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Article

Warehouse Layout Design for an Automotive Raw Material Supplier

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Abstract. The case-study company faces the limited space situation. Thus, the company decides to uninstall their temporary warehouses and re-locate products in two permanent warehouses. The objective of this research is to design the layouts of the two permanent warehouses so that the spaces can be efficiently used and the total picking distance is low. The past data, Invoices and Stock Data, are used for developing layouts designing processes. This research involves the collecting of Product Size Data to calculate the required space for the products. There are two phases in layout designing process. The first phase is the product categories grouping. This phase categorizes product categories into two groups for the two warehouses. The second phase is the layouts designing. In this phase, the layouts of the two warehouses and the locations of the products are designed. According to the company requirements and policies, the Adapted Class-Based Turnover Assignment is adopted in order to design the layouts for the two warehouses. Layouts of the warehouses are designed, analyzed, and evaluated. The best layouts give the best trade-off between quantitative results, i.e., the total picking distance and the remaining space, and qualitative results, i.e., the usability and the product suitability. The designed layouts are applied in the case-study company. This research develops a systematic and practical layout designing method which is flexible and can be adopted in other warehouses.

Keywords: Warehouse layout design, warehouse management, automotive industry.

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1. Introduction

Warehouses play an important role for the companies in Thailand automotive industry, which is one of the major sources of country's GDP [1]. This research designs the warehouse layout for a raw materials and equipment supplier in an automotive industry. The core activity of the case-study company is selling the raw materials to the customers who are manufacturers in an automotive industry. Most of the raw materials are imported from other countries, while some of them are in-house produced. The company classifies products into many product categories based on their characteristics (components, physical appearances, and chemical characteristics) or applications. There are various forms and packages of the products in the same product category. Although the products are in the same product categories, the product forms and packages might be different. Each warehouse stores several product categories, and Warehouse A is the main warehouse of the company, which stores the highest number of product categories.

According to the historical sales, the company's market has been increasing. The higher number of sold products results in the higher needed storage spaces in the warehouses. Therefore, Warehouse A faces a limited space situation as shown in Fig. 1. The company management team also decides to stop using some of their temporary warehouses and build a new permanent warehouse, Warehouse B. Figure 2 illustrates a temporary warehouse of the company. Figure 3 illustrates the storage area of Warehouse B. The company plans to move products from the temporary warehouses to Warehouse A and Warehouse B. These situations lead to the following problems that will be answered in this research.

1) Which products should be located in the existing warehouse (Warehouse A) and the new warehouse (Warehouse B)?

2) What are the suitable warehouse layouts for Warehouse A and Warehouse B?

Fig. 1. Insufficient space situation in Warehouse A.

Fig. 2. A temporary warehouse currently used in this company.

Fig. 3. New Warehouse B.

This research aims to design the layouts of Warehouse A and Warehouse B. The meaning of layout in this paper is to assign the locations for all related products, using historical data to analyze the required spaces for each of them. We measure the layouts performance by the qualitative measurement (the suitability of the locations for each product category) and quantitative measurement (the sum of the total picking distance from the designed layout).

In order to assign the location of products, we consider products' characteristics, required spaces, and the company designing method constraints. The company management team has decided that the products in the same category will be stored in the same warehouse. This research develops the systematic and practical method to design warehouse layouts. The objective is to design the layouts of the existing warehouse (Warehouse A) and the new warehouse (Warehouse B) so that the spaces can be efficiently used and the total picking distance from all invoices is low. There are 5 main steps in this research, i.e.:

1) Literature Reviewing of related research in this area
2) Collecting the required data for this research. (Product information, storage information, warehouse information, stock data, invoice data, and product size data are required in this research.)
3) Grouping product categories into 2 groups and designing the layouts for Warehouse A and Warehouse B. After the product categories are grouped and the layouts for both warehouses are concluded, we analyze the candidate layouts. The best layout for each of the warehouses will be chosen in this step.
4) Validating, implementing, and evaluating the layouts. We adjust the best layouts and implement the layouts in both warehouses. The new layouts are compared with the existing layouts.
5) Concluding and recommending the future work.

2. Literature Review

Warehouse design problem was defined and grouped to three decision levels: (1) Strategic level (2) Tactical level and (3) Operational level. Ashayeri and Gelders [1] provided a comprehensive review of warehouse design and concluded that a pure analytical approach or a pure simulation approach did not generally lead to a practical design. They suggested a combination of analytical and simulation approaches. Duve and Bocker [2] developed a step-wise design method and proposed several examples using that method in warehouse design. Hassan [3] proposed 14 steps framework for designing a warehouse layout. They concluded that warehouse information, the operating policies, the product classifications, the space requirement determination, and the spaces calculation are required in order to design warehouse layout. Pandit and Palekar [4] proposed analytical models and simulation to explore the impact of the layout of a conventional warehouse on the response time.

According to Bartholdi and Hackman [5], there are two main storage strategies, i.e., the dedicated storage and the shared storage strategies. The concept of dedicated storage or fixed position storage is to locate a product in one specific location. The more popular products are assigned in more convenient locations. In contrast, shared storage is opposite to dedicated storage in which products in shared storage can be located in more than one location. A Class-based storage is a dedicated storage which is related to ABC analysis and it is usually used to increase the overall throughputs. The products in a class-based storage can be categorized into three groups, Group A, Group B, and Group C. Products categorized as Group A are the most frequently picked products, while Group C is the least frequently picked. The most frequently picked products, about 20 per cent of overall product: Group A, will be assigned to the most convenient locations of the warehouse. However, the percentage for each group is usually depends on the company policies [6].

Hausman et al. [7] proposed three storage policies:

1) Random Storage Assignment; store a product closest to the I/O without any concern on the turnover.
2) Turnover-Based Assignment; store the highest-turnover pallets closest to the I/O.
3) Class-Based Turnover Assignment; the policy aims to the products from turnover into classes and store a product within its class location.

They found that Turnover-based Assignment had the lowest the traveling time, while the Class-Based Turnover assignment could result in the lowest overall time. They suggested this Class-Based method was also more practical than the Turnover-Based assignment. Frazelle and Sharp [8] found that the correlated assignment policy which aimed to store the ordered-together products in the same storage area could reduce the retrieval time, compared to the typical storage policies. Muppani and Adil [9] developed branch and bound algorithm (BBA) and dynamic programming algorithm (DPA) to minimize the traveled distance of class-based policy and compare the result to the turnover-based policy. They found that the class-based policy can yield lower traveled distance than the turnover-based policy. Their research developed the keeping policies based on automatic warehouse system. Battista et al. [10] compared storage policies, i.e., random storage assignment and turnover-based assignment. They found that the turnover-based strategy could reduce 37.8% of travelling time as compared to the original layout.

Each business has different characteristics. The solution of the warehouse layout designing depends on the product characteristics and the company policies. For example, in the paper reel business in China, the turnover-based assignment is efficient and effective for developing the warehouse layout. Because one stack can be stored more than one type of same product category, so Linear Programming (IP) is developed to solve this problem [11]. Amarase [12] designed a new layout of a plastic resins trading company. He designed the layout of the warehouse by dividing the layout into 2 areas, i.e., front and back. The popular products were located in the front area, while the other products were assigned to the back area.

For the picking policy, there are many methods proposed in the literature. Amarase [12] measured the picking distance of each product from its location to the preparing area (distance in X and Y axes) in order to develop the picking policy of the plastic resins trading warehouse. Koster and Poort [13] compared optimal solution; polynomial algorithm; and S-shape heuristics to minimize the total picking time. They found that S-shape heuristics perform well in the narrow-aisle high-bay pallet with many items scenario. Roodbergen and Koster [14] used dynamic programming to formulate the shortest traveling path for a warehouse with three cross aisles. Other research related to design and planning of warehousing systems can be found in Cormier and Gunn [15], Cormier [16], Van den Berg and Zijm [17] and Rouwenhorst et al. [18]. Other issues in design and control of order-picking processes in particularly were discussed in Goetschalckx and Ashayeri [19], Choe [20], Roodbergen and Meller [21] and Wäscher [22].

Unlike the previous research mentioned above, this paper aims to develop a practical and systematic approach for warehouse layout designing method that takes account of both product characteristics and quantitative measurement in order to develop the layout that can be efficiently applied to our case-studied automotive supplier, under their business requirement. All details of the proposed methodology are provided, e.g., how company's data are analyzed, each step of layout designing process, layout validation, implementation and evaluation.

3. Company Data and Analysis

The first step for warehouse layout design is getting warehouse storage information as well as products' characteristics and their flows. The case-study company's historical invoice data, product size data, and historical inventory data are collected and analyzed. Each type of data used in this research are described below.

1) Product Data

There are 198 products and 17 product categories involved in this research. Product categories are Foundry Sand, Refractories Lining, Coatings, Exothermic Sleeve & Power, Mica Products & Insulation, Temperature & CE Products & Service, Special Alloy-Inoculant / Magnesium, Fluxes, Adhesive Product, Non-Ferrous

Product & Other Fluxes, Ceramic Product, Sand Slag, Refractor Castable, Refractor Plastic & Others, Other Chemicals, Parting & Releasing Agent, and Raw Material for Refractory Production. The number of products in each product category is shown in Table 1.

Table 1. Product categories and the number of products in each product category.

CID	Product Category	Number of Products
2	Foundry Sand	3
3	Refractories Lining	22
6	Coatings	4
7	Exothermic Sleeves & Powder	57
8	Mica Products & Insulation	18
9	Temperature & CE Products & Service	7
12	Special Alloys-Inoculant / Magnesium	10
13	Fluxes	1
14	Adhesive Product	6
17	Non-Ferrous Product & Other Fluxes	13
18	Ceramic Product	21
20	Sand Slag	3
21	Refractor Castable	6
22	Refractor Plastic & Others	21
23	Other Chemicals	3
25	Parting & Release Agent	2
26	Raw Material for Refractory Production	1
	Total	198

The forms and packages of products affect the storage locations. This research summarizes the package types of all studied product categories. Some product categories have only one package type, while some product categories have two package types. Table 2 summarizes the product packages for every studied product categories. The differences in product characteristics and packages affect the appropriate locations for the products, for instance, products on pallet, boxes on a pallet, small plastic drums on a pallet, and plastic gallons on a pallet should be stored on the rack, while the other packages should be stored on the floor. We will use the information of product characteristics and packages in order to assign the locations to each product.

2) Types of Racks

There will be three types of storage racks in Warehouse A and Warehouse B, i.e., floor stacking, single-deep selective rack, and flow rack. Types of racks have already been selected by company management. There will be floor stacking and single-deep selective racks in Warehouse A. For Warehouse B, there will be floor stacking and flow racks.

3) Warehouses

Warehouse A is the main warehouse of the company. There are two storage areas in Warehouse A, the single-deep selective rack area and the floor stack area. The pink areas in Fig. 4 represent the floor stack areas of the warehouse. We separate the floor stack areas into three zones, Zone A, Zone B1, and Zone B2 as presented in Fig. 4.

The number presented in each zone in Fig. 4 is the maximum capacity of stacks (for floor stack zones) and location (for selective rack zone) in the zones. Zone A can store 17 rows of 7-pallets deep stacks or 119 stacks. Zone B1 and Zone B2 can store 20 rows of 6-pallets deep stacks or 120 stacks, individually. The blue area in Fig. 4 is the selective rack area, which consists of 7 racks. The number above each rack represents the number of locations in each rack. The maximum capacity of selective rack area is 694 locations.

Table 2. Product packages of all product categori.

CID	Product Category	A big bag on a pallet	Small bags on a pallets	Products on pallet	Boxes on a pallet	Big Plastic drums on a pallet	Small plastic drums on a pallet	Metal drums on a pallet	Plastic gallons on a pallet
2	Foundry Sand	√							
3	Refractories Lining		√	√					
6	Coatings					√			
7	Exothermic Sleeves & Powder		√	√					
8	Mica Products & Insulation			√	√				
9	Temperature & CE Products & Service				√				
12	Special Alloys-Inoculant / Magnesium	√							
13	Fluxes	√							
14	Adhesive Product				√				
17	Non-Ferrous Product & Other Fluxes			√	√				
18	Ceramic Product				√				
20	Sand Slag		√						
21	Refractor Castable		√						
22	Refractor Plastic & Other		√				√		
23	Other Chemical		√					√	
25	Parting & Release Agent								√
26	Raw Material for Refractory Production	√							
	Total								

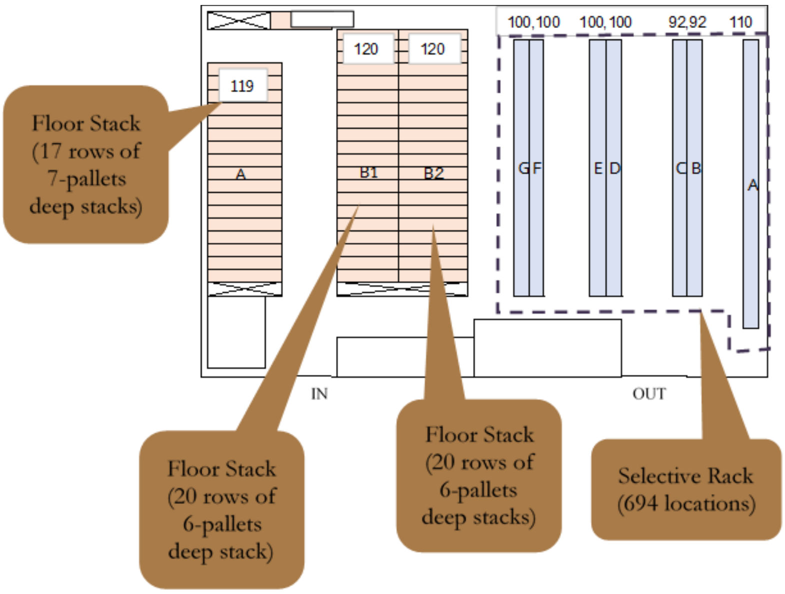

Fig. 4. The storage areas of Warehouse A.

There are two storage areas in Warehouse B, floor stack area and flow rack area. For the stack area, we separate the area into two zones, Zone A and Zone B as presented in Fig. 5. Flow rack area is defined as zone C as shown in Fig. 5. The maximum capacities of Zone A, Zone B, and Zone C are 147 stacks, 161 stacks, and 36 pallets, respectively, as presented in Fig. 5.

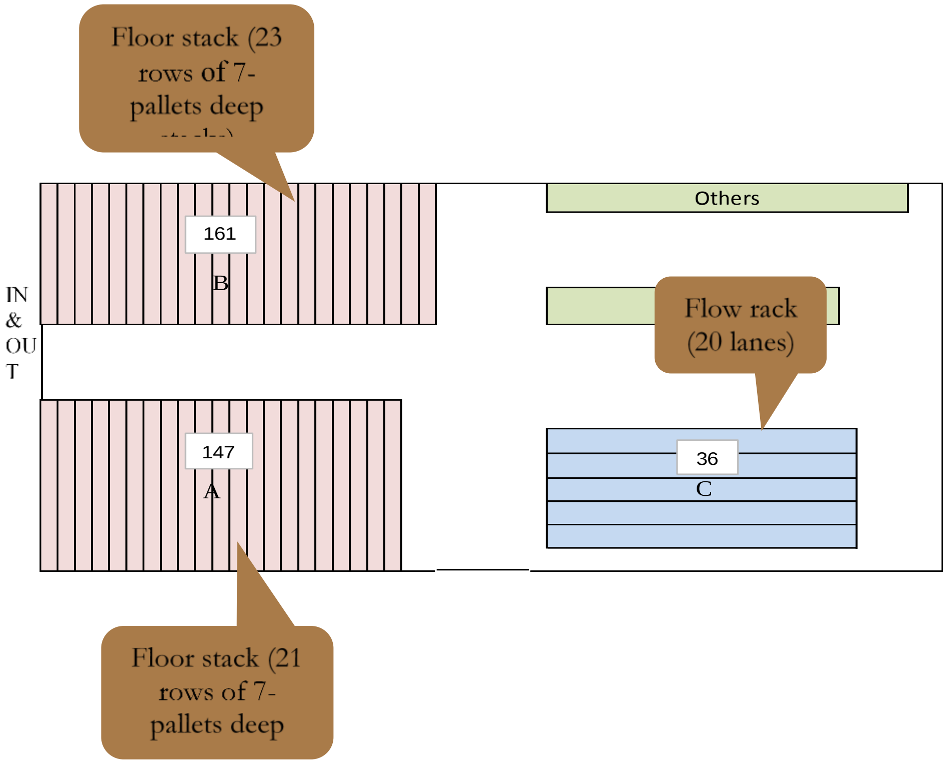

Fig. 5. The storage areas of Warehouse B.

4) Invoice Data

Invoice data record the purchasing information, i.e., Category ID (CID), Category Name, Customer Name, Product ID (PID), Product Name, Invoice ID, date of purchasing, the number of purchased products, product unit, and pack size. Table 3 illustrates the example of invoice data. The columns present the information of invoices as mentioned.

Table 3. Invoice data.

CID	Product Category	Customer	PID	Product Name	Invoice ID	Date of Purchasing	Quantity	Unit	Pack Size
20	Sand Slag	Customer1	0001	Product1	I0001	03/10/2014	100	kgs	20kg/ bag
20	Sand Slag	Customer2	0001	Product1	I0002	04/10/2014	200	kgs	20kg/ bag
06	Coating	Customer2	0002	Product2	I0002	04/10/2014	90	kgs	30kg/ drum

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5) Stock Data

The company checks stocks at the end of every month. The measurement of products is demonstrated in many units, i.e., weight (ton), quantity (piece), length (metre), volume (litre) and set. Table 4 illustrates an example of stock data for Product3.

Table 4. Stock Data.

CID	Product Category	PID	Product Name	Unit	Month											
					1	2	3	4	5	6	7	8	9	10	11	12
14	Adhesive Product	0003	Product3	Piece	4517	2580	3245	1537	6857	4676	3813	2153	3131	2377	4049	1365

6) Product Size Data

Currently, the company has recorded information about pack quantity, product units, and pack size for only 109 products out of 198 products. In addition, there are no records of products dimensions, pallet dimension, the number of products per pallet, the maximum number of pallets per stack, and the maximum number of pallets per retrieving. The dimensions of the products are required in order to design the spaces for the products. Therefore, this research develops product size collecting form for the warehouse supervisors to collect the product size data of the studied products as presented in Fig. 6. The product size data consist of pack quantity, product unit, packaging, pieces per package, dimension of products, pallet size, number of products per pallet, the maximum number of pallets per stack, and the maximum number of pallets per retrieving.

The warehouse supervisors collect the Product Size data by counting the number of products per pallet, measuring the size of the products, measuring the size of the pallets, numbering units per picking, and identifying the maximum number of pallets per stack. Figure 7 presents an example of collected Product Size data.

PID	Product Name	Pack Qty	Unit	Packing	Pack Size	Product			Pallet			Unit/Pallet	Max Overlay	Max retrieve
						Width	Length	Height	Width	Length	Height			

Fig. 6. Product size collecting form.

PID	Product Name	Pack Qty	Unit	Packing	Pack Size	Product			Pallet			Unit/Pallet	Max Overlay	Max retrieve
						Width	Length	Height	Width	Length	Height			
1	SKU-1	40	PCS	BOX	40 PCS/BOX	26	39	21	100	100	150	2240	1	2240
2	SKU-2	20	PCS	BOX	20 PCS/BOX	30	36	26	110	110	150	600	1	600
3	SKU-3	12	PCS	BOX	12 PCS/BOX	15.5	20	24.5	100	100	150	2592	1	2592
4	SKU-4	30	KGS	BOX	30 KGS/BOX	29	40	27	80	120	120	960	1	960
5	SKU-5	8	PCS	BOX	8 PCS/BOX	35	35	26	110	110	160	320	1	320
6	SKU-6	24	PCS	BOX	24 PCS/BOX	30	40	29	110	110	160	960	1	960

Fig. 7. Example of product size data.

4. Research Methodology

There are 2 main processes in research methodology, i.e., Product categories grouping process and Warehouse layouts designing process. In the first process, the product categories will be grouped into two groups for Warehouse A and Warehouse B, then, the products will be assigned to their locations. Table 5 summarizes the workflows of the 2 main processes.

Table 5. Workflow of research methodology.

1. Product categories grouping process	2. Warehouse layouts designing process
1. Company requirement identification for grouping product categories 2. Product category grouping 3. First grouping plan 4. Final grouping plan	1. Company requirement identification for layout design 2. The number of picking calculation 3. Product and product category ranking 4. Designing layout for Warehouse B 5. Evaluating the layouts and choosing the best layout for Warehouse B 6. Designing the layout of stack zone for Warehouse A 7. Evaluating the layouts and choosing the best layout for stack zone for Warehouse A 8. Designing the layout of single-deep selective rack zone for Warehouse A 9. Evaluating the layouts and choosing the best layout of selective rack zone for Warehouse A

4.1. Product Categories Grouping

There are 4 processes in product category grouping, i.e., identifying company requirement, dividing product categories, developing the first grouping plan, and developing the final grouping plan. The first step aims to understand the company requirements and nature of the products. Then, we develop a grouping logic. After that, we compare the grouping plans to the warehouses' capacities. The Product Size data is analyzed in order to calculate the space for each product category. Next, the members in the groups are adjusted. Finally, the final grouping plan is developed. The final part is the conclusion of the product category grouping process for Warehouse A and Warehouse B.

Since the company requires to store the same product category in the same warehouse, we group product categories for Warehouse A and Warehouse B. The company requirements for product category grouping are identified to understand the products characteristics. There are three company requirements, i.e., (1) products are stored in safe locations, (2) in-house products are in Warehouse A, and (3) Warehouse A is required to store as many product categories as possible.

In order to group product categories for the two warehouses, we categorize product categories into 4 groups based on the product characteristics, product packages, and the company requirements, i.e., Fragile Product, In-house Product, Sell-in-piece Product, and Sell-in-bulk Product. Product categories in each group are summarized in Table 6.

Table 6. Four Groups of Product Categories.

Fragile Products	In-House Products	Sell-in-Piece Products	Sell-in-Bulk Products
Exothermic Sleeves & Powder	Refractor Castable	Adhesive Products	Foundry Sand
Mica Products & Insulation	Refractory Plastic & Other	Parting & Release Agent	Refractories Lining
Temperature & CE Products & Service			Coatings
Non-Ferrous Product & Other Fluxes			Special Alloys-Inoculant / Magnesium
Ceramic Product			Sand Slag
			Other Chemical
			Raw Material for Refractory Production
			Fluxes

Then, the first grouping plan is developed. Fragile Products and Sell-in-piece Products should be located on the racks for the safety reasons. Since Warehouse A is close to the production warehouse, In-house Products should be located in Warehouse A. Fragile Products, and Sell-in-piece Products should also be stored in selective racks in Warehouse A.

In order to locate as many products as possible in Warehouse A, we compare the spaces of the warehouses to the required spaces for the products. the capacity of the warehouses is measured, and the required spaces of each product is calculated. The total required spaces of each product category are summed up. Finally, the grouping plan is determined.

We calculate the required spaces for all products by using the maximum stock data as the representatives. The calculations for sell-in-bulk products and non-sell-in-bulk products are different. The constraint of non-sell-in-bulk product is the number of units/pallet, while the constraint of sell-in-bulk product is the maximum number of units/retrieving. Table 7 summarizes the required spaces for the two types of products.

Table 7. Space Calculation.

Non-sell-in-bulk Product	Sell-in-bulk Product
$\frac{\text{Maximum stock data}}{\text{\# of units/pallet}}$	$\frac{\text{Maximum stock data}}{\text{\# of units/stack}}$

After the required spaces of all products have been calculated, we sum up the spaces of all product categories. For sell-in-bulk products, after calculating the number of required pallets, we change the number of required pallets into the number of required rows. The required spaces are then compared to the warehouses' capacities. Figure 8 summarizes the flow chart of product category grouping process and Table 8 presents product categories for Warehouse A and Warehouse B.

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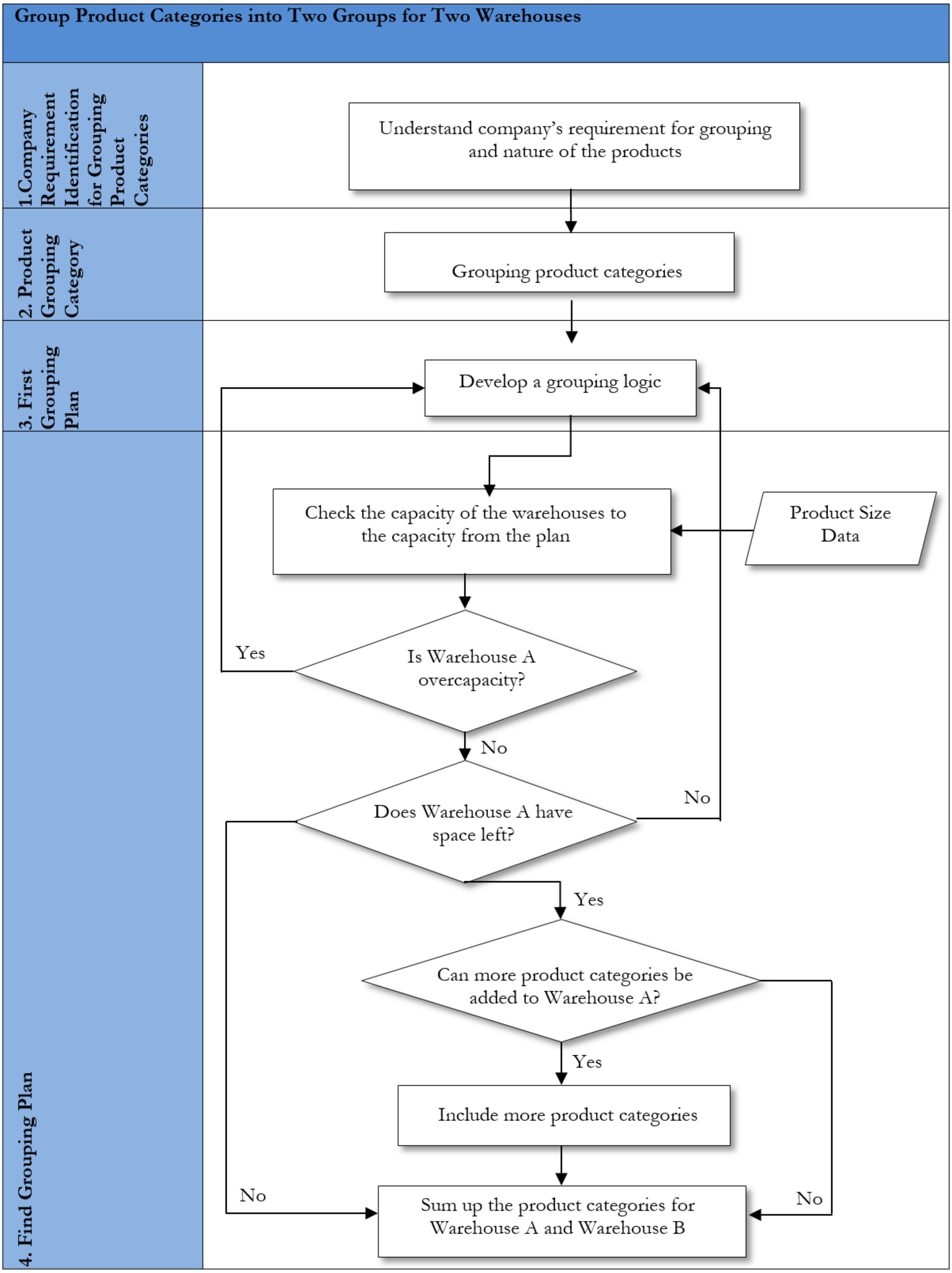

Fig. 8. Flow process chart of product category grouping.

Table 8. The product categories for Warehouse A and Warehouse B.

Warehouse A		Warehouse B	
CID	**Product Category**	**CID**	**Product Category**
7	Exothermic Sleeve	20	Sand Slag
3	Refractories Lining	6	Coating
22	Refractory Plastic	26	Raw Material for Refractories
25	Parting & Releasing Agent Product	12	Special Alloy
8	Mica	2	Foundry Sand
14	Adhesive Product		
9	Temperature & CE Product		
18	Ceramic Product		
17	Non-ferrous Product		
21	Refractor Castable		
23	Other Chemical		
13	Fluxes		

4.2. Warehouse Layouts Designing

After dividing product categories into two groups for Warehouse A and Warehouse B, the second process is designing the layouts of Warehouse A and Warehouse B. The methodology starts from identifying company's layout requirements. Then, the number of picking of product categories and products are ranked. After that, we design the layouts of Warehouse A and Warehouse B, evaluate them qualitatively and quantitatively. Finally, the best layouts are determined. Figure 9 presents the flow process chart of designing layout for Warehouse A and Warehouse B

The locations of products will be identified in this process. We start from identifying the company requirements for product locations. The first requirement is storing the same product category in the same area, so we separate locations of all product categories into 3 locations, i.e., Warehouse B, stack zone of Warehouse A, and single-deep selective rack zone of Warehouse A. The second requirement is determining the products' locations by the frequency of picking. The last requirement is minimizing warehouse spaces utilization. The space utilization requires products to be located according to their constraints and space-saving locations.

Product categories and products of every product categories are ranked from the highest number of picking frequency to the lowest number of picking frequency. We need to change the information in the invoice to the number of picking. The number of picking calculation procedure of non-sell-in-bulk products and sell-in-bulk products are different. The constraint of non-sell-in-bulk products is the number of units/pallet, while the constraint of sell-in-bulk product is the maximum number of units/retrieving, as summarized in Table 9.

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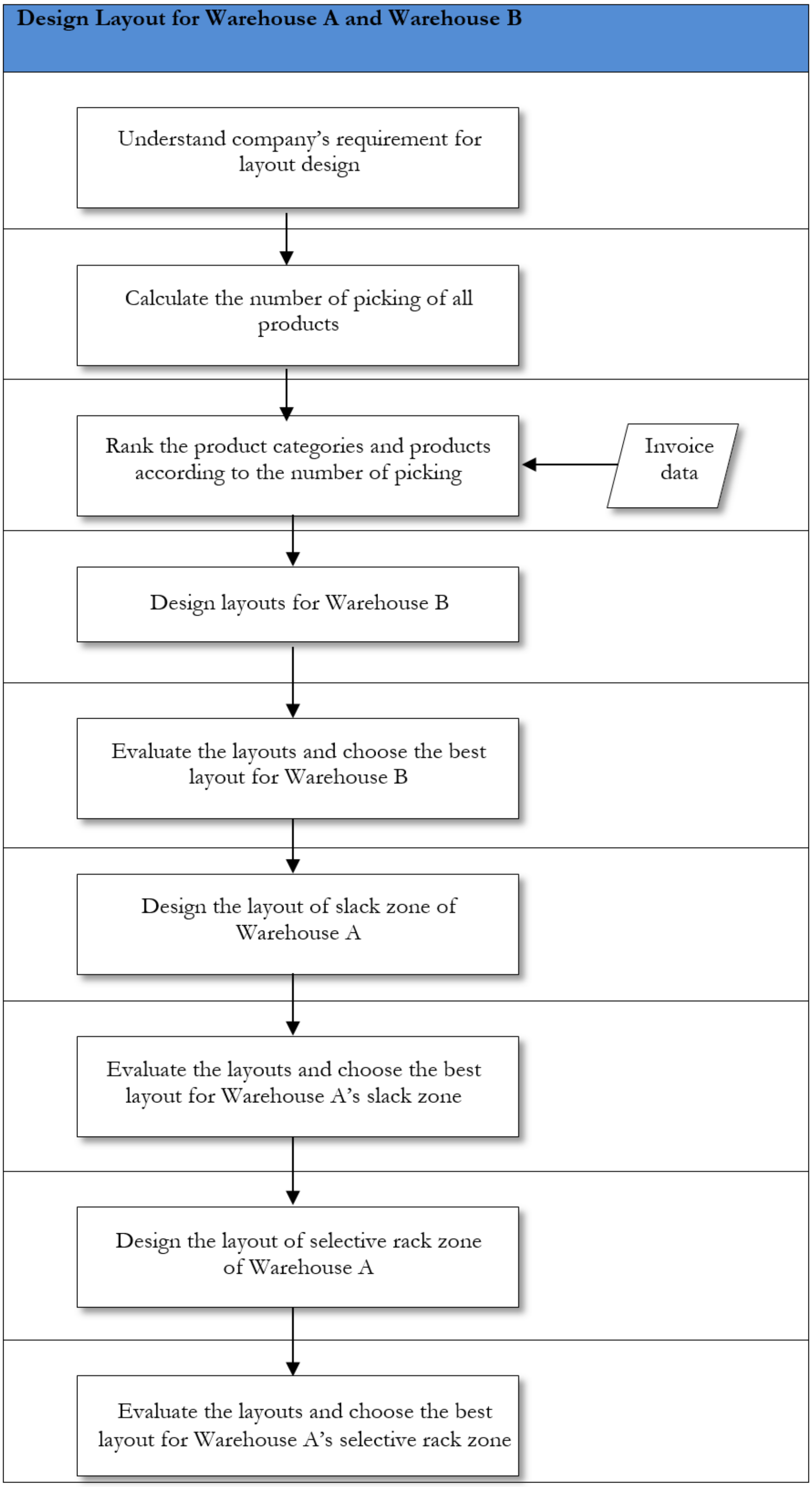

Fig. 9. Flow process chart of warehouse layouts designing.

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Table 9. The number of picking calculation procedure.

Non-sell-in-bulk Product	Sell-in-bulk Product
$\frac{\text{\# of the products from each invoice}}{\text{\# of units/pallet}}$	$\frac{\text{\# of the products from each invoice}}{\text{Max. \# of units/retrieving}}$

We calculate the number of picking of every product in every product category from the historical data occurred in year 2015. Also the company management mentioned that they expect sales to grow about 10% for the following year. Thus, the forecast information is also used in this research. After that we sum up the number of picking of every product in the same product categories. Table 10 and Table 11 show the number of picking of every product categories in Warehouse A and Warehouse B, respectively. The product categories in both warehouses are ranked from the highest number of picking to the least number of picking.

Table 10. Number of picking of all product categories in Warehouse A in year 2015.

Warehouse A			
CID	**Category**	**# of Invoices**	**# of picking**
7	Exothermic Sleeve	1,683	1,699
3	Refractories Lining	988	1,661
22	Refractory Plastic	1,290	1,559
25	Parting & Releasing Agent Product	1,015	1,119
8	Mica	580	832
14	Adhesive Product	766	782
9	Temperature & CE Product	610	610
18	Ceramic Product	359	360
17	Non-ferrous Product	340	343
21	Refractor Castable	206	207
23	Other Chemical	61	95
13	Fluxes	75	75

Table 11. Number of picking of all product categories in Warehouse B in year 2015.

Warehouse B			
CID	**Category**	**# of Invoices**	**# of picking**
20	Sand Slag	1,255	1,405
6	Coating	586	693
26	Raw Material for Refractories	189	649
12	Special Alloy1 (Non-Pack)	455	535
2	Foundry Sand	119	321

4.2.1. Layout of Warehouse B

Since we have already calculated the number of required rows for each product category in the last process, next, we design the locations of the product categories in Warehouse B. The forms and packages of the products are different. Therefore, The Class-Based Turnover Assignment concept is adopted in this research.

The products and the product categories with higher number of picking will be located closer to the shipping area than the products and product categories with lower number of picking.

We start from developing Layout#1 of Warehouse B. Then, we find an alternative way to improve the layouts. Thus, Layout#2, Layout #3, and Layout#4 of Warehouse B are developed. Then, all of them are evaluated by considering the left space, the total picking distance, and the number of locations of each product category. Finally, the best layout for Warehouse B is chosen. Figure 10 presents the steps of layout designing for Warehouse B.

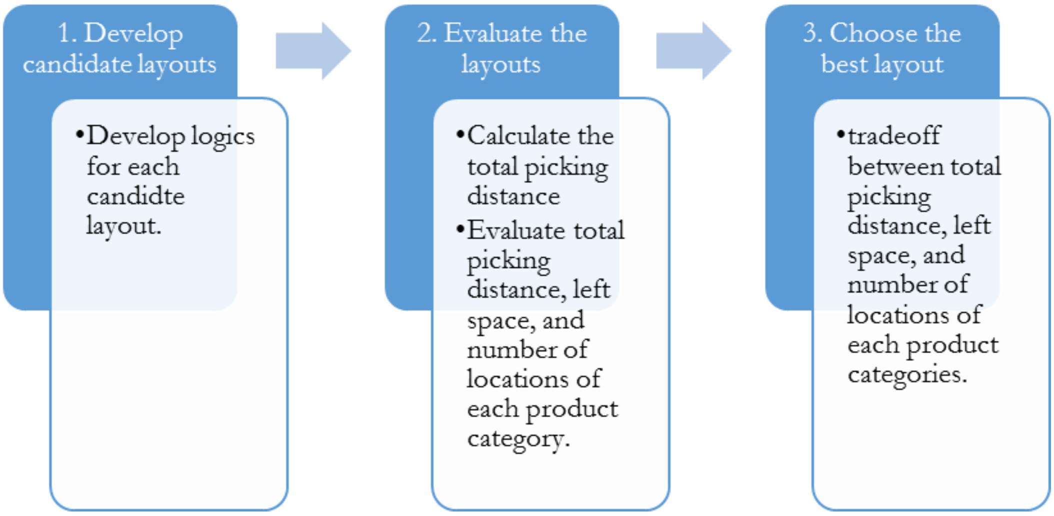

Fig. 10. Layout design process for Warehouse B.

There are 4 candidate layouts of Warehouse B from the process described above.

1) Layout#1

The design concept of this layout is to locate the lowest number of picking products to the flow rack and consider the space-saving condition at the same time. We consider from the lowest number of product category picking to the highest number of product category picking. If the products can be overlaid by more than 3 pallets, we will locate them in the stack area.

2) Layout#2

The design concept of this layout is to locate products having low number of pallets per stack (2 and 3 pallets) in the flow rack, and then consider the space-saving condition in the stack area.

3) Layout#3

The design concept of this layout is similar to the concept of Layout#2. We assign the same products as Layout#2 in the flow rack, since this decision results in maximum available space (as mentioned in the previous layout designing process). Sand Slag-SKU-1 are located in Zone A, while Sand Slag-SKU-2 are located in Zone B.

4) Layout#4

The design concept of this layout is similar to the concept of Layout#2. We assign the same products as Layout#2 in the flow rack, since this decision results in maximum available space (as mentioned in the previous layout designing process). We locate Sand Slag-SKU-1 in Zone B and Sand Slag-SKU-2 in Zone A.

After the 4 candidate layouts are developed, the total picking distances, vacant spaces, and number of locations of product categories of the 4 layouts are compared. The total picking distance is calculated by multiplying the number of picking to the distance from the product to the gate. We measure the distance of each product from the centroid of the location to the gate, since all products in Warehouse B will be transferred out via the gate. Next, we sum up the horizontal and vertical ditance and then multiply it by 2 again (go back and fourth). Figure 11 illustrates an example of the total picking distance calculation.

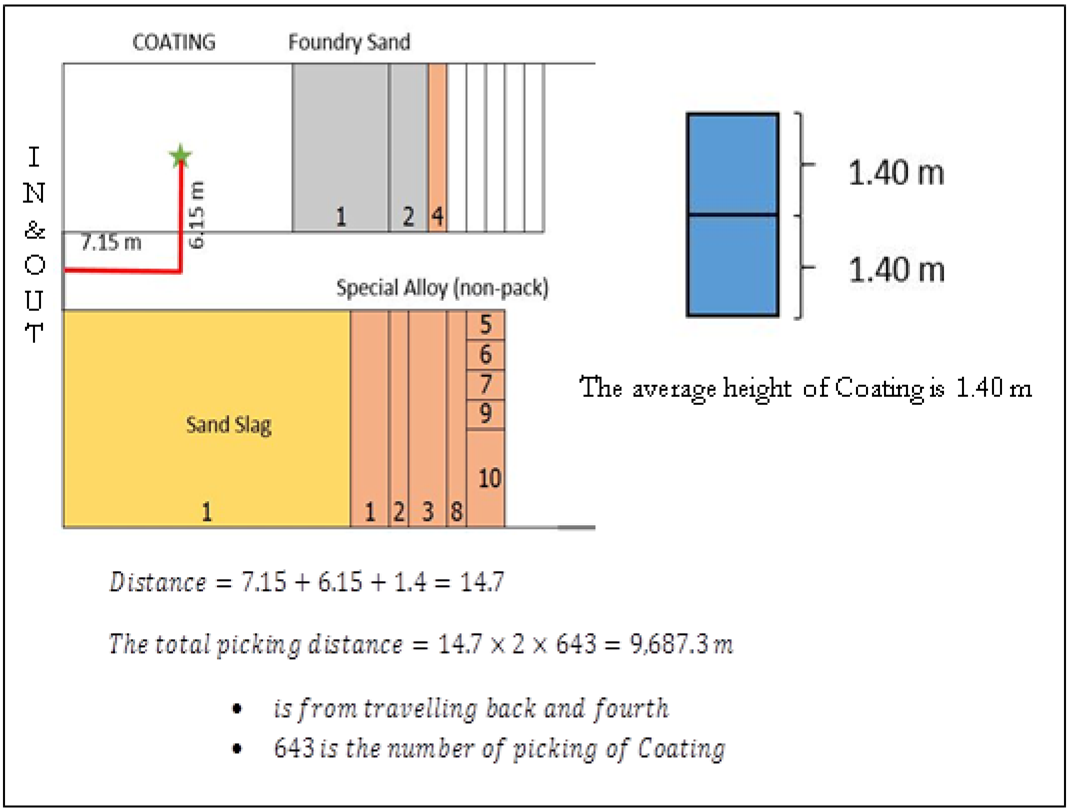

Fig. 11. An example of the total picking distance calculation.

The best layout is the layout which has the best trade-off between the distance, space and usability. We compare the 4 layouts. Table 12 presents the total picking distance, left space, and number of product categories located in more than 1 location of all 4 candidate layouts.

Table 12. Candidate layouts of Warehouse B.

Layout	Total picking distance (km)	Left space	# of product categories with more than 1 location in stack area
#1	189.18	5 rows and 1 lane	1
#2 (Best Layout)	213.56	7 rows	1
#3	213.96	7 rows	2
#4	209.51	4 rows	1

When we compare layout#2 to Layout#4, Layout#4 gives the lower total picking distance, but there is not a significant difference. However, Layout#2 gives better trade-off and the higher number of remaining spaces which is more important.

When we compare Layout#2 to Layout#3, Layout#2 gives lower total picking distance, while both layouts have 7 rows of stack left. However, Layout#2 gives better trade-off than Layout#3, and Layout#2 is also more practical. Moreover, Layout#2 stores higher number of product categories altogether in the stack area, while Layout#3 locates higher number of product categories separately in the stack area.

Comparing Layout#2 to Layout#1, Layout#1 gives the shortest total picking distance. However, 5 rows of stack and 1 lane of flow rack are remained. The lane of flow rack is not practical since we can locate just 1 product for that lane. So, having 7 vacant rows is better than having 6 vacant rows with 1 lane. The total picking distances of Layout#1 and Layout#2 are not significantly different and Layout#2 gives the highest number of remaining rows.

For these reasons, Layout#2 is the most suitable layout of Warehouse B as presented in Fig. 12.

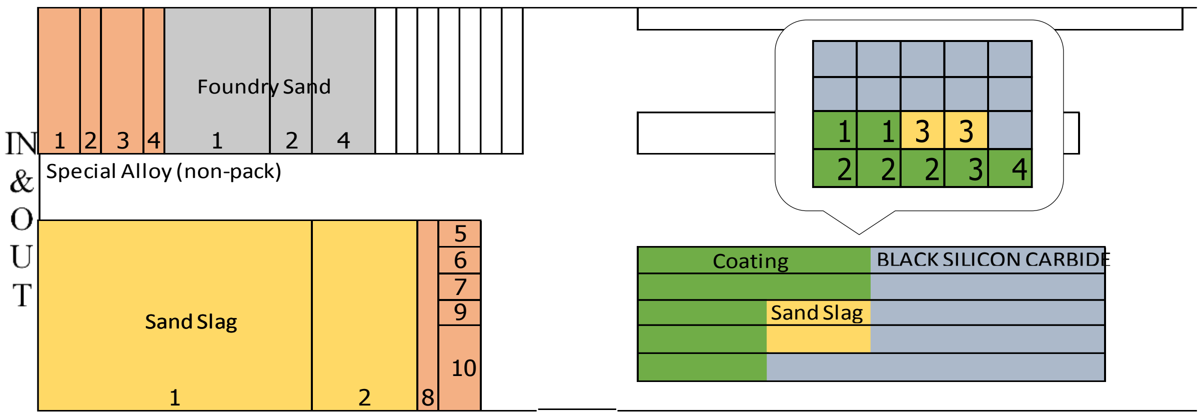

Fig. 12. The most suitable layout of Warehouse B.

4.2.2. Layout of floor stack area in Warehouse A

We start from calculating the number of required rows of each product and divide the storage area into 3 zones: Zone A, Zone B1, and Zone B2. Then, we develop Layout#1 and other candidate layouts for stack based on the product category constraints. After that, all the candidate layouts are evaluated. The total picking distance, the vacant spaces, and the zones of the vacant spaces are considered. Finally, the best layout is chosen. Figure 13 presents the steps of layout designing for stack area in Warehouse A.

Each product category requires different number of rows. Refractories Lining requires the highest number of rows, so either Zone A, Zone B1, or Zone B2 alone is not enough for locating the whole product category. Locating Refractories Lining in Zone A and Zone B2 or Zone B1 and Zone B2 are also not practical since the same product category will be picked from different aisles. The capacities of Zone A and Zone B1 are sufficient and practical, so this location is the most suitable location for Refractories Lining. The number of rows calculation method is presented in Table 13.

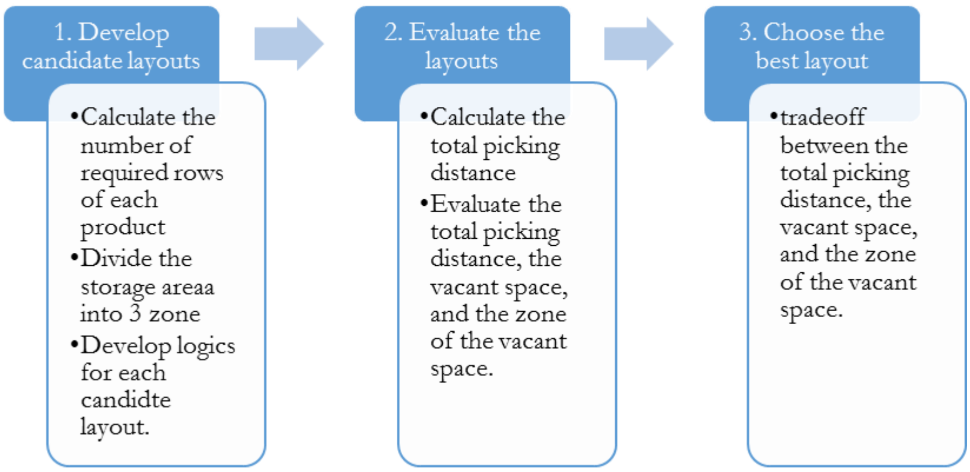

Fig. 13. Designing layout for stack area in Warehouse A.

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Table 13. The number of rows calculation method for Warehouse A.

Rows
$\frac{\text{\# of the pallets}}{\text{\# of pallets/stack} \times \text{\# of stacks/row}}$

There are 7 candidate layouts for the stack zone of Warehouse A and Layout#2 is the most suitable layout. Layout#2 concept is to gather the vacant rows in only Zone B2 which is the furthest from the packing area in Warehouse A and to locate higher frequently picked Refractory Lining products in Zone A before fulfilling Zone B1. For other product categories, the higher number of picking product categories are located closer to the preparing area.

There are vacant rows in zone B1, A, and B1 for Layout#1, Layout#3, and Layout#4, respectively. Layout#6 and Layout#7 have vacant rows in Zone B2, similar to Layout#2, but the locations of product categories are different. Both Layout#6 and Layout#7 locate Fluxes in zone B1, while Layout#2 locates Fluxes in zone B2. The total picking distance of Layout#2 is less than the total picking distances from Layout#6 and Layout#7. Table 14 presents the total picking distance, left space, and zones of the left space of all 7 candidate layouts.

Considering the total picking distance, the vacant spaces, and the zones of the vacant spaces, the most suitable layout of the stack area in Warehouse A is Layout#2. It can be seen in Table 14 that Layout#2 has the highest vacant space in best zone (zone B1) and gives the shortest total picking distance under this condition. Figure 14 presents the most suitable layout of floor stack area in Warehouse A.

Table 14. Candidate layouts of floor stack area in Warehouse A.

Layout	Total picking distance (km)	Left space		
		Zone A	Zone B1	Zone B2
#1	135.19	0	4	0
#2 (Most suitable)	132.87	0	0	4
#3	133.45	2	0	1
#4	134.80	1	3	0
#5	132.87	1	0	3
#6	133.50	0	0	4
#7	131.25	0	1	3

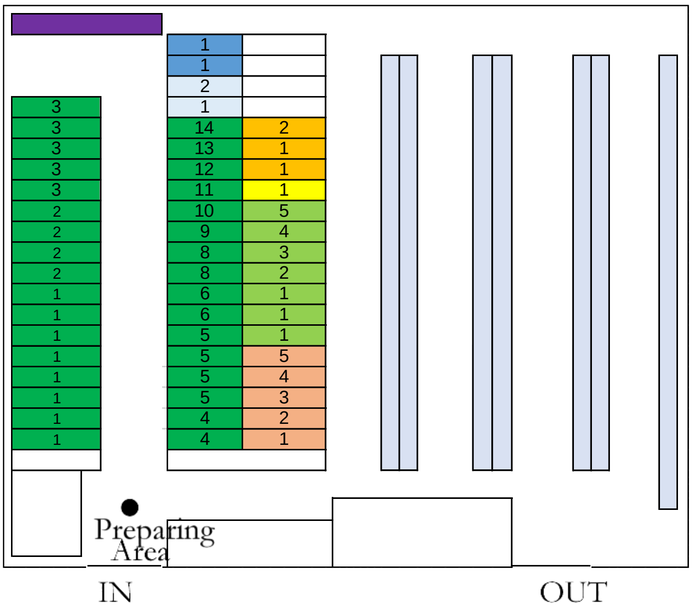

Fig. 14. The most suitable layout of stack area in Warehouse A.

4.2.3. Layout of selective racks area in Warehouse A

We start from developing the candidate layouts for Warehouse A. Then, we evaluate the layouts by considering the total picking distance, the product requirements, and the number of product categories' locations. Figure 15 presents the steps of layout designing for selective rack area in Warehouse A.

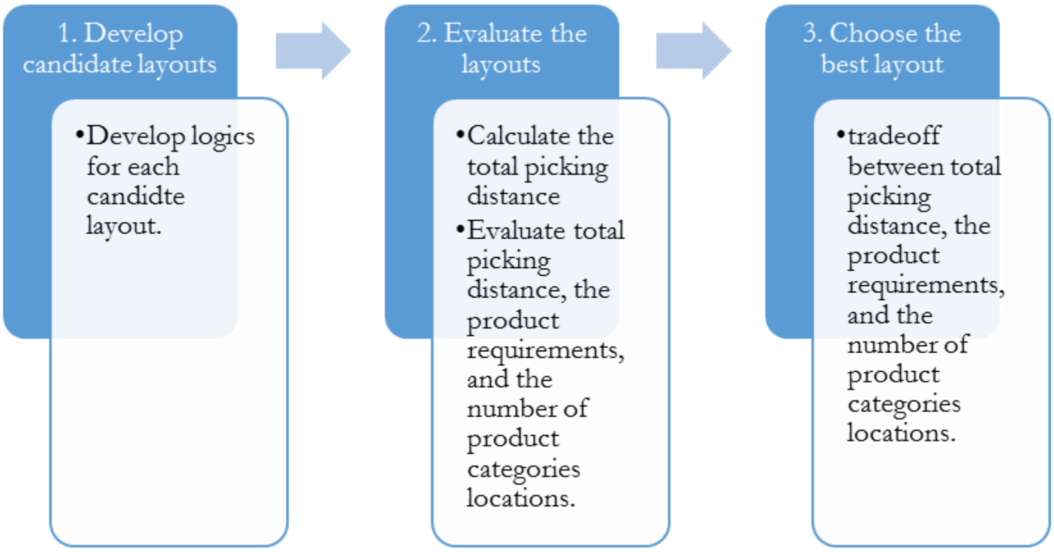

Fig. 15. Designing layout for selective rack area in Warehouse A

There are 7 racks as presented in Fig. 16. Rack G is closest to the preparing area, while rack A is furthest from the preparing area. Rack G, F, E, and D have maximum capacity at 100 pallets/rack. Rack C and B have maximum capacity at 92 pallets/rack. Rack A has maximum capacity at 110 pallets/rack.

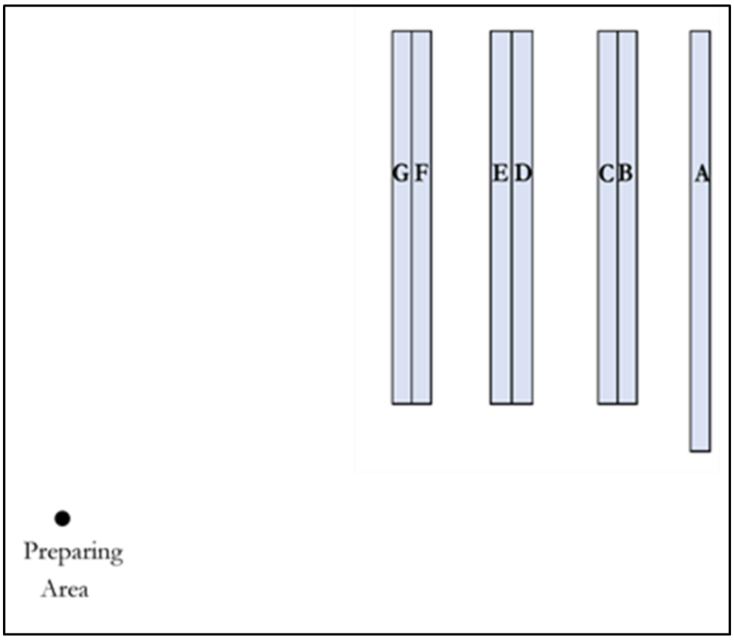

Fig. 16. Single-deep selective racks in Warehouse A.

Four layouts are designed for the selective rack zone of Warehouse A. We firstly design Layout#1, then this layout is improved by adding more constraints into the layouts. Concept of Layout#1 is to locate the most frequently picked product categories closer to the preparing area. We try to locate the products from the same product category in the same rack. Concept of Layout#2 is similar to the concept of Layout#1, but we fix Refractories Plastic in rack C. Concept of Layout#3 is similar to concept of Layout#2, but we locate Exothermic Sleeve products in 3 racks, rack G, rack F, and rack E. Layout#4's concept is similar to concept of Layout#3, but we separate the location of Exothermic Sleeve type A, into 2 locations. The product constraints are gradually added as the layouts are designed.

The total picking distances of each layouts and vacant space are compared for 4 layouts. As we develop the candidate layouts, Layout#4 gives the best trade-off between usability and the total distance. Layout#4 gives the least total picking distance and locate most of Exothermic Sleeve products in the first floor to the fourth floor of the racks. Figure 17 presents the most suitable layout of rack area in Warehouse A. The number in each rack represents the number of required locations for each product category. The colour in each rack represents the product category as presented in Table 15. For Exothermic Sleeve, there are 6 types: Type F, Type A, Type P, Type FO, and Type EC.

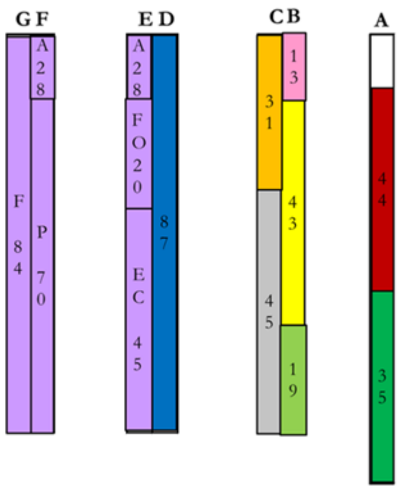

Fig. 17. The most suitable layout of rack area in Warehouse A.

Table 15. Product Categories for Selective Rack Zone of Warehouse A as presented in Fig. 17.

Product Category	colour
Exothermic Sleeve	
Parting Releasing Agents	
Refractories Plastic	
Mica	
Adhesive Products	
Temperature Products	
Ceramic Product	
Non-Ferrous Product	
Refractory Lining	

We compare the total picking distance, the product requirements, and the number of product categories locations. Layout#4 gives the best trade-off between the total picking distance, the number of product category locations, and product requirements. Table 16 presents the total picking distance and the disadvantages in term of product requirements and number of product categories locations of all candidate layouts.

Table 16. Candidate layout of rack area in Warehouse A.

Layout	Disadvantages	Total Distance (km)
#1	Sleeve FO is located in rack D, while other Exothermic Sleeve products are located in rack G, E, and F There are 2 locations of Refractor Plastic	734.73
#2	Sleeve A is located in rack C, while other Exothermic Sleeve products are located in rack G, E, and F	742.14
#3	Some Exothermic Sleeve products are assigned to the fifth floor of the rack.	748.60
#4 (Most suitable)	Sleeve A has to be stored in 2 locations	609.55

5. Results Validation and Implementation

After layouts for both warehouses are designed, they need to be validated and implemented. After implement the new design in the actual warehouses, the layouts are evaluated by comparing to the old layouts and layouts designed by the warehouse department. The layout result is validated in order to response to the current stock volume. For both Warehouses, the demand is based on the company forecasting. Consequently, the assigned spaces will be validated that there are enough spaces for the stocks. Table 17 presents the total picking distance and left spaces from all candidate layouts according to the most recent data. Layout#1 and Layout#4 have less left space, compared to Layout#2 and Layout#3, so we will compare just Layout#2 and Layout#3.

The total picking distances of Layout#3 and Layout#2 are not significantly different, while Layout#3 separates product categories in many locations as presented in Fig. 18 and Fig. 19. Consequently, Layout#2 perform the best.

Table 17. Validated layouts of Warehouse B.

Layout	Total picking distance (km)	Left space
#1	187.83	2 rows and 1 lane
#2 (Best Layout)	220.98	4 rows
#3	219.87	4 rows
#4	210.75	1 rows

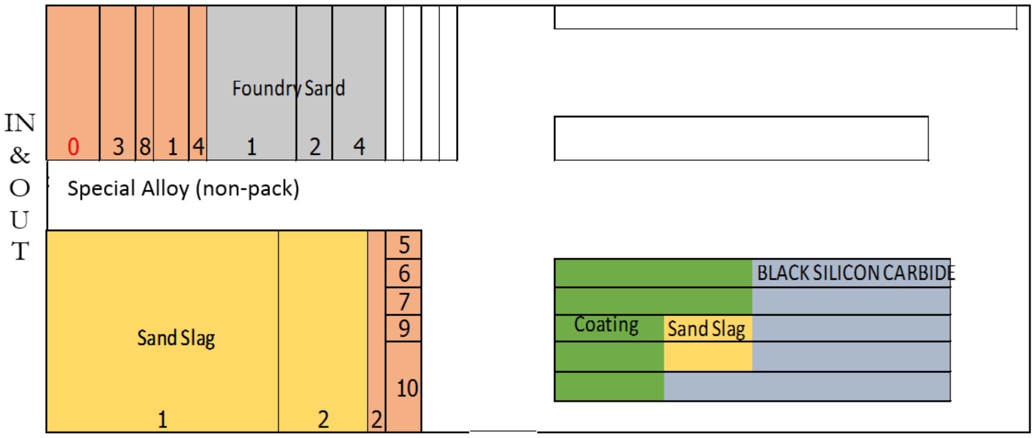

Fig. 18. Validated Layout#2 of Warehouse B.

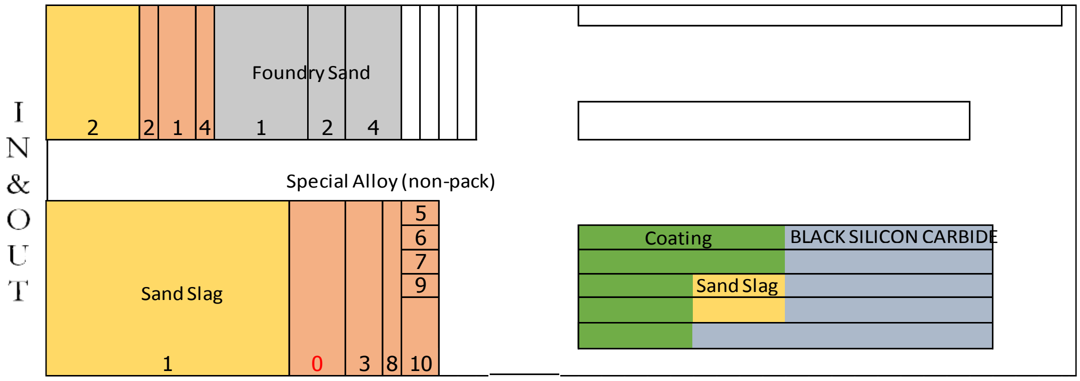

Fig. 19. Validated Layout#3 of Warehouse B.

For Warehouse A, we have to adjust the locations of the products in single-deep selective racks. The spaces of stacked products from this research are sufficient for the current situation. Since we have located products to every rack, there are remaining spaces in the top level of all selective racks. Some products require spaces more than the forecasting (20.7% of all products). The products can be located according to the plan and the additional products are located on the top level of the selective racks. For instance, we locate some products from Exothermic Sleeve type F in rack G on the top floor of the rack G. Figure 20 presents rack G before validation, while Fig. 21 presents rack G after validation. The final validated layout for Warehouse A is presented in Fig. 22.

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G

Exothermic Sleeve Type F

	10									2	4	4						5	
10	10	10	9	12	12	8	6	2	2	2	4	4	1	1	3	3	11	5	13
10	10	10	9	12	8	6	6	2	2	2	4	1	1	7	3	3	11	5	13
10	10	10	9	12	8	6	6	2	2	2	4	1	1	7	3	11	11	5	13
10	10	10	9	12	8	6	6	2	2	2	4	1	1	7	3	11	11	5	13

Fig. 20. Rack G (before validation).

G

Exothermic Sleeve Type F

	10			9	12	8		6	2	2	4	4						5	
10	10	10	9	9	12	8	6	6	2	2	4	4	1	1	3	3	11	5	13
10	10	10	9	9	12	8	6	2	2	2	4	1	1	7	3	3	11	5	13
10	10	10	9	9	12	8	6	2	2	2	4	1	1	7	3	11	11	5	13
10	10	10	9	9	12	6	6	2	2	2	4	1	1	7	3	11	11	5	13

Fig. 21. Rack G (after validation).

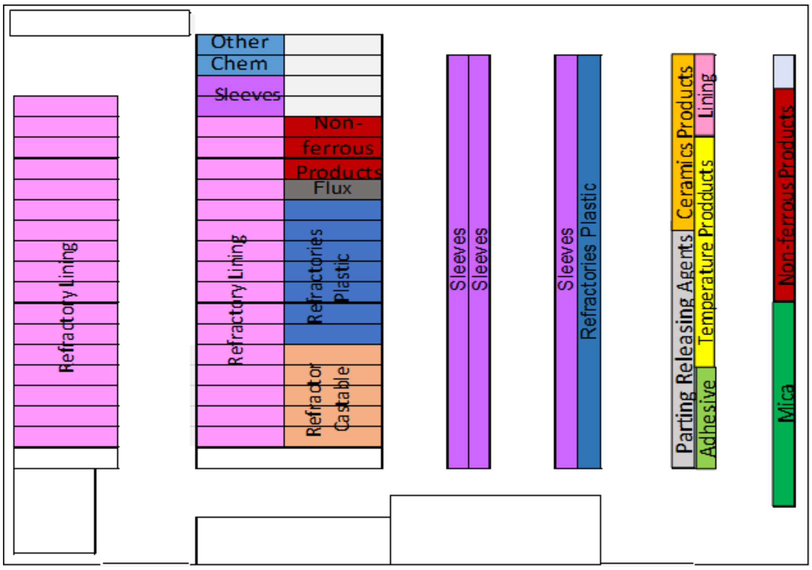

Fig. 22. Validated layout for Warehouse A.

For Warehouse B, the products are located according to the plan. The spaces for each product is enough. Figure 23 presents the changes in Warehouse B for each zone.

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Zone	Before	After
Zone A		
Zone B		
Zone C		

Fig. 23. Implementation of Warehouse B.

For Warehouse A, we have located the products according to the plans, Layout#2 of stack zone and Layout#4 of the selective rack zone. The space for products in both the stack zone and the rack zone are sufficient. Figure 24 presents the changes in Warehouse A for each zone.

Zone	Before	After
Zone A		
Zone B2		
Selective Rack		

Fig. 24. Implementation of Warehouse A.

First, layout of Warehouse A are evaluated. There is no fix location in the old layout of warehouse A, and the products in the same product category are located separately. The products can be located in any space, so it takes time to find the products. From this research, the proposed layout of Warehouse A provides the fixed locations of all products. The method locates products and product categories according to the frequency of picking, so it facilitates the warehouse processes. The new layout is also efficient since the products are assigned based on space-saving condition. The new layout Warehouse A reduces the total picking distance from 1068 km to 1034 km (reduce the total picking distance 34 km)

In addition, we also compare the proposed layout to a layout that warehouse department first designed. We found that the layout from warehouse department does not concern about the number of picking and the space for the stocks. Product categories are located according to product categories' characteristics. Fragile Products, In-house Products, and Sell-in-piece Products will be located in selective rack, while Sell-in bulk Products will be located in stack zone. Since the layout from this research concerns product categories' characteristics, company requirements, company policies, and the number of picking, this layout design the locations of product individually. Layout from this research is very practical for the company.

Second, we evaluated the layout of Warehouse B. Since Warehouse B is the new warehouse, we will evaluate by comparing the proposed layout to a layout that warehouse department first designed. The layout from the warehouse department also does not use the number of picking in order to assign the location to the products and the forecasted stock volume. Accordingly, the layout of Warehouse B from this research is more appropriate and well designed.

6. Conclusion

The objective of this paper is to design the layouts of the existing warehouse (Warehouse A) and the new warehouse (Warehouse B) so that the spaces can be efficiently used and the picking distance from all invoices is low. According to the company policy, Warehouse B is constructed and products in temporary warehouses will be located in the permanent warehouses. There are two main phases in developing layouts. First phase is to group product categories that are going to be in each warehouse. In order to group product categories, understanding and identifying company requirements are important. Then, product categories will be divided by using the company constraints.

When comparing the new proposed layout (Warehouse A) to the old layout, the proposed layout of Warehouse A reduces the total picking distance of the same products from 1068 km to 1034 km (reduce the total distance by 34 km). This research also designs warehouses based on the characteristics of the products. For example, Fragile Products, Sell-in-piece Products, and In-house Products are located in Warehouse A which is the main warehouse of the company (close to the shipping area and production warehouse). We also design the locations in product category level and product level under the company constraints and product constraints. For example, some products have to be located in the first floor of the rack. It is important to understand the products and locate them in the appropriate locations.

In summary, this research proposes the systematic and practical layout designing method for a supplier in the automotive industry. This method uses the historical data together with the constraints and observed data in order to develop the layouts. The layout is adaptive for any company since the method considers the product constraints and company requirements.

For future work, it is interesting to extend this research to consider more product constraints other than those considered in this paper in order to response to products in other warehouses, or even in other companies in the automotive industry. Also, it is important to validate the warehouse layout every year as the picking information will be different from year to year, so that the spaces for layout will be most suitable for the recent information. Thus, it can be interesting for future work to find out the most accurate forecasting method for each product so that the data used for the methodology will be most effective.

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