMA \in J$
CHMB = Set of material number for color high materials class B = {1505,1506,…,1576}, where $CHMB \in J$
CHMC = Set of material number for color high materials class C = {1577,1578,…,1664}, where $CHMC \in J$
GRMA = Set of material number for general raw materials class A = {1665,1666,…,1976}, where $GRMA \in J$
GRMB = Set of material number for general raw materials class B = {1977,1978,…,2184}, where $GRMB \in J$
GRMC = Set of material number for general raw materials class C = {2185,2186,…,2319}, where $GRMC \in J$
CRM = Set of material number for combustible raw materials = {2320,2321}, where $CRM \in J$
BM = Set of material number for bulk materials = {2322,2323,…,2451}, where $BM \in J$
PMMA = Set of material number for perm medium materials class A= {2452,2453,…,2602}, where $PMMA \in J$
PMMB = Set of material number for perm medium materials class B= {2603,2604,…,2697}, where $PMMB \in J$
PMMC = Set of material number for perm medium materials class C= {2698,2699,…,2773}, where $PMMC \in J$
PHMA = Set of material number for perm high materials class A = {2774,2775,…,3048}, where $PHMA \in J$
PHMB = Set of material number for perm high materials class B = {3049,3050,…,3258}, where $PHMB \in J$
PHMC = Set of material number for perm high materials class C = {3259,3260,…,3491}, where $PHMC \in J$
CP = Set of material number used in color production = {1,2,…,1664}, where $CP \in J$
MP = Set of material number used in making production = {1665,1666,…,2321}, where $MP \in J$
PP = Set of material number used in perm production = {2322,2323,…,3491}, where $PP \in J$
K = Set of usage area = {1,2,3}, where 1 = making area, 2= perm area, and 3 = color area

Parameters:
$Dist_{ik}$ = Distance from location i to usage area k
$Freq_j$ = Picking frequency per location of material j

Decision variable:
x_{ij} = 1 if material j is in location i; 0 otherwise
Objective function:
Minimize Total Picking Distance =

$$\sum_{j\in MP}\sum_{i\in I}\left(x_{ij}\times Dist_{i1}\times 2\times Freq_j\right)+\sum_{j\in PP}\sum_{i\in I}\left(x_{ij}\times Dist_{i2}\times 2\times Freq_j\right)+\sum_{j\in CP}\sum_{i\in I}\left(x_{ij}\times Dist_{i3}\times 2\times Freq_j\right) \quad (14)$$

Constraints:

$$\sum_{j\in J} x_{ij}\leq 1, \qquad \forall_{i\in I} \quad (15)$$
$$\sum_{i\in I} x_{ij}=1, \qquad \forall_{j\in J} \quad (16)$$
$$\sum_{i\in LR}\sum_{j\in CLMA} x_{ij}=274 \quad (17)$$
$$\sum_{i\in LR}\sum_{j\in CLMB} x_{ij}=152 \quad (18)$$
$$\sum_{i\in LR}\sum_{j\in CLMC} x_{ij}=145 \quad (19)$$
$$\sum_{i\in MR}\sum_{j\in CMMA} x_{ij}=305 \quad (20)$$
$$\sum_{i\in MR}\sum_{j\in CMMB} x_{ij}=182 \quad (21)$$
$$\sum_{i\in MR}\sum_{j\in CMMC} x_{ij}=245 \quad (22)$$
$$\sum_{i\in HR}\sum_{j\in CHMA} x_{ij}=201 \quad (23)$$
$$\sum_{i\in HR}\sum_{j\in CHMB} x_{ij}=72 \quad (24)$$
$$\sum_{i\in HR}\sum_{j\in CHMC} x_{ij}=88 \quad (25)$$
$$\sum_{i\in MR}\sum_{j\in GRMA} x_{ij}=312 \quad (26)$$
$$\sum_{i\in MR}\sum_{j\in GRMB} x_{ij}=208 \quad (27)$$
$$\sum_{i\in MR}\sum_{j\in GRMC} x_{ij}=135 \quad (28)$$
$$\sum_{i\in MR}\sum_{j\in CRM} x_{ij}=2 \quad (29)$$
$$\sum_{i\in MRF}\sum_{j\in BM} x_{ij}=130 \quad (30)$$
$$\sum_{i\in MR}\sum_{j\in PMMA} x_{ij}=151 \quad (31)$$
$$\sum_{i\in MR}\sum_{j\in PMMB} x_{ij}=95 \quad (32)$$
$$\sum_{i\in MR}\sum_{j\in PMMC} x_{ij}=76 \quad (33)$$
$$\sum_{i\in HR}\sum_{j\in PHMA} x_{ij}=275 \quad (34)$$
$$\sum_{i\in HR}\sum_{j\in PHMB} x_{ij}=210 \quad (35)$$
$$\sum_{i\in HR}\sum_{j\in PHMC} x_{ij}=233 \quad (36)$$

Total picking distance as demonstrated in Eq. (14) equals the summation of picking distance of materials located in making production (first term), picking distance of materials located in perm production (second term) and picking distance of materials located in color production (last term). The objective function is subjected to 22 constraints as presented in Eq. (15) to Eq. (36). For the first constraint as equated in Eq. (15), each i location can be used to store one material at most. The second constraint as shown in Eq. (16) indicates that each material in each group must be assigned in one location. Eq. (17) to Eq. (19) implies that color low materials class A, B, and C have to be located at low racks. At the same time, color medium materials class A, B, and C, general raw materials class A, B, and C, and combustible materials have to be stored at medium racks as demonstrated in Eq. (20) to Eq. (22), Eq. (26) to Eq. (29), and Eq. (31) to Eq. (33), respectively. Eq. (23) to Eq. (25) and Eq. (34) to Eq. (36) show that color high pack materials class A, B, and C and perm high pack materials class A, B, and C have to be located at high racks. For Eq. (30), bulk materials can be stored only on the first floor of warehouse which includes locations i = 574 to 839.

The results from optimization model report final locations for each group of materials under grouping level 2 as illustrated in Fig. 5.

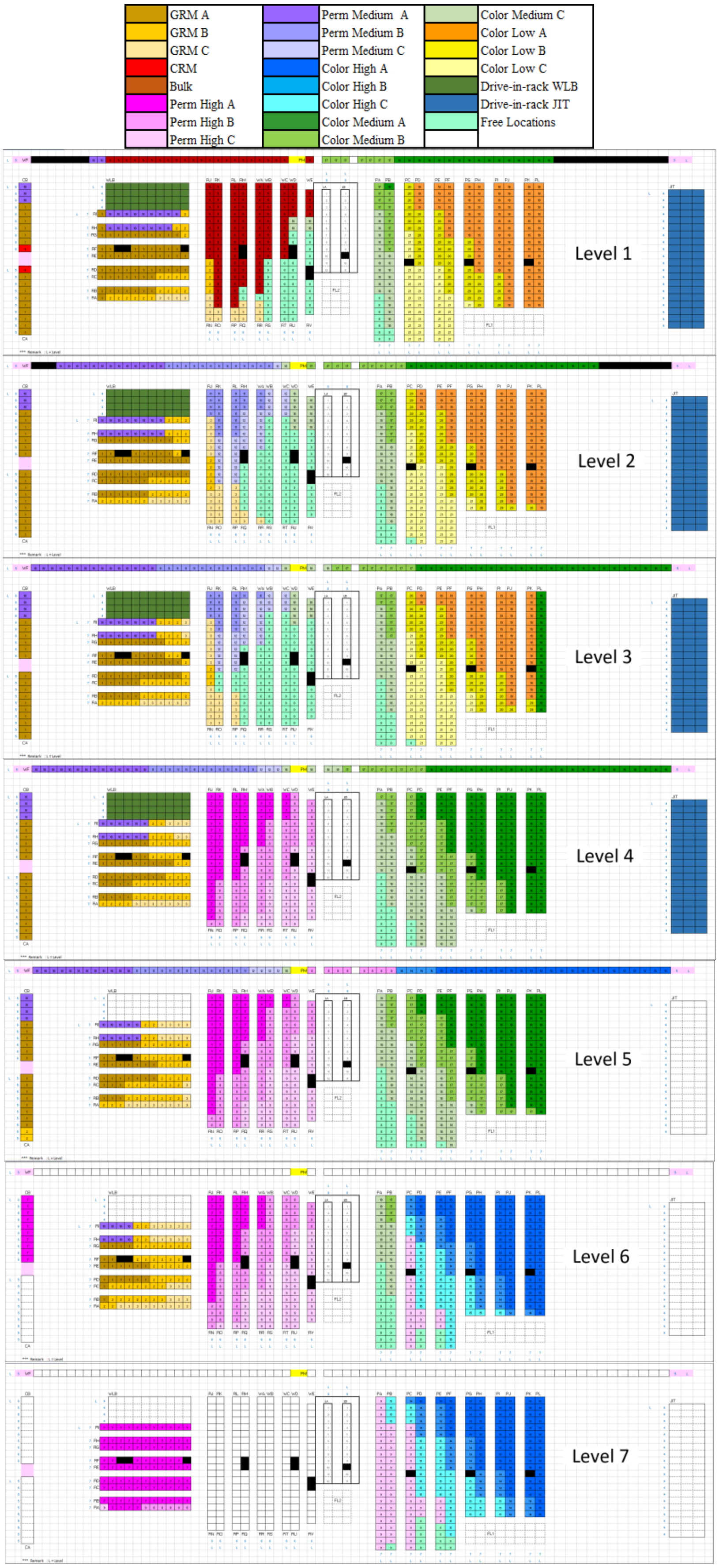

Fig. 5. Final assigned locations for each group of raw materials under grouping level 2 in this warehouse.

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Total picking distance calculated based on new assigned locations for each group of materials under grouping level 2 is 1,102.45 km.

3.7. Finalizing Grouping of Materials in the Raw Materials Warehouse

As mentions in part 3.3, grouping level 1 and grouping level 2 will be compared in terms of space required and picking distance reduction. Grouping that requires lower space and results in shorter picking distance will be selected to implement in this warehouse. The comparison of required space and total picking distance between grouping level 1 and grouping level 2 is shown in Table 14.

Table 14. Compare total required space and picking distance between grouping level 1 and grouping level 2.

	Grouping Level 1	Grouping Level 2	Differences
Total Required Spcae (#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%. However, total picking distance of grouping level 2 is shorter than grouping level 1 by 199.32 km or 15.3%. Based on these comparisons, grouping level 2 is more attractive to implement than grouping level 1. So, grouping level 2 is selected to implement in this warehouse.

4. Results

4.1. Capacity Enhancement from Removing Obsolete Materials from Warehouse and Applying Beam Height Adjustment

From reviewing current inventory levels and demand in the next 12 months of materials in this warehouse, 457 SKUs with 649 pallets have inventories but zero demand in the next 12 months. After confirming with planning team, 283 SKUs with 368 pallets are obsolete materials and can be removed from warehouse for further destroying process. As a result, warehouse capacity can be increased by 9.04% from clearing up obsolete materials from the studied warehouse.

By considering beam height adjustment to match with actual size of materials, the capacity in the warehouse is increased by 3.61% as illustrated in Table 15.

Table 15. The comparison of rack's available in the 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	1126	R2	120	2147	
R4	140	737	R3	190	1097	
R5	190	1285	R4	200	400	
DIR	200	400				
Total		**4070**	**Total**		**4217**	**3.6%**

Overall, warehouse capacity is improved by 12.65% or 515 more locations are available in the warehouse. After assigning locations for each group of materials, 326 locations remain available including 2 locations of low racks, 306 locations of medium racks, and 18 locations of high racks. As finished products can be located in medium and high racks, 324 locations can be used for storing finished products at this internal raw materials warehouse.

4.2. Utilization Improvement from Reallocating Space for Each Group of Materials

After reallocating space for each group of materials based on maximum month end inventory, utilization in warehouse is significantly improved as assigned space is more balanced with the requirement as demonstrated in Fig. 6 and Fig. 7.

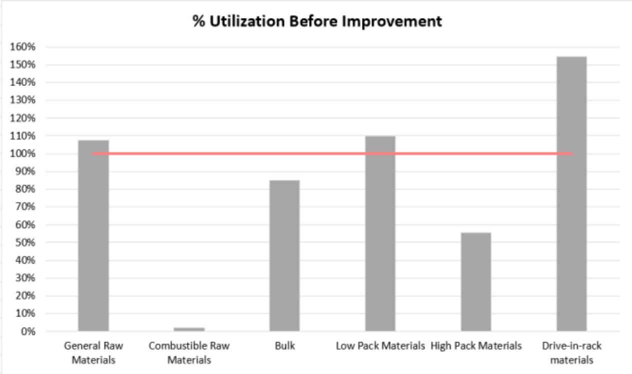

Fig. 6. Utilization before improvement.

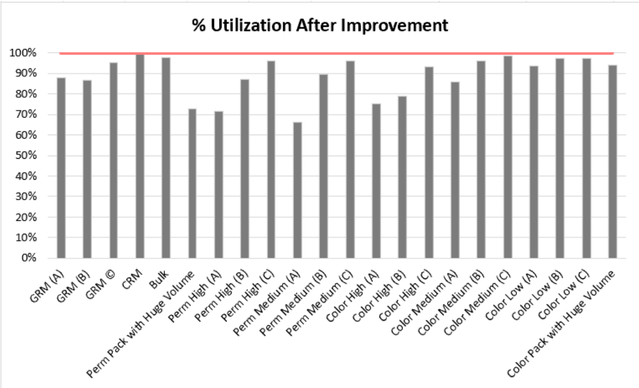

Fig. 7. Utilization after improvement.

From above figures, they clearly demonstrate that utilization of each material's group after improvement is more balance than utilization of each material's group before improvement. Average utilization of each material's group is lower than 100%. Therefore, there are few materials overflowing across the assigned locations and less human effort required to manually locate the overflowing materials to other locations.

4.3. Picking Distance Reduction from Reassigning Locations for Each Group of Materials

Based on new assigned locations for each group of materials, overall picking distance is reduced significantly as materials were located in proper locations and assigned based on ABC class-based storage. Detail calculation of total picking distance before improvement is shown in Table 16 and the comparison of total picking distance before and after improvement is shown in Fig. 8.

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Table 16. 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	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**

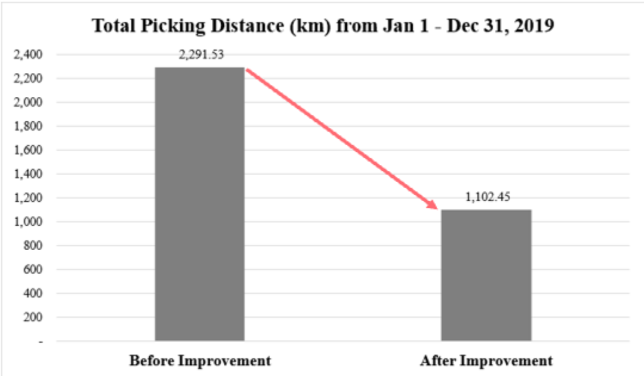

Fig. 8. Comparison of total picking distance before and after improvement.

The result presents that total picking distance after improvement is reduced by 1,189.08 km or 51.9% compared to total picking distance before improvement.

4.4. Cost Saving from Storing Some Finished Products at the Raw Materials Warehouse

As 324 locations are available for storing finished products at this raw materials warehouse, storage cost reduction of 874,800 THB per year at external public warehouse is obtained. For the calculation, external public warehouse charges the case study company at rate 7.5 THB per pallet per day. Thus, saving 324 locations can reduce storage cost at external public warehouse by 324 locations × 7.5 THB per pallet per day × 30 days per month × 12 months per year = 874,800 THB per year.

5. Robustness Analysis of the Proposed Model

In this chapter, robustness of the proposed model is analyzed and contingency plan is developed. As space for each material's group is allocated based on maximum forecasted month end inventory, changing in forecast can impact the utilization, total picking distance, and cost saving as presented earlier in part 4. For sensitivity analysis in this part, forecasted inventory is assumed to increase by 5% and 10%. Then, utilization is measured based on space allocation in part 3.4. In case that utilization is over 100%, contingency plan developed under this research is applied for assigning overflow materials to other available locations and additional picking travel distance is also 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 previous allocated space is based on maximum month end inventory. Figure 9 illustrates average utilization and Table 17 presents monthly utilization for scenario 1 that forecasted inventory is increased by 5%.

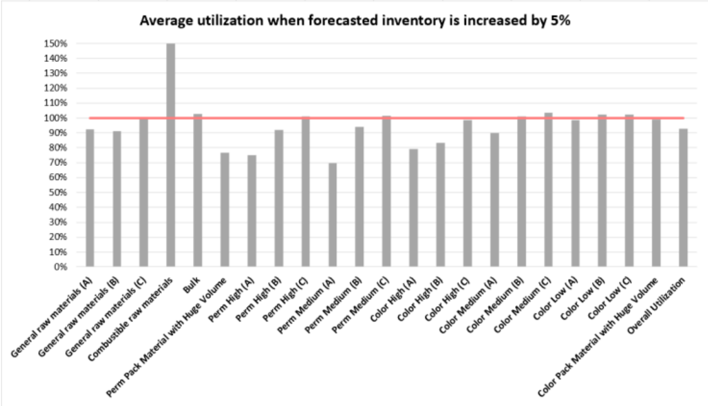

Fig. 9. Average utilization of scenario 1 that forecasted inventory is increased by 5%.

Table 17. 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 Fig. 9 and Table 17 demonstrates that utilization over 100% occurring in some group of materials and in some months. As the company has policy to reassign locations for each group of materials once a year, contingency plan is needed for handling with overflow materials occurring during a year.

Figure 10 reveals 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 following 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 SAP system. So, once assigned locations are full, SAP 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 total picking distance.

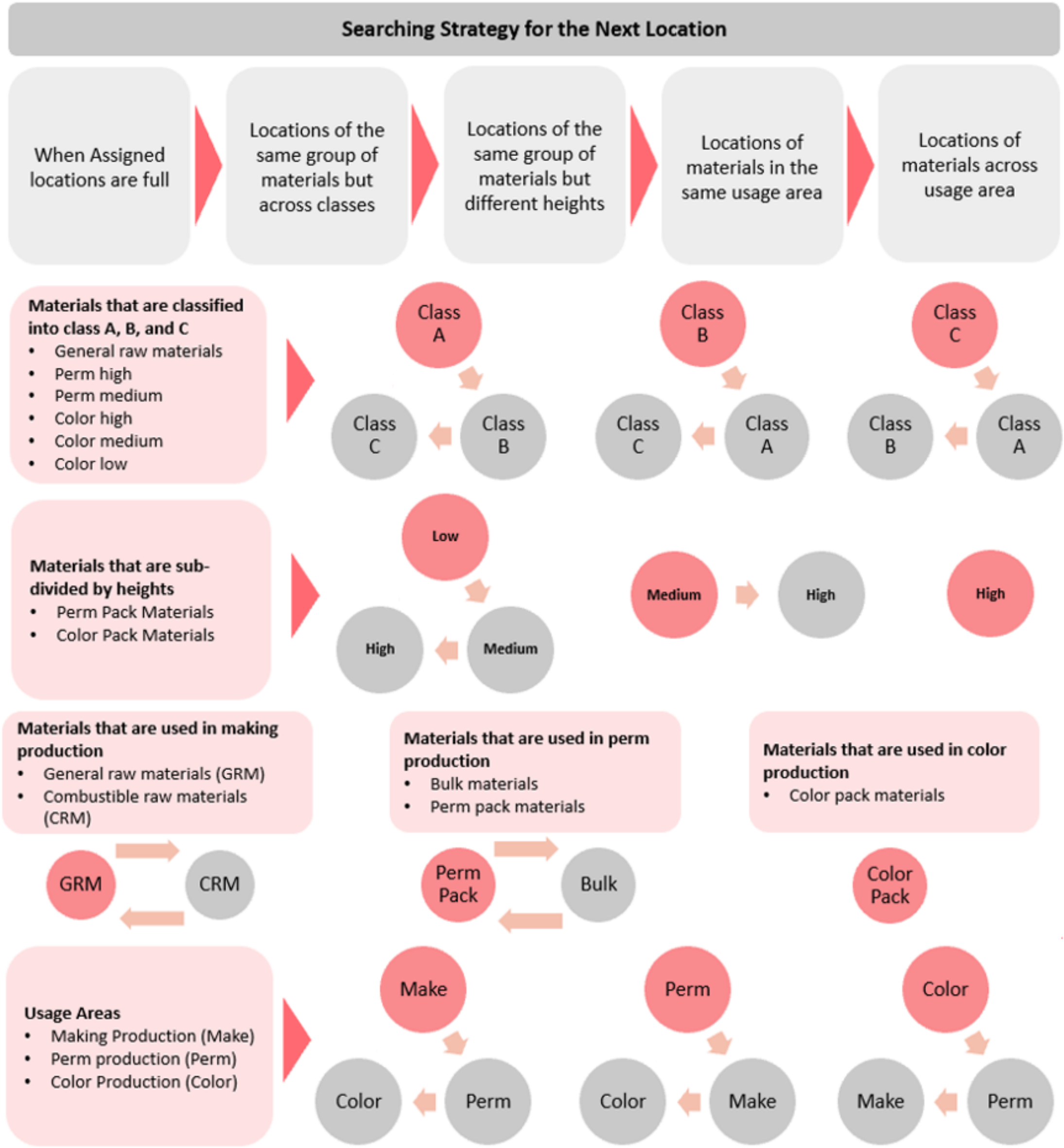

Fig. 10. Overall searching strategy for the next locations.

Table 18 and Table 19 present the summary of searching strategy for the next locations under material's group levels and material's class levels, respectively.

Table 18. Searching strategy for the next locations under material's 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 19. Searching strategy for the next locations under material's 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, 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 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 20, 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 Fig. 11 and Table 21, respectively. It is noticeable that utilization of all material's groups after using searching for the next locations strategy is not over 100% as the next locations are always available in this scenario.

Table 20. 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%**

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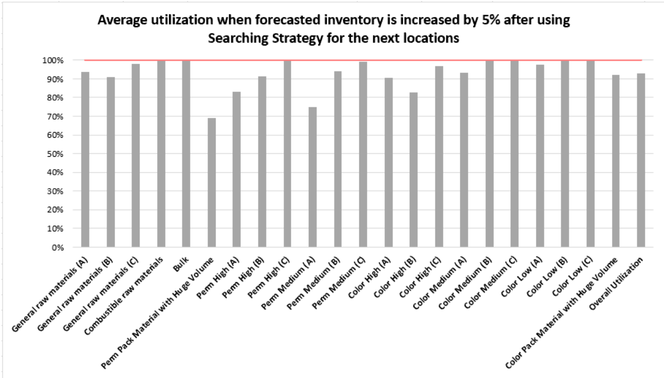

Fig. 11. Average utilization of scenario 1 after using searching strategy for the next locations.

Table 21. 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 the scenario 2 that forecasted inventory is increased by 10%, over utilization is expected to be more severe than the scenario 1 that forecasted inventory is increased by 5%. Figure 12 presents average utilization and Table 22 illustrates monthly utilization for scenario 2 that forecasted inventory overshoots from the base case by 10%.

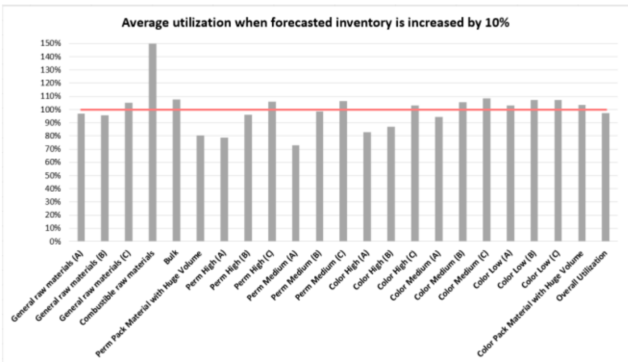

Fig. 12. Average utilization of scenario 2 that forecasted inventory is increased by 10%.

Table 22. 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 previous part is also applied in this scenario. However, searching strategy is found to be invalid in some months including February, March, April, and May as there are not enough suitable racks to locating certain type of materials. In this case, some of assigned locations for finished products are needed to allocate back to materials as summarized in Table 23.

Table 23. 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 base case scenario, this directly impacts cost saving that is claimed in part 4.4. To store fresh finished products at this warehouse, minimum space required is 320 locations in order to be still profitable. Thus, fresh finished products should not be stored at the 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 874,800 THB, only 583,200 THB is obtained.

By 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 base case as presented in Table 24. In addition, additional working effort required to allocate materials back to their assigned locations is estimated to be 182 touches per month.

Table 24. Total picking distance of 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, Fig. 13 and Table 25 shows an updated average utilization and monthly utilization in the raw materials warehouse, consecutively.

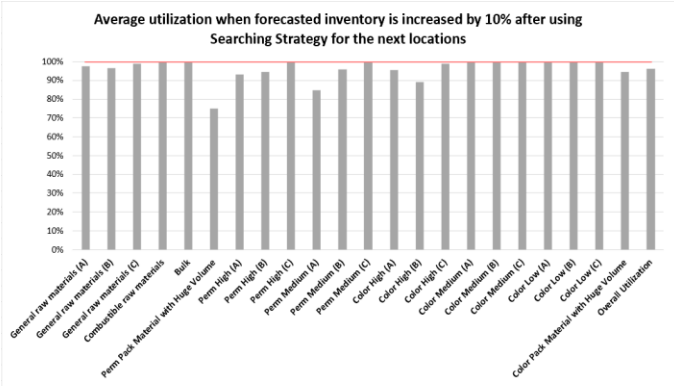

Fig. 13. Average utilization of scenario 2 after using searching strategy for the next locations and allocating some space of finished products to overflow materials.

Table 25. Monthly utilization of the scenario 2 after using 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

6. Conclusion

The objective of this research was to enhance the efficiency of a case study's internal raw materials warehouse via identifying the optimal storage location for each material. At the same time, this research aimed to improve capacity and utilization of the internal raw materials warehouse in order that some finished products can be located here, and the case study company can save cost from storing some selected finished products at external public warehouse.

For the methodologies used in this research, first, current inventory and demand in the next 12 months of each SKU were extracted from SAP system. SKUs that had inventory but absent of demand in the next 12 months were reviewed by planning team to confirm whether they can be written-off and removed from the warehouse. The result presented that 283 SKUs with 368 pallets were obsolete materials and can be discarded from the warehouse. Therefore, the available space was increased by 9.04% from clearing obsolete materials from the raw materials warehouse. Second, all SKUs of raw materials in the warehouse were regrouped according to types, sizes, and turnover rate. Two levels of grouping were developed which were grouping level 1 (considers only material types and size) and grouping level 2 (considers materials types, sizes, and turnover rate) 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. Third, space was allocated to each group of materials based on maximum month end inventory for both grouping level 1 and grouping level 2. After total required space for each group of materials was revealed, total required locations for each type of racks was also disclosed and beam height adjustment was considered to match with the actual requirement in the fourth step. As the warehouse currently had more high racks than necessary, reducing beam height resulted in capacity enhancement by 3.6%. In the fifth step, each group of materials under grouping level 1 and grouping level 2 was assigned to certain locations in the warehouse. Optimization model was used to identify the most appropriate locations for each group of materials with an objective function to minimize total picking distance. After locations for each group of materials were identified, 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 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, 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. So, it was chosen to implement in this warehouse.

As compared to current situation, total capacity was enhanced by 12.65% through clearing obsolete products from the raw materials warehouse and beam height adjustment. Utilization was more balanced throughout warehouse and less materials overflow across assigned locations. These helped to reduce human effort in manually assigning locations for overflow materials. In addition, picking distance was expected to be reduced about 51.9% as materials were located in more proper locations. After current internal raw materials warehouse was improved, 324 locations were available to store finished products at here. Thus, annual cost saving of 874,800 THB was obtained from storing some finished products at raw materials warehouse instead of storing them at external public warehouse.

In the later part of this research, robustness of the proposed model was analyzed. Forecast inventory was assumed to be increased by 5% and 10%. Then, impacts of these changes toward utilization, picking distance, and cost saving were reported. In case that utilization was over 100%, contingency plan developed in this research can be used to manage the overflow materials. For the first scenario that forecasted inventory was expanded by 5%, over utilization was observed in some groups of materials and in some months. Searching for the next locations strategy was used to handle with overflow materials. Based on this scenario, total picking distance was increased about 2.3% as some materials were located across assigned locations which were not proper locations. Nevertheless, established searching for the next locations strategy was always valid in this scenario since there was always suitable rack available during searching for the next location. So, it was not necessary to allocate some space of finished products to overflow materials and cost saving from locating some finished products at the warehouse was still the same. For the second scenario, forecasted inventory was boosted up by 10%. In this case, searching strategy for the next locations was invalid in some months due to inadequate suitable racks for locating certain type of materials. Hence, some assigned locations for finished products were allocated to overflow materials which directly impacted cost saving obtained from storing some finished products at this raw materials warehouse. The cost saving remained 583,200 THB per year and the total picking distance was risen by 5.2% compared to base case scenario.

For further study, separating locations for returned materials and assigning smaller beam height than normal locations are interesting to study as they should help to enhance capacity, utilization, and efficiency of the warehouse. In addition, warehouse reshuffling can also be beneficial to study in this warehouse due to large size of warehouse with variety of SKUs number. The optimized strategy for warehouse reshuffling can help to reduce reshuffling cost and enlarge the benefits gained from reassigning locations for each group of materials.

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