Warehouse design for an automotive raw materials supplier

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บริษัทกรณีศึกษาประสบปัญหาพื้นที่ในการจัดเก็บสินค้าไม่เพียงพอ อีกทั้งบริษัทยังได้ยกเลิกการใช้คลังสินค้าชั่วคราว โดยจะย้ายสินค้าในคลังสินค้าชั่วคราวนั้นไปยังคลังสินค้าถาวรจำนวนสองคลัง ดังนั้นงานวิจัยนี้จึงมีวัตถุประสงค์ออกแบบแผนผังของคลังสินค้าถาวรทั้งสองคลัง เพื่อให้มีการใช้พื้นที่อย่างมีประสิทธิภาพและมีระยะทางในการหยิบสินค้าที่ต่ำ โดยงานวิจัยมีการใช้ข้อมูลในอดีต ได้แก่ ใบคำสั่งซื้อ (Invoice Data) และข้อมูลสินค้าคงคลัง (Stock Data) ในการออกแบบแผนผังคลังสินค้า รวมทั้งมีการเก็บข้อมูลขนาดของสินค้า (Product Size Data) มาใช้ในการคำนวณพื้นที่การจัดเก็บสินค้า

การออกแบบแผนผังคลังสินค้าแบ่งออกเป็นสองช่วง ช่วงแรกคือการจัดกลุ่มประเภทของสินค้า โดยมีการจัดกลุ่มสำหรับคลังสินค้าถาวรแต่ละคลัง ช่วงที่สองคือการออกแบบแผนผังคลังสินค้าโดยใช้หลักการจัดเก็บตามระดับของสินค้า (Class-Based Turnover Assignment) ตามนโยบายและความต้องการของบริษัท ผู้วิจัยได้ออกแบบ วิเคราะห์ และประเมินแผนผังคลังสินค้าทั้งสองคลัง โดยแผนผังที่ดีที่สุดเป็นแผนผังที่ให้ผลการประเมินดีทั้งด้านปริมาณ (ระยะทางทั้งหมดในการหยิบสินค้า และจำนวนที่ว่างในคลังสินค้า) และด้านคุณภาพ (ความเหมาะสมในการดำเนินกิจกรรมของคลังสินค้า และความเหมาะสมของตำแหน่งของสินค้าต่อคุณลักษณะของสินค้า) โดยแผนผังคลังสินค้าที่ออกแบบได้นำไปใช้จริงในบริษัทกรณีศึกษา งานวิจัยนี้ได้สร้างวิธีการออกแบบแผนผังคลังสินค้านี้มีแบบแผนและสามารถนำไปใช้ได้จริง วิธีการออกแบบนี้มีความยืดหยุ่นและสามารถนำไปประยุกต์ใช้ในการออกแบบแผนผังคลังสินค้าอื่นต่อไปได้

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The case-study company faced limited space situation. The company decided to uninstall the temporary warehouses and locate products in two permanent warehouses. The objective of this research is to design the layouts of the two permanent warehouses so that the space can be efficiently used and the total picking distance is low. The past data, Invoice Data and Stock Data, are used for developing layouts designing processes. This research involves collecting Product Size Data for calculating required space for the products.

There are two phases in layout designing process. First phase is product category grouping. This phase categorises product categories into two groups for the two warehouses. The second phase is layout designing. The layout of the two warehouses and location of products are designed. According to company requirement and policies, adapted Class-Based Turnover Assignment is adopted in order to design the layouts for two warehouses. Layouts of the warehouses are designed, analysed, and evaluated. The best layouts give the best trade-off between quantitative results, i.e., total picking distance and the remaining space, and qualitative results, i.e., usability and product suitability. The designed layouts are applied in the case-study company. This research contributes the systematic and practical layout designing method. The developed method is flexible and can be adopted to other layout designing.

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CONTENTS

Page

THAI ABSTRACT iv

ENGLISH ABSTRACT v

ACKNOWLEDGEMENTS vi

CONTENTS vii

LIST OF FIGURES 1

LIST OF TABLES 6

CHAPTER 1 : Introduction 9

1.1 Background of the Research 9

1.2 Statement of Problem 12

1.3 Research Objectives 15

1.4 Scope 15

1.5 Expected Benefits 18

1.6 Methodology 18

1.7 Framework of the Research 19

CHAPTER 2 : Literature Review 23

2.1 Related Theories 23

2.1.1 Warehouse 23

2.1.2 Warehouse Systems 24

2.1.3 Warehouse Operation 24

2.1.4 Storage 24

2.1.5 Class-based storage 25

2.1.6 Layout Framework 25

Page

2.1.7 Typical Warehouse Layout.....26
2.1.8 Material Handling.....27
2.2 Related Research.....28
2.2.1 Storage policy.....28
2.2.2 Facility Layout Problem (FLP).....29
2.2.3 Picking policy.....30
2.3 Conclusion of Literature Review.....31
CHAPTER 3 : Company Data and Analysis.....32
3.1 Studied Products.....32
3.2 Product Packages.....45
3.3 Studied warehouses.....48
3.4 Warehouse Activity.....50
3.4.1 Preparing storage areas.....50
3.4.2 Receiving products.....52
3.4.3 Picking and shipping products.....54
3.5 Company's Data for This Research.....56
3.5.1 Invoice data.....57
3.5.2 Stock data.....57
3.5.3 Product size data.....58
3.5.4 Storage Data.....60
3.6 Conclusion of Company Data and Analysis.....64
CHAPTER 4 : Research Methodology.....65
4.1 Conceptual Design and Overview of the Research Methodology.....65

Page

4.2 Group Product Categories into Two Groups for Two Warehouses................67

4.2.1 Company Requirement Identification for Grouping Product Categories..69

4.2.2 Product Category Grouping 69

4.2.3 First Grouping Plan 70

4.2.4 Final Grouping Plan 72

4.2.5 Conclusion of Product Category Grouping..83

4.3 Design Layout for Warehouse 8 and Warehouse 10 85

4.3.1 Company Requirements Identification for Layout Design.....................88

4.3.2 The Number of Picking Calculation 89

4.3.3 Products and Product Categories Ranking...91

4.3.4 Design Layout for Warehouse 10 94

4.3.5 Evaluate the Layouts and Choose the Best Layout for Warehouse 10 109

4.3.6 Design the Layout of Stack Zone for Warehouse 8 112

4.3.7 Evaluate the Layouts and Choose the Best Layout of Stack Zone for Warehouse 8.. 120

4.3.8 Design the Layout of Single-Deep Selective Rack Zone for Warehouse 8 123

4.3.9 Evaluate the Layouts and Choose the Best Layout of Selective Rack Zone for Warehouse 8 132

4.3.10 Conclusion of Layout Designing for Warehouse 8 and Warehouse 10 133

4.4 Conclusion of Methodology 137

Page

CHAPTER 5 : Result ... 138

5.1 Validate the layouts ... 138

5.2 Implementation ... 142

5.2.1 Warehouse 10 ... 142

5.2.2 Warehouse 8 ... 143

5.3 Evaluate the layouts ... 145

CHAPTER 6 : Conclusion ... 150

6.1 Conclusion ... 150

6.2 Recommendation ... 152

REFERENCES ... 154

Appendix A: Candidate Layouts of Warehouse 10 ... 157

Appendix B: Candidate Layout of Stack Area of Warehouse 8 ... 162

VITA ... 167

LIST OF FIGURES

Figure 1.1: World Automotive Production in 2014 (OICA, 2014) 9

Figure 1.2: An Example of Different Product Forms and Package of Products in Exothermic Sleeve Category 10

Figure 1.3: The Company's Historical Sales (in TON) from 2009 – 2015.................. 11

Figure 1.4: The Company Situation in Warehouse 8 12

Figure 1.5: Warehouse 3A.. 13

Figure 1.6: Warehouse 4.. 13

Figure 1.7: Warehouse 5.. 13

Figure 2.1: U-shaped Layout (Kittithreerapronchai, 2013) 26

Figure 2.2: I-shaped Layout (Kittithreerapronchai, 2013) 27

Figure 2.3: Custom Layout (Kittithreerapronchai, 2013)... 27

Figure 3.1: An Example of a Product from Foundry Sand 33

Figure 3.2: An Example of a Sell-in-Bulk Product from Refractories Lining 34

Figure 3.3: An Example of a Sell-in-piece Product from Refractories Lining 34

Figure 3.4: An Example of Products from Coating 35

Figure 3.5: An Example of a Sleeve Product from Exothermic Sleeve 35

Figure 3.6: An Example of a Power Product from Exothermic Sleeve 36

Figure 3.7: An Example of a Mica Sheet Product from Mica 36

Figure 3.8: An Example of an Other Product from Mica... 37

Figure 3.9: An Example of a Product from Temperature & CE Products & Service 37

Figure 3.10: An Example of a Product from Special Alloys-Inoculant / Magnesium 38

Figure 3.11: The Product of Fluxes 39

Figure 3.12: An Example of a Product from Adhesive Product..................................39

Figure 3.13: An Example of a Product from Non-Ferrous Product & Other Fluxes 40

Figure 3.14: An Example of a Product from Ceramic Product 41

Figure 3.15: An Example of a Product from Sand Slag..41

Figure 3.16: An Example of a Product from Refractor Castable 42

Figure 3.17: An Example of a Sell-in-piece Product from Refractor Plastic & Other 43

Figure 3.18: An Example of a Sell-in-bulk Product from Refractor Plastic & Other 43

Figure 3.19: An Example of a Product from Other Chemical 44

Figure 3.20: An Example of a Product from Parting & Release Agent 44

Figure 3.21: The product of Raw Material for Refractory Production 45

Figure 3.22: The Layout of Warehouse 8..48

Figure 3.23: The Dimensions of Warehouse 10 49

Figure 3.24: Preparing Storage Areas Process 51

Figure 3.25: Receiving Products Process 53

Figure 3.26: Picking and Shipping Products Process 55

Figure 3.27: Invoice Data 57

Figure 3.28: Stock Data 58

Figure 3.29: Floor Stack Area in Warehouse 8 60

Figure 3.30: Single-deep Selective Rack Area of Warehouse 8 61

Figure 3.31: Storage Areas of Warehouse 8..62

Figure 3.32: Floor Stack Area of Warehouse 10...63

Figure 3.33: Flow Rack Area of Warehouse 10 63

Figure 3.34: Storage Area of Warehouse 10 64

Figure 4.1: Framework of the Methodology..66

Figure 4.2: Product Category Grouping Process..67

Figure 4.3: Flow Process Chart of Product Category Grouping for Two Warehouses..68

Figure 4.4: Five Steps for Comparing the Capacity of First Plan to the Full Capacity of Warehouse 8...72

Figure 4.5: Internal Layout and Storage Options of Warehouse 8 73

Figure 4.6: Internal Layout and Storage Options of Warehouse 10 74

Figure 4.7: An Example of Space Calculation of a Non-sell-in-bulk Product...........75

Figure 4.8: An Example of Space Calculation of a Sell-in-bulk Product 75

Figure 4.9: Stack Zones of Warehouse 8 79

Figure 4.10: An Example of Number of Rows in Zone A Calculation........................80

Figure 4.11: An Example of Number of Rows in Zone B Calculation 80

Figure 4.12: First Floor Stack Layout of Warehouse 8..81

Figure 4.13: Layout Designing Process..86

Figure 4.14: Flow Process Chart of Designing Layout for Warehouse 8 and Warehouse 10..87

Figure 4.15: An Example of Conversing Invoice into Number of Picking for a Non-sell-in-bulk Product...90

Figure 4.16: An Example of Conversing Invoice into Number of Picking for a Sell-in-bulk Product 90

Figure 4.17: Conclusion of Products and Product Categories Ranking 94

Figure 4.18: Three Zones of Warehouse 10 95

Figure 4.19: Example of the Number of Required Rows of Product in Warehouse 10 Calculation 96
Figure 4.20: Example of the Number of Required Lanes of Product in Warehouse 10 Calculation 97
Figure 4.21: Layout#1 of Warehouse 10 103
Figure 4.22: Layout#1 Designing Process for Warehouse 10.... 104
Figure 4.23: Layout#2 of Warehouse 10 107
Figure 4.24: Layout#2 Designing Process for Warehouse 10.... 108
Figure 4.25: An Example Distance Measurement of Warehouse 10.... 110
Figure 4.26: An Example of Distance Calculation 110
Figure 4.27: An Example of the Number of Required Rows of Product in Warehouse 8 Calculation.... 113
Figure 4.28: Assigned location for Refractories Lining 115
Figure 4.29: Layout#1 of Stack Zone of Warehouse 8.... 118
Figure 4.30: Layout#2 of Stack Zone of Warehouse 8.... 119
Figure 4.31: Example Distance Measurement of Stack Area in Warehouse 8.... 121
Figure 4.32: Selective Rack Zone of Warehouse 8 124
Figure 4.33: The Layout Designing Concepts of Single-deep Selective Rack of Warehouse 8.... 127
Figure 4.34: Layout#1 of Selective Rack Zone of Warehouse 8.... 128
Figure 4.35: Layout#2 of Selective Rack Zone of Warehouse 8.... 129
Figure 4.36: Layout#3 of Selective Rack Zone of Warehouse 8.... 130
Figure 4.37: Layout#4 of Selective Rack Zone of Warehouse 8.... 131
Figure 5.1: Validated Layout#2 of Warehouse 10.... 139
Figure 5.2: Validated Layout#3 of Warehouse 10.... 140

Figure 5.3: Rack G 141

Figure 5.4: Validated Rack G 141

Figure 5.5: Rack C 141

Figure 5.6: Validated Rack C 142

Figure 5.7: Old Layout of Warehouse 8 146

Figure 5.8: New Layout of Warehouse 8 147

Figure 5.9: New Layout of Warehouse 8 from Warehouse Department 148

Figure 5.10: New Layout of Warehouse 10 from Warehouse Department 149

Figure 5.11: New Layout of Warehouse 10 149

LIST OF TABLES

Table 1.1 : Product Category Name and Number of Products Used in the Research 17

Table 1.2: The Framework of the Research 19

Table 3.1: The Package Types of Product categories 47

Table 3.2: Description of Preparing Storage Areas Process 52

Table 3.3: Description of Receiving Products Process 54

Table 3.4: Description of Picking and Shipping Products Process 56

Table 3.5: Product Size Collecting Form 59

Table 3.6: An Example of Product Size Data 59

Table 4.1: Four Groups of Product Categories 70

Table 4.2: First Grouping Plan 71

Table 4.3: Space Requirement of All Products 76

Table 4.4: First Plan's Space Requirement for Warehouse 8 77

Table 4.5: First Plan's Space Requirement for Warehouse 10 77

Table 4.6: The Number of Required Rows of Sell-in-bulk Products 82

Table 4.7: Product Categories for Warehouse 8 and Warehouse 10 83

Table 4.8: Conclusion of Steps in Product Category Grouping 84

Table 4.9: Layout Constraints of Product Categories 88

Table 4.10: Conclusion of the Number of Picking Calculation 91

Table 4.11: Rank of Product Category in Warehouse 8 92

Table 4.12: Rank of Product Category in Warehouse 10 92

Table 4.13: Rank of Temperature & CE Product 93

Table 4.14: The number of stack’s rows and flow rack’s lanes of Product Categories in Warehouse 10 97

Table 4.15: The Layout Designing Concepts of Warehouse 10.... 100

Table 4.16: Maximum Number of Pallets per Stack of Products in Warehouse 10 105

Table 4.17: Conclusion of Number of Rows and Lanes Calculation for Warehouse 10 109

Table 4.18: Candidate Layouts for Warehouse 10.... 111

Table 4.19: Rank of Product Categories in Floor Stack Zone of Warehouse 8..... 113

Table 4.20: Rank of Products from Refractor Castable.... 114

Table 4.21: Product Categories for Stack Zone of Warehouse 8.... 116

Table 4.22: The Layout Designing Concepts of Stack Area of Warehouse 8......... 117

Table 4.23: Conclusion of Number of Rows Calculation for Warehouse 8........... 120

Table 4.24: Candidate Layouts for Stack Zone of Warehouse 8.... 122

Table 4.25: Rank of Product Categories in Selective Rack Zone of Warehouse 8125

Table 4.26: Rank of Products from Adhesive Product.... 125

Table 4.27: Product Categories for Selective Rack Zone of Warehouse 8 126

Table 4.28: Candidate Layouts for Rack Zone Layouts of Warehouse 8............... 133

Table 4.29: Conclusion of Steps in Layout Design 134

Table 5.1: Validated Layouts for Warehouse 10.... 139

Table 5.2: Implementation of Zone A of Warehouse 10 142

Table 5.3: Implementation of Zone B of Warehouse 10 143

Table 5.4: Implementation of Zone C of Warehouse 10 143

Table 5.5: Implementation of Zone A of Warehouse 8 144

Table 5.6: Implementation of Zone B1 of Warehouse 8 144

Table 5.7: Implementation of Zone B2 of Warehouse 8 145

Table 5.8: Implementation of Selective Rack Zone of Warehouse 8..................... 145

CHAPTER 1:
Introduction

1.1 Background of the Research

An automotive Industry is one of the most important industries in Thailand. According to Thailand Board of Investment (BOI), approximately 12% of Thailand's GDP came from automotive sector (BOI, 2015). In 2004, Thailand was the 12th biggest automotive producer (TAI, 2012). About 1.9 million vehicles were produced in 2014 (OICA, 2014) as presented. Figure 1.1 presents the world automotive production by country. The automotive industry is also the source of employment. There are more than 500,000 jobs in the automotive industry in 2012 (TAI, 2012). This research also targets to solve the problems of a company in an automotive supply chain.

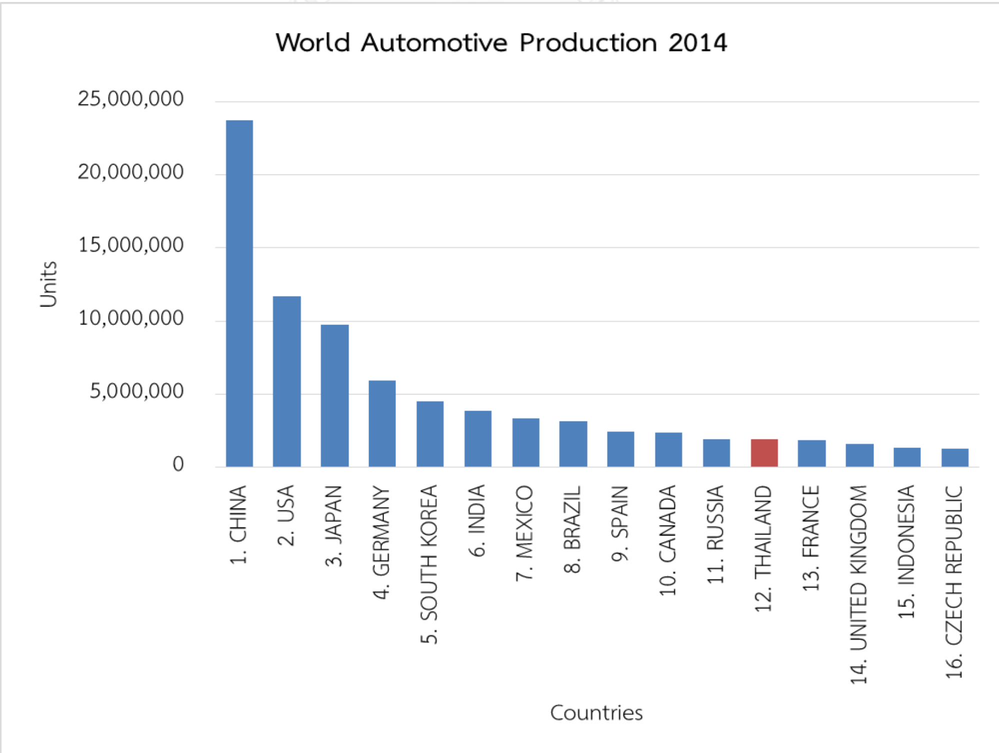


Figure 1.1: World Automotive Production in 2014 (OICA, 2014)

The studied company is a supplier of foundry raw materials and equipment for an automotive industry. The company is located in Samutprakarn, Thailand. The company is a trading company. The core activities of the company are buying and selling products. Most of the raw materials sold by this company are imported from other countries, while some of them are produced in-house.

The company classifies products into many product categories. For example, Exothermic Sleeve, Temperature Products, and Special Alloy etc. Product categories are not classified by the sources of the products (imported products and in-house products). Products in the same product category have similar characteristics (components, physical appearance, or chemical characteristics) or application. There are various forms of products and packages. In the same product category, the products may have different forms and packages. Figure 1.2 illustrates the two products from Exothermic Sleeves category which have different forms and packages.

Figure 1.2: An Example of Different Product Forms and Package of Products in Exothermic Sleeve Category

Previously, there were 9 warehouses in the company area. Each warehouse stored different product categories; Warehouse 1 stored Carbon products, Warehouse 2 stored Foundry Coke, Warehouse 3 stored old machines, Warehouse 3A stored Refractories Lining, Warehouse 4 stored Sand Slag, Warehouse 5 stored Coating, Warehouse 6 stored Ferro Alloys, Warehouse 7 stored Foundry Pig Iron, and Warehouse 8 stored most of ready-to-ship products. Four warehouses were studied in this research, i.e., Warehouse 3A, Warehouse 4, Warehouse 5 and Warehouse 10. Warehouse 8 is a permanent warehouse; while Warehouse 3A, Warehouse 4, and Warehouse 5 are temporary warehouses.

The company decided to cancel some warehouses and build a new permanent warehouse. This decision leads to the problem of this research. The details of the problem are described in Statement of Problem.

According to the historical sales as presented in Figure 1.3, the company's market has been increasing. Even though there is a drop of sale in 2011 due to the major flood in Thailand, the company could recover in the following year. In 2014, the company sold 29,130 tons of products. The company increased the number of sales to 35,000 tons of products in 2015.

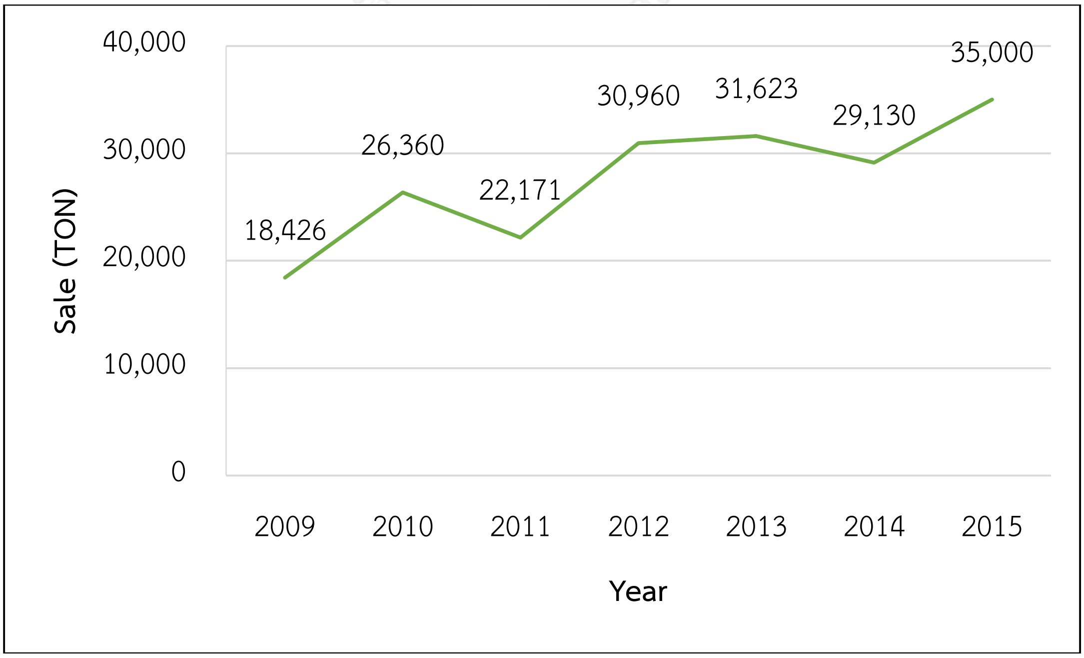


Figure 1.3: The Company's Historical Sales (in TON) from 2009 – 2015

1.2 Statement of Problem

The company has two warehouse strategies. The first strategy is locating one type of product categories to one warehouse. This strategy aligns with the company warehouse activities and warehouse system. The second strategy is locating as many products as possible in Warehouse 8. Since Warehouse 8 is close to the production warehouse and shipping area, Warehouse 8 is the main warehouse of the company. Locating as many products as possible in Warehouse 8 will enhance the efficiency of warehouse activities.

Warehouse 8 faced a limited space problem. Figure 1.4 shows the current situation of a lack of storage space in Warehouse 8. The company also planned to stop using the temporary warehouses (Warehouse 3A, Warehouse 4, and Warehouse 5) after relocating the products to the two permanent warehouses; Warehouse 8 and Warehouse 10. Figure 1.5, Figure 1.6, and Figure 1.7 demonstrate the temporary warehouses (Warehouse3A, Warehouse 4, and Warehouse 5, respectively).

Figure 1.4: The Company Situation in Warehouse 8

Figure 1.5: Warehouse 3A

Figure 1.6: Warehouse 4

Figure 1.7: Warehouse 5

The higher number of sold products results in the higher required storage space in warehouses. For this reason, the company decided to construct a new warehouse (Warehouse 10) to expand the storage space. Since other warehouses are assigned to store just one type of product category, there are enough warehouse space in the warehouses. Warehouse 1, Warehouse 2, Warehouse 3, and Warehouse 7 store Carbon product, Coke product, old machines, and foundry pig iron, respectively, while Warehouse 6 is a production warehouse which stores Ferro Alloy. The company does not require to relocate these products or redesign the layouts of these warehouses. Consequently, Warehouse 1, Warehouse 2, Warehouse 3, Warehouse 6, and Warehouse 7 did not face limited space problem and were out of the scope of this research.

This situation raises two questions.

1) Which products should be located in Warehouse 8 and Warehouse 10?
2) What are suitable layouts for Warehouse 8 and Warehouse 10?

Because the two warehouses are separated by an external road, and the products in the same product category have to be stored in the same warehouse, the solutions to these questions are important to the company. If the company does not well plan the product locations, warehouse supervisors will spend longer time preparing the products for each invoice. This situation may cause the following disadvantages to the company.

1) Late shipping

   Since each invoice takes longer time to prepare, it will take longer time to prepare all orders for shipping. This can cause late shipping.

2) Higher cost

   The company has to spend on the fuel cost and penalty cost in case of late shipping. Furthermore, the company may need to spend on human resources and facilities, e.g., drivers, warehouse supervisors, or trucks, in order to maintain the working efficiency.

1.3 Research Objectives

The objective of this research is to design the layouts of the existing warehouse (Warehouse8) and the new warehouse (Warehouse 10) so that the space can be efficiently used and the total picking distance from all invoices in 2014 is low.

1.4 Scope

1) The locations of products and the layouts depend on the company's policies, inventory policies, picking and shipping policies, and material handling.

   a) The company stores the same product category in the same warehouse.

   b) The dimensions of Warehouse8 and Warehouse are 2,226 square metres and 2,250 square metres, respectively. The details of both warehouses are described in CHAPTER 3: Company Data and Data Analysis.

   c) For the storage area of Warehouse 8, there are 57 rows of stacks and 694 locations of single-deep selective racks. For single-deep selective racks in Warehouse 8, after locating the first four levels of the racks, the top floor of the racks are considered as the storage locations. The top floor of the racks are reserved space. There are 7 racks in Warehouse 8. For floor stack area of Warehouse 8, there are 7 pallets per row (17 rows) and 6 pallets per row (20 rows). The details of the storage area are described in CHAPTER 3: Company Data and Data Analysis.

   d) The reserved rack in Warehouse 8 is not involved in this research.

e) For the storage area of Warehouse 10, there are 44 rows of stacks and 20 lanes of flow rack. A row of stack can locate 7 stacks. Each lane of the flow rack can locate 18 pallets. The details of the storage area are described in CHAPTER 3: Company Data and Data Analysis.

f) Reach truck is the material handling of the company. The maximum weight per a picking time is 2 tons (the maximum capacity of the reach truck.)

g) The maximum weight per pallet of the single-deep selective rack is 1 ton (Warehouse 8). The maximum weight per pallet of the flow rack is 1.5 tons (Warehouse 10.) The maximum height of pallets for both racks is 170 cm.

2) This research considers only the net storage areas of Warehouse 8 and Warehouse 10. The support areas are not involved in this research.

3) Efficiently use space is to locate products in the space-saving locations.

4) The results of this research in terms of warehouse layout consist of 2 main parts. :

a) Product categories grouping

This part will divide product categories into 2 groups for Warehouse 8 and Warehouse 10.

b) Warehouse layouts design

This part will design the layouts of new warehouse (Warehouse 10) and existing warehouse (Warehouse 8). Each product will be assigned to appropriate locations in the warehouses.

5) This research considers all products categories which are stored in Warehouse 3A, Warehouse 4, Warehouse 5, and Warehouse 8. There are 198 products and 17 product categories involved in this research. Table

1.1 presents all product categories, and information: names, IDs (CID), and the number of products in each product category.

Table 1.1 : Product Category Name and Number of Products Used in the Research

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 & Other	21
23	Other Chemical	3
25	Parting & Release Agent	2
26	Raw Material for Refractory Production	1
	Total	198

6) All products are placed on pallets.

7) This research includes the implementation and validation, but does not include the operation design for the warehouse supervisors and warehouse manager.

8) This research uses total picking distance as an efficiency measurement. The total picking distance is the sum of distance from all invoices in 2014.

9) The historical invoice data from 1st January 2014 – 31st December 2014 are used for research analysis.

1.5 Expected Benefits

1) The company can effectively make a decision on selecting product categories to be stored in Warehouse 8 and Warehouse 10 and designing appropriate layouts for both warehouses.

2) The company can apply product category grouping method and layout designing method presented in this thesis to improve the warehouse layouts in the future.

3) The total picking distance from the final layouts of Warehouse 8 and Warehouse 10 is low. This research adopts the distances as the measurement. The total picking distance is calculated from the sum of picking distance of all invoices in 2014.

1.6 Methodology

1) Study the company's background, company products, studied warehouses, and warehouse activities (receiving, picking, and shipping).
2) Study the related theories and researches.
3) Review the company data: invoice data, stock data, and product size data. Then, analyse all data and determine what additional data required to be collected.
4) Collect additional data.
5) Develop logics to answer these questions:
    a) Which products should be located in Warehouse 8 and Warehouse 10?
    b) What are suitable layouts for Warehouse 8 and Warehouse 10?

6) Test the results with historical data.

7) Implement the layouts according to the designs.

8) Validate and evaluate the chosen layouts.

9) Summary and write thesis report.

1.7 Framework of the Research

There are six chapters in this research, namely, Introduction, Literature Review, Company and Data Analysis, Methodology, Result, and Implementation. Table 1.2 summarise the detail processes in each chapter and the contents in each chapter.

Table 1.2: The Framework of the Research

Chapter	Process	Result
Chapter1: Introduction	1) Study the overview of the automotive industry, the current warehouse situation and problems, company policies and company requirements 2) Identify the thesis problem and objectives 3) Develop the methodology and define the scope of the research 4) Develop thesis framework	1) Background of the Research 2) Statement of problem 3) Research objectives 4) Research scope 5) Expected benefits 6) Methodology 7) Framework of the research
Chapter2: Literature Review	1) Study theories and researches that related to warehouse design	1) Related theories 2) Related research 3) Conclusion of Literature Review

	2) Differentiate the work from other previous researches 3) Develop the rough methodology concept from the related theories or researches	
Chapter3: Company and Data Analysis	1) Study the warehouse activities, the warehouse data and the interested products 2) Analyse the warehouse data and start planning the methodology steps 3) Collect the required data that have not been recorded by the company 4) Analyse the products and product categories and choose the appropriate location for the products.	1) Studied products 2) Studied warehouses 3) Warehouse activities 4) Company's data for this research 5) Conclusion of company data and analysis
Chapter4: Research Methodology	1) Summarise the information from all previous chapters and develop the methodology 2) Separate the methodology into 2 phases; grouping product categories phase and designing layout phase	1) Grouped product categories for two warehouses 2) Designed layout for Warehouse 8 and Warehouse 10

	3) Develop the processes for each phase 4) Calculate the total picking distance of all candidate layouts 5) Analysis the pros and cons of the candidate layouts of both warehouses based on the constraints 6) Evaluate the total picking distance, advantages, and disadvantages 7) Choose the best layouts for both warehouses	
Chapter5: Result	1) Validate and evaluate the layouts. Use the current information and validate the layouts of both warehouses 2) Implement by relocating the products according to the chosen layouts 3) Evaluate the new layouts to the old layouts and the layout from the warehouse official	1) Layouts validation 2) Implementation 3) Layouts evaluation
Chapter6: Conclusion	1) Conclude the results, information, and analysis of this study	1) Conclusion 2) Recommendation

	2) Develop recommendation for the further study	

CHAPTER 2:
Literature Review

This chapter will be separated into three parts. The first part is the Related Theories, describing about the basic knowledge of warehouses. The second part is Related Researches. The last part is the conclusion of the literature review.

2.1 Related Theories

2.1.1 Warehouse

Warehouse is a place to store the products until they are required (Kulwiec, 1985). Tompkins, J. (Tompkins, 1998) defined warehouse as a place for receiving, storing, picking, and shipping goods. These activities are the major functions of warehouses. The objective of each warehouse is different, so warehouses can be categorised in to three types (Berg and Zijm, 1999).

1) Distribution warehouses; storing suppliers' products (including assembling the products) and delivering the products to the customers.
2) Production warehouse; storing the raw material, semi-goods, and finished goods from the production department.
3) Contract warehouses; storing customers' product (can be called as public warehousing).

The studied warehouses are the mixing warehouse between distribution warehouse and production warehouse since they contain in-house products and suppliers' products.

2.1.2 Warehouse Systems

Warehouse systems or working systems in warehouses are different according to technology used in each warehouse. There are also three types of warehouse systems (Berg and Zijm, 1999)

1) Manual warehousing systems, the picker retrieves products at the locations.
2) Automated warehousing systems, the products move to the picker, i.e., carousel.
3) Automatic warehousing systems, the products move to the robot picker.

The studied warehouses adopt manual warehousing system to operate the warehouse activities.

2.1.3 Warehouse Operation

According to Gu et al. (Gu et al., 2007), there are four basic warehouse operations, i.e., receiving, storage, order picking, and shipping.

1) Receiving; receiving product from the receiving dock.
2) Storage; storing the received products to the assigned location.
3) Order picking; using material handling to pick the ordered products from the location.
4) Shipping: preparing ordered products, packing, and shipping the products to a customer.

2.1.4 Storage

According to Bartholdi and Hackman, there are two main storage strategies, i.e., dedicated storage and shared storage (John J. Bartholdi and Hackman, 2011). The concept of dedicated storage or fixed position storage is to locate a product in one specific location. The more popular product is assigned in more convenient location. Shared storage is opposite to dedicated storage. A product can be located in more than 1 location. This company wants to use dedicated storage since dedicated storage is easy to manage especially for manual warehousing system.

2.1.5 Class-based storage

According to Bartholdi and Hackman (John J. Bartholdi and Hackman, 2011), class-based storage is the way to increase overall throughput by changing location of the products. Class-based storage is a dedicated storage which is related to ABC analysis. The most frequently picked products are about 20 per cent of all products. By moving the location of these products to the front of the racks, the pickers will save time or increase productivity. The groups are A (accounted for most activity), B (accounted for moderate activity) and C (accounted for least activity). The ABC analysis is from the basic of Pareto (80-20). Only 20 per cent of the products account for 80 per cent of the warehouse activities. However, the percentage for each product type depends on the company policy and final look of the percentage (Tostar and Karlsson, 2008s).

2.1.6 Layout Framework

Hassan, M. (Hassan, 2002) proposed steps for designing warehouse layout. The steps for designing the layout framework are as follows.

1) Specifying the type and purpose of warehouse.
2) Forecasting and analysis of expected demand.
3) Establishing operating policies.
4) Determining inventory levels.
5) Class formation.
6) Departmentalization and the general layout.
7) Storage partition.
8) Design of material handling, storage, and sortation systems.

9) Design of aisles.

10) Determining space requirements.

11) Determining the number and location of input and output points.

12) Determining the number and location of docks.

13) Arrangement of storage.

14) Zone formation.

2.1.7 Typical Warehouse Layout

There are three typical warehouse layouts; U-shaped layout, I-shape layout, and Custom layout.

U-shaped layout has single I/O. It is usually designed for distribution warehouse. The drawback for this layout is there could be congestion near the receiving and shipping area. Figure 2.1 is U-shape layout.

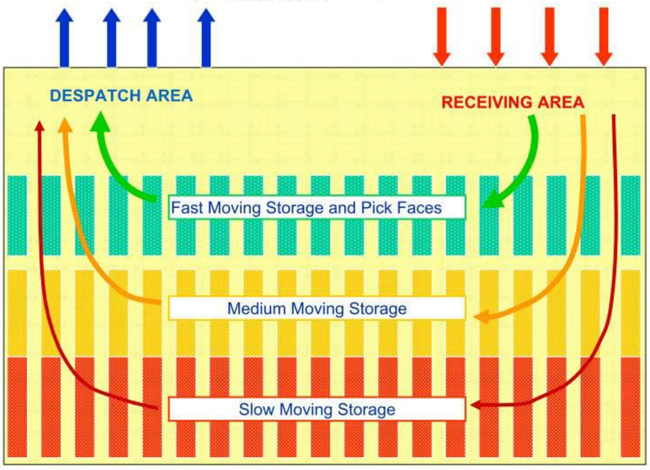


Figure 2.1: U-shaped Layout (Kittithreerapronchai, 2013)

I-shaped layout has two I/O. This layout is usually designed for production warehouse. Because every product come in one side and come out another side of the warehouse, long travelling distance is the drawback. Figure 2.2 is I-shaped layout.

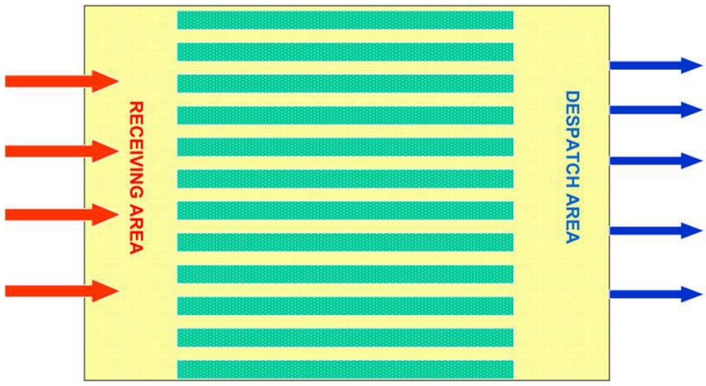


Figure 2.2: I-shaped Layout (Kittithreerapronchai, 2013)

Custom layout is the combination between U-shaped layout and I-shaped layout. This layout is designed following the function and operation of the warehouse. This layout mostly congests. Figure 2.3 is custom layout.

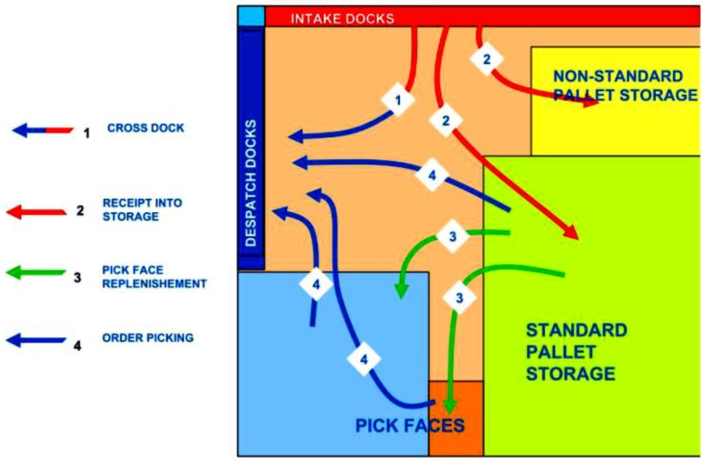


Figure 2.3: Custom Layout (Kittithreerapronchai, 2013)

2.1.8 Material Handling

Warehouse obviously involves material handling through its activities. There are four main activities for every warehouse; receiving, storing, order picking, and shipping.(Kulwiec, 1985). Material handling is used to move the products within warehouses. The movement of the raw materials, semi-goods, and finished goods through the processes of production and warehousing is known as material handling.

2.2 Related Research

There are three types of researches that are related to layout design. First is about developing storage policy, second is about developing picking policy, and the last is Facility Layout Problem.

2.2.1 Storage policy

Hausman et al. proposed three storage policy (Hausman et al., 1976);

1) Random Storage Assignment; storing a product closest to I/O without concerning the turnover.
2) Turnover-Based Assignment; storing the highest-turnover pallet closest to I/O.
3) Class-Based Turnover Assignment; dividing the products from turnover into classes and storing a product within its class location.

Hausman et al. found that Turnover-based Assignment is the most efficient policy for travelling time reduction. The more classes in Class-Based Turnover assignment could reduce more travelling time. This Class-Based method is also more practical than the Turnover-Based assignment (Hausman et al., 1976).

Frazelle and Sharp found that the correlated assignment policy which is storing the ordered-together products in the same storage area can reduce the retrieval time comparing to the typical storage policy (Frazelle and Sharp).

Muppani and Adil developed branch and bound algorithm (BBA) and dynamic programming algorithm (DPA) to minimise the travelling distance of class-based policy and then compare to the dedicate policy (turnover-based policy). They found that class-bases policy can yield lower travel distance than the dedicated policy (Muppani and Adil, 2008). However, the research developed the keeping policies based on automatic warehouse system which is different from the studied warehouses.

Battista et al. compared storage policies; random storage assignment and turnover-based assignment. They found that the turnover-based strategy could reduce 37.8% of travelling time comparing to the original layout (Battista et al., 2011).

Each business has different characteristics. Accordingly, there is no universal solution of designing layout. For example, paper reel business in China, turnover-based assignment is efficient and effective for developing the layout. Because one stack can be store more than 1 type of products which in the same class, so Linear Programming (IP) is developed to solve this problem (Zhang et al., 2000). Amarase, N. designed the 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 are located in front area, while unpopular products are assigned to the back area. (Amarase, 2001).

2.2.2 Facility Layout Problem (FLP)

According to Meller, D. and Gau, K. (Meller and Gau, 1996) Facility Layout Problem (FLP) is to find the most effective layout that contains the number of departments. Each department requires unequal areas. Material handling cost is typically used as efficiency measurement. Chutima, P. (Chutima, 2001) used Genetic Algorithm (GA) to minimise total travelling cost. He found that GA is a sensitive algorithm, some parameters should be considered carefully. Yiangkamolsing, C. (Yiangkamolsing, 2005) solved Constraint-Based Facility Layout Problem (CBFLP) by using Multi Objective Fuzzy-Genetic Algorithms (MOFGA). He found that MOFGA gives a good solution with an acceptable time limit.

2.2.3 Picking policy

After finishing designing the warehouse layout or improve the picking process, many researches use optimising method and Heuristic methods to minimise the travelling distances and travelling time (picking time). For example:

Amarase, N. measured the picking distance of each product from its location to the preparing area (distance in X and Y axises) in order to develop the picking policy of the plastic resins trading warehouse (Amarase, 2001).

Koster and Poort compared optimal solution, polynomial algorithm, and S-shape heuristic to minimise the total picking time (Koster and Poort, 1998). They found that S-shape heuristic performed well in the narrow-aisle high-bay pallet with many items scenario.

Roodbergen and Koster used dynamic programming to formulate the shortest travelling path for a warehouse with three cross aisles (Roodbergen and Koster, 2001).

2.3 Conclusion of Literature Review

As a result of the review, warehouse layout design depends on the stored products characteristics. U-shaped and I-shaped are designed according to the external design of the warehouses. Class classification is used to develop storage policies. Picking policy is used to measure the layout efficiency and also can develop the route to minimise the travelling time.

This research develops the design method for the studied foundry raw material supplier which has two warehouses. This research takes account of both product characteristics and quantitative measurement in order to develop the layout for the warehouses. There is no researches developed the practical methods to design the layouts of two warehouses like this research.

After categorising the product categories, the warehouse layouts will be designed under the company constraints. The three storage policies (Hausman et al., 1976) will be applied in layout designing. Company's picking policies will be used for analysis.

CHAPTER 3:
Company Data and Analysis

This chapter describes the details of studied product categories. The product categories' characteristics and forms are presented in this chapter. The warehouse activities of the company are also described and summarised. Warehouse data are analysed. The data that are required in this research are identified. All the data are studied so that there are sufficient information for the research methodology to be completed in the next step.

3.1 Studied Products

Since this research aims to design the location for the products from Warehouse 3A, Warehouse 4, Warehouse 5, and Warehouse 8, there are 198 products and 17 product categories involved in this study. We analysed all invoices from 2014 and identified all products and product categories. All of them were stored in Warehouse 3A, Warehouse 4, Warehouse 5, and Warehouse 8. The 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 & Other, Other Chemical, Parting & Releasing Agent, and Raw Material for Refractory Production.

1) <u>Foundry Sand</u>

There are only sell-in-bulk products in this product category. The products are either packed in small bags inside a big or packed in a standard size bag. The sand is used in sand casting process. Figure 3.1 illustrates products from Foundry Sand.

Figure 3.1: An Example of a Product from Foundry Sand

2) <u>Refractories Lining</u>

There are a number of Refractories Lining products that are used in installing induction furnace lining. Most of the products are sell-in-bulk products and imported from other countries. These products are the main raw materials for installing induction furnace lining. The products are dry grains of ferrous materials. Figure 3.2 presents the appearance of a sell-in-bulk product of Refractories Lining. Sell-in-piece products are minority of Refractories Lining products. These products are the outside support materials for induction furnace lining installation. The products are breakable. Figure 3.3 presents one of the sell-in-piece products from Refractories Lining.

Figure 3.2: An Example of a Sell-in-Bulk Product from Refractories Lining

Figure 3.3: An Example of a Sell-in-piece Product from Refractories Lining

3) <u>Coating</u>

This product category is foundry coating. The coating can enhance the property of the casting surface. There are two groups of Coating: Water based coating and Alcohol based coating. The products are contained in big plastic drums. Figure 3.4 illustrates the Coating products.

Figure 3.4: An Example of Products from Coating

4) Exothermic Sleeve

There are two groups of Exothermic Sleeve products, i.e., sleeve and powder. The major product group is sleeve. There are many shapes of sleeve products for various foundry works. Sleeve products are piled up on pallets. According to the observation, sleeve products are easy to break, while powder products are unable to break. Figure 3.5 and Figure 3.6 illustrate examples of sleeve product and powder product, respectively. Sleeve products are used as foundry risers for ferrous and non-ferrous casting. Powder products are used for covering the upper surfaces of feeder heads in foundry process.

Figure 3.5: An Example of a Sleeve Product from Exothermic Sleeve

Figure 3.6: An Example of a Power Product from Exothermic Sleeve

5) <u>Mica Products & Insulation (Mica Product/ Mica)</u>

Mica Product & Insulation, Mica Product, or Mica is an insulation of coils in induction furnaces and other electric parts in foundry processes. Accordingly, there are many forms of Mica Product & Insulation. The Majority of the products are Mica sheet (in sheet forms). Mica sheet products are compulsory to be stored on the floor since they are easy to be torn. Figure 3.7 presents an example of a Mica sheet product. Other products of Mica are in box packages. Figure 3.8 illustrates an example of an other product. There is no sell-in-bulk products in Mica Product & Insulation. All of products are piled up on pallets.

Figure 3.7: An Example of a Mica Sheet Product from Mica

Figure 3.8: An Example of an Other Product from Mica

6) Temperature & CE Products & Service (Temperature Product)

The products in Temperature & CE Products & Service category are thermocouple probes. The products of this product category are used for measure temperature during the foundry processes. All products are fragile and packed in boxes. Figure 3.9 presents an example of a product from Temperature & CE Products & Service.

Figure 3.9: An Example of a Product from Temperature & CE Products & Service

7) Special Alloys-Inoculant / Magnesium (Special Alloy)

Special Alloys-Inoculant / Magnesium or Special Alloy is composed in foundry process in order to adjust the casting material properties. The components and component ratio of each product are different according to the type of casting work. All of the products are sell-in-bulk products. The products are either powder or grains. Figure 3.10 presents an example of Special Alloys-Inoculant / Magnesium products.

Figure 3.10: An Example of a Product from Special Alloys-Inoculant / Magnesium

8) <u>Fluxes</u>

This product category is used to maintain the property of the materials in the crucible. There is one product in this product category, since this research focuses on the products in Warehouse 3A, Warehouse 4, Warehouse 5 and Warehouse 8. The product is a bulk product. Figure 3.11 shows the product of Fluxes.

Figure 3.11: The Product of Fluxes

9) Adhesive Product

Adhesive Product is used as glue for general foundry work. The products can be used for mould and core assembly. The products in this product category are sold in pieces or tubes. The products' package are made of plastic, so the products have to be stored inside boxes. Figure 3.12 presents an example a product from Adhesive Product.

Figure 3.12: An Example of a Product from Adhesive Product

10) Non-Ferrous Product & Other Fluxes (Non-Ferrous Product)

This product category contains a number of products. All of products do not compose of ferrous components. Most of the products in this product category are crucibles. Other products are flux feeder and non-ferrous materials.

Most of the products are required to be stored on shelves since they are fragile. Figure 3.13 present an example a product from Non-Ferrous Product & Other Fluxes.

Figure 3.13: An Example of a Product from Non-Ferrous Product & Other Fluxes

11) <u>Ceramic Product</u>

There is a number of ceramic products. All of the products are fragile and required to be stored on shelves. There are 3 groups of Ceramic Product, i.e., ceramic sleeve, ceramic spoon and ceramic foam filter. The application of the products are different. Ceramic sleeve is used as a gate for the molten metal, ceramic spoon is used as a ladle, and ceramic foam filter is used as a filter in foundry process. Figure 3.14 illustrates an example of Ceramic Product.

Figure 3.14: An Example of a Product from Ceramic Product

12) <u>Sand Slag</u>

All products of Sand Slag are sell-in-bulk products. Products are packed in small bags. The bags are piled up on pallets. The application of Sand Slag is to clean the slag in the molten metal. Figure 3.15 illustrates an example product of Sand Slag.

Figure 3.15: An Example of a Product from Sand Slag

13) <u>Refractor Castable</u>

Refractor Castable is refractory castable material. The products of this product category are all dry and packed in bulk package. Refractor Castable can be used in many casting work, e.g., patching the lining, being the base of induction furnace etc. Figure 3.16 illustrates an example product from Refractor Castable.

Figure 3.16: An Example of a Product from Refractor Castable

14) <u>Refractor Plastic & Other (Refractor Plastic)</u>

There are many forms and packages of Refactor Plastic & Other products. Some products are sell-in-bulk products and required to be stored in stack area. Some products are sell-in-piece products. The sell-in-piece products are sold in small plastic drums or boxes depending on the forms of the products. The application of this product category is general refractory patching. The products are used in ladle patching, furnace patching, and other general purposes. Examples of a sell-in-piece product and a sell-in-bulk products are shown in Figure 3.17 and Figure 3.18, respectively.

Figure 3.17: An Example of a Sell-in-piece Product from Refractor Plastic & Other

Figure 3.18: An Example of a Sell-in-bulk Product from Refractor Plastic & Other

15) <u>Other Chemical</u>

The products in this product categories are bulk products, i.e., metal drums and bags. The products in this product category cannot be categorised into any other groups. Figure 3.19 illustrates an example product of Other Chemical.

Figure 3.19: An Example of a Product from Other Chemical

16) Parting & Release Agent

Parting & Release Agent is mould releasing agent. All of the products are in plastic gallons. Each pallet is piled up with a number of products. A pallet of products cannot be piled up. Figure 3.20 is an example of a product from Parting & Release Agent.

Figure 3.20: An Example of a Product from Parting & Release Agent

17) Raw Material for Refractory Production

There are one product in this product category. The product is the raw material for manufacturing foundry products and crucibles. Figure 3.21 shows the product of Raw Material for Refractory Production.

Figure 3.21: The product of Raw Material for Refractory Production

3.2 Product Packages

According to the product information in section 3.1, there is a number of product packages. This section summarises the product package of each product category. Some product categories have one package type, while some product categories have two package types.

For one type of package, the package type of Foundry Sand, Special Alloys, Fluxes, and Raw Material for Refractories is a big bag on a pallet. There is one package type of Coating and Parting & Releasing Agent Product, big plastic drums on a pallet and plastic gallons on a pallet, respectively. There is one type of package of Temperature Product, Adhesive Product, and Ceramic Product, boxes on a pallet. There is also one type of package of Sand Slag and Refractor Castable, small bags on a pallet.

For two package types, there are two packages types of Refractories Lining and Exothermic Sleeve, small bags on a pallet and products on a pallet. There are also two package types of Refractory Plastic, small bags on a pallet and small plastic drums on a pallet. Other Chemical has two types of packages; small bags on a pallet and metal drums on a pallet. There are two packages types of Mica Products and Non-ferrous Product, boxes on a pallet and product on a pallet.

Table 3.1 presents the summarised package types of all studied product categories. The package types and product characteristics are considered in CHAPTER 4: Research Methodology in order to group product categories for Warehouse 8 and Warehouse 10.

Table 3.1: The Package Types of Product categories

CID	Product Category	Package							
		A big bag on a pallet	Small bags on a pallet	products on a pallet	Boxes on a pallets	Big plastic drumson 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	Coating					√			
7	Exothermic Sleeve		√	√					
8	Mica			√	√				
9	Temperature & CE Product				√				
12	Special Alloys-Inoculant / Magnesium	√							
13	Fluxes	√							
14	Adhesive Product				√				
17	Non-ferrous Product			√	√				
18	Ceramic Product				√				
20	Sand Slag		√						
21	Refractor Castable		√						
22	Refractory Plastic		√				√		
23	Other Chemical		√					√	
25	Parting & Releasing Agent Product								√
26	Raw Material for Refractories	√							

3.3 Studied warehouses

Warehouse 8 is the main warehouse of the company since it is located close to the company office, shipping area, and production warehouse. Warehouse 8 and Warehouse 10 have different dimensions. The size of warehouses 8 and Warehouse 10 are 2,226 square metres and 2,250 square metres, respectively. Figure 3.22 and Figure 3.23 show the dimension and internal details of the current layouts of Warehouse 8 and Warehouse 10, respectively.

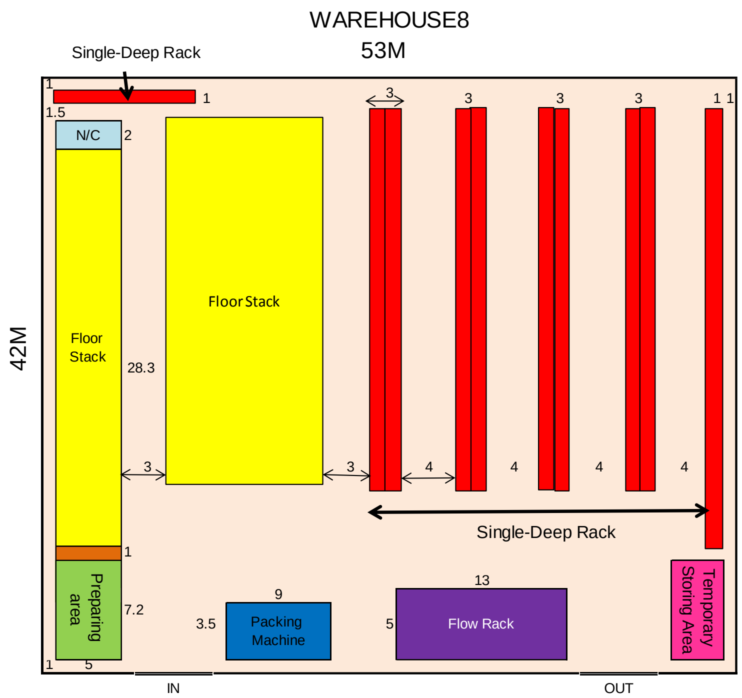


Figure 3.22: The Layout of Warehouse 8

Warehouse 8 contains single-deep selective rack area and floor stack area. The warehouse is already installed single-deep selective racks with 694 locations as presented in red areas of Figure 3.22. The yellow areas in the layout of Warehouse 8 are the floor stack areas. Other colours represent other areas which are Light green area is the preparing area. The manual packing machine, warehouse server, and warehouse officials work area are located in light green area. The dark blue area is automatic packing machine. The light blue area is the spare area. Dead stock product or special ordered products are located in this area. The purple area is flow rack area. Flow rack is used for the ready-to-deliver products. After packing or wrapping the ordered products, the warehouse supervisors will move the ready-to-deliver orders into the flow rack’s lanes. The pink area is the temporary storing area. This area used to stores Parting & Releasing Agent products.

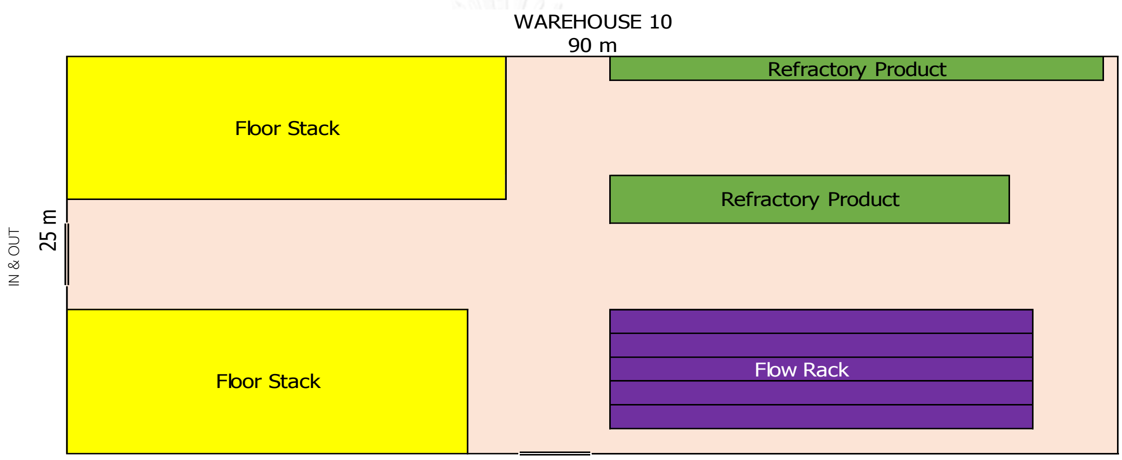


Figure 3.23: The Dimensions of Warehouse 10

Warehouse 10 contains floor stack area and flow rack as presented in Figure 3.23. The yellow area is the floor stack areas of the warehouse. The purple area is the flow rack area of the warehouse. In Warehouse 10, both floor stack areas and flow rack area are considered as the storing location. Green areas are not considered as the storing location, because the areas are reserved for other departments of the company.

3.4 Warehouse Activity

In order to ship products to the customers, all products have to pass all warehouse processes. Warehouse manager and warehouse supervisors have responsibilities to control and carry out all processes within the warehouses. In addition to the picking and shipping process, there are preparing storage areas process and receiving products process. All three warehouse activities (preparing storage area, receiving products, and picking and shipping products) are systematically recorded in Work Instruction (WI).

3.4.1 Preparing storage areas

This process is the first warehouse process. After receiving the inbound information from the purchasing department, the warehouse manager and warehouse supervisors have to prepare the storage areas for the products following the WI. Figure 3.24 shows the preparing storage areas processes. Table 3.2 presents the details of steps in the process.

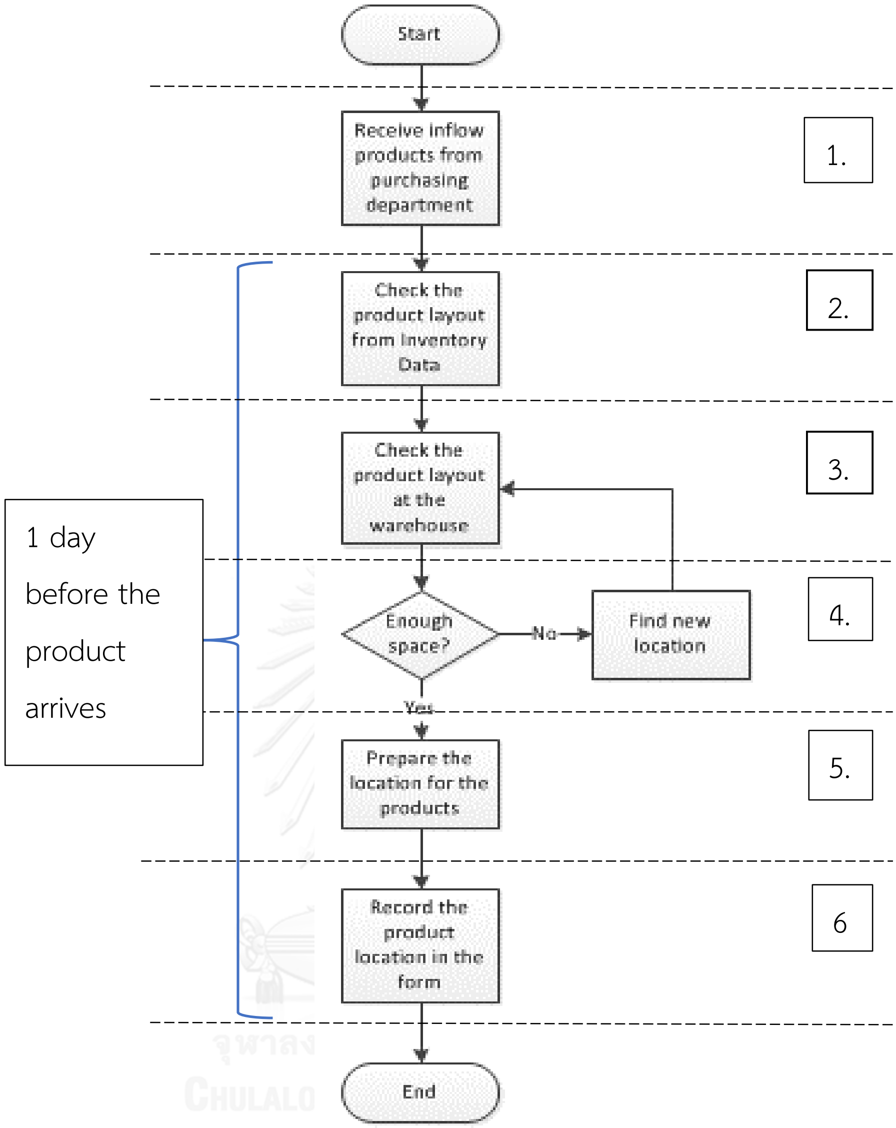


Figure 3.24: Preparing Storage Areas Process

Table 3.2: Description of Preparing Storage Areas Process

No.	Process Description
1.	The warehouse manager receives the list of inbound products from purchasing department.
2.	The warehouse manager checks the location of the products from the Inventory Database.
3.	The warehouse manager goes to the warehouse and checks the real storage locations.
4.	If there is not enough space to store the products, the warehouse manager finds the new locations for the products.
5.	The warehouse manager assigns a warehouse supervisor to prepare receiving area and pallets for the inbound products.
6.	The warehouse supervisor records the products' locations in the Storage Preparing Form.

3.4.2 Receiving products

When the products are arrived, the warehouse supervisors have to check the products and store them at the prepared location until there are any requisitions from the customers. Receiving products process contains many steps as presented in Figure 3.25. Table 3.3 presents the details of steps in Receiving Products Process.

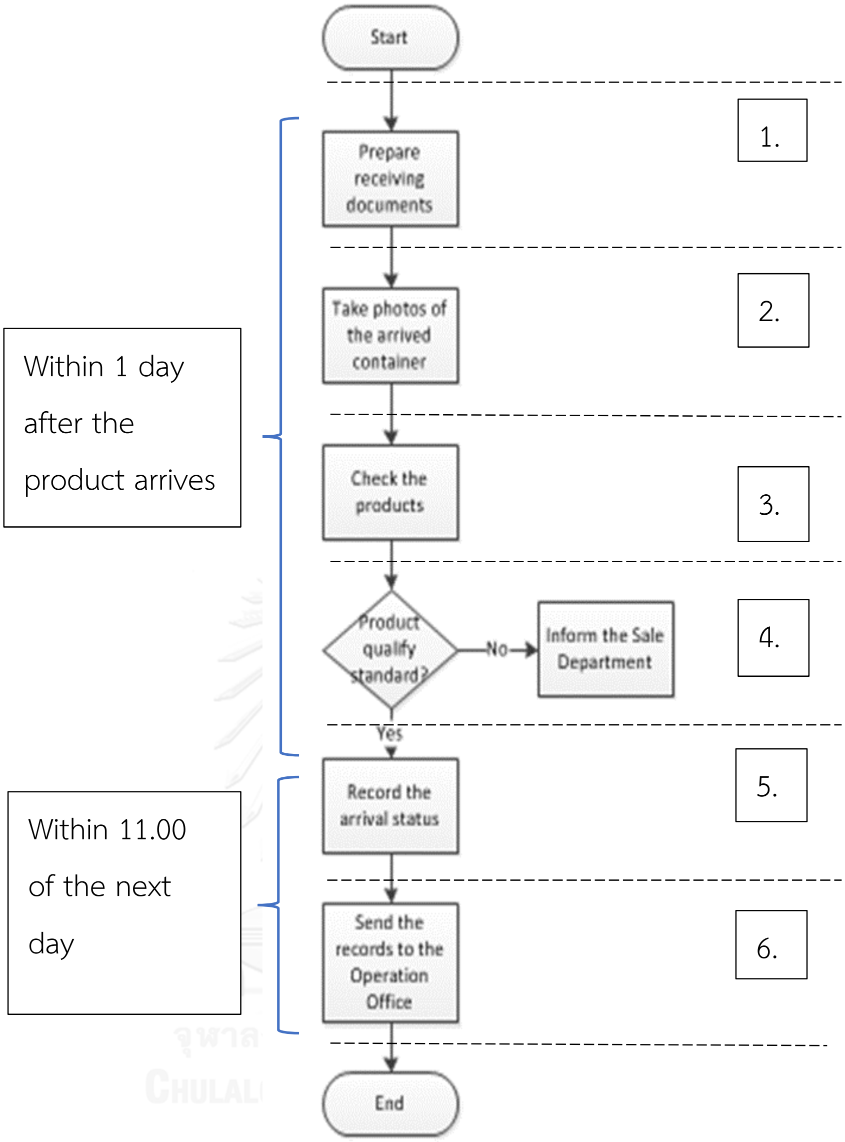


Figure 3.25: Receiving Products Process

Table 3.3: Description of Receiving Products Process

No.	Process Description
1.	When the products are arrived at a warehouse, a warehouse supervisor prepares documents (copy of invoices, copy of product requisitions, or packing lists) to check the inbound products.
2.	The warehouse supervisor takes photos of products' containers and containers IDs. The warehouse supervisor records inbound products and their photos in computer file (R:\Home\ampawa\1).
3.	The warehouse supervisor checks products' packages, weights, and lots.
4.	If there are any problems, the warehouse supervisor informs the purchasing department immediately.
5.	If there is no problem, the warehouse supervisor fills in the Receiving Form.
6.	The warehouse supervisor sends the Receiving Form to the operation office.

3.4.3 Picking and shipping products

This process combines 2 processes together, picking process and shipping process. Because the company ships products 3 times every day, the company can merge the two processes together. Figure 3.26 presents the picking and shipping products process. Table 3.4 presents the details of steps in Picking and Shipping Products Process.

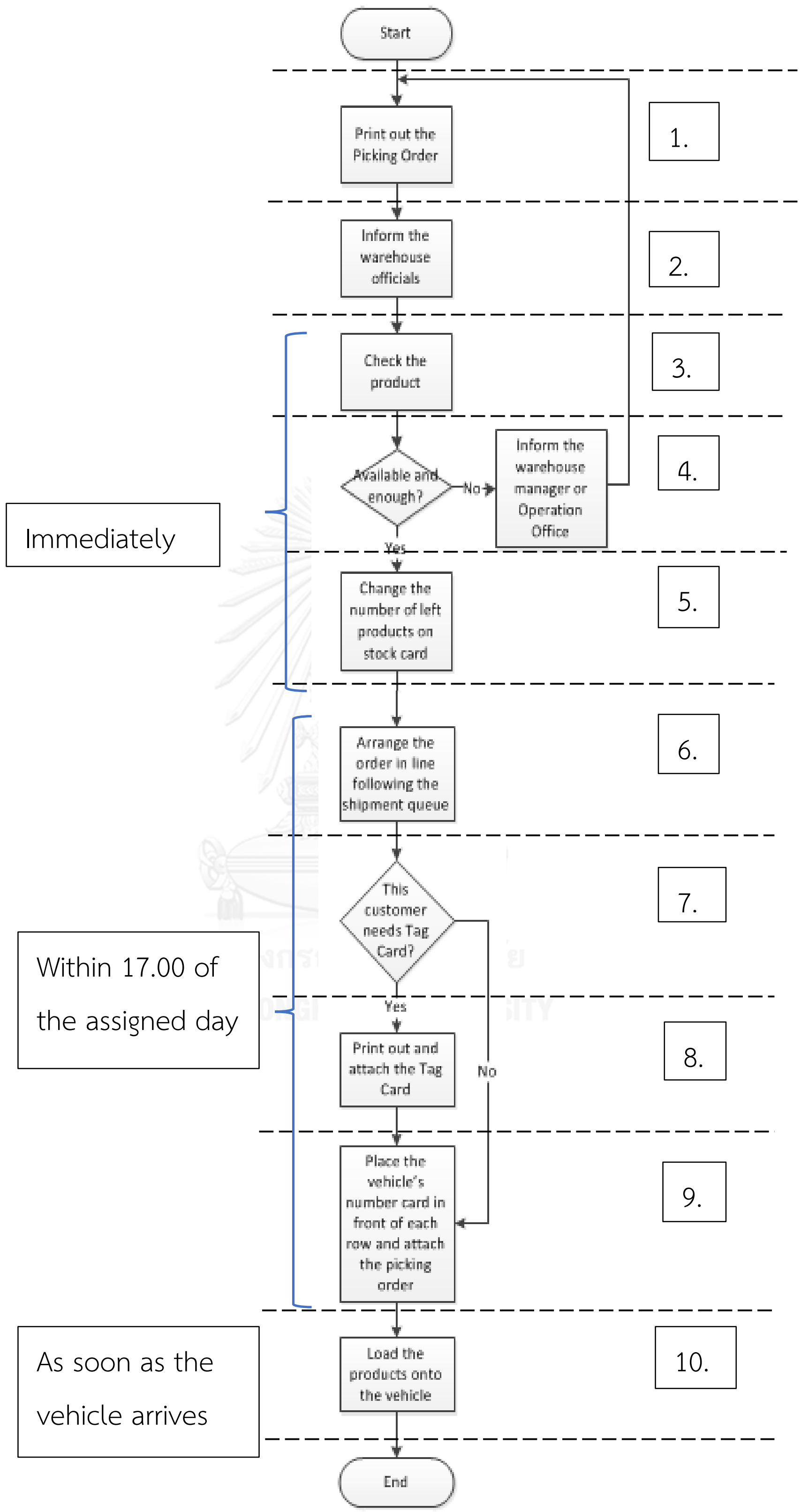


Figure 3.26: Picking and Shipping Products Process

Table 3.4: Description of Picking and Shipping Products Process

No.	Process Description
1.	The shipping manager updates Picking Orders 3 times a day (13:00, 15:00, and 17:00) and prints out the Picking Orders.
2.	The warehouse manager assigns Picking Orders to a warehouse supervisor.
3.	The warehouse manager controls picking process, prioritises Picking Orders following the queues and checks products (Lot number, amount of products, packing).
4.	If products are out of stock or a lot number is not as same as Picking Order's lot number, the warehouse supervisor inform the warehouse manager and operation office.
5.	The warehouse supervisor changes the number of left products in stock card.
6.	The warehouse supervisor arranges product orders in a row following the queue and separates each row for each vehicle.
7.	Check if customers need any Tag Cards?
8.	If a customer needs Tag Card, attach Tag Card. The warehouse manager prints and attaches Tag Card.
9.	A shipping supervisor places the vehicle's number card in front of the order row and attaches the picking order.
10.	The warehouse manager and driver finally check the product together. Then, the warehouse supervisor loads the products onto the vehicle.

3.5 Company's Data for This Research

There are four groups of data used in this research, invoice data, stock data, product size data, and storage data. The data were collected from 1st January 2014 to 31st December 2014.

3.5.1 Invoice data

Invoice data record the purchasing information, i.e., category ID (CID), category name, customer name, Product ID (PID), invoice ID, Invoice No., date of purchasing, the number of purchased products, product unit, pack size, package quantity, packaging unit and year of purchasing. Figure 3.27 presents the invoice data of the company.

CID	Category	ID	Customer	PID	Product Name	InvoiceID	InvoiceNo	Date	Quantity	Unit	Pack Size	Pack Qty	Pack Unit	Packing	Year	Month
04	Ferro Alloys	13-60-1023		1.4E+09		140021	57100380	10/10/57	1000	KGS	1000 KGS/BULK	1000	KGS	BULK	2014	10
14	Adhesive Pro	13-60-1023		1.4E+09		140021	57100380	10/10/57	40	TUBE	20 PCS/BOX	20	PCS	BOX	2014	10
26	Raw Material	13-60-1023		1.41E+09		140021	57100380	10/10/57	2000	KGS	25 KGS/BAG	25	KGS	BAG	2014	10
25	Parting & Rel	13-60-1023		1.43E+09		140021	57100380	10/10/57	80	LITRE	20 LITER/GAL	20	LITER	GAL	2014	10
26	Raw Material	13-60-1023		1.41E+09		140022	57100381	10/10/57	2000	KGS	25 KGS/BAG	25	KGS	BAG	2014	10
22	Refractor Pla:	13-60-1023		1.51E+09		140022	57100381	10/10/57	60	KGS	30 KGS/DRUM	30	KGS	DRUM	2014	10
06	Coatings	13-60-1023		1.4E+09		140022	57100381	10/10/57	120	KGS	30 KGS/DRUM	30	KGS	DRUM	2014	10
04	Ferro Alloys	13-20-4367		1.41E+09		140023	57100382	10/10/57	1000	KGS	25 KGS/BAG	25	KGS	BAG	2014	10
25	Parting & Rel	13-30-1016		1.43E+09		140024	57100383	9/10/57	40		20 LITRE/DRUM	20	LITRE	DRUM	2014	10
20	Sand Slag	13-30-1016		1.4E+09		140036	57100384	9/10/57	600	KGS	300 KGS/PALLET	300	KGS	PALLET	2014	10
20	Sand Slag	13-30-1016		1.4E+09		140038	57100385	10/10/57	500	KGS	300 KGS/PALLET	300	KGS	PALLET	2014	10
20	Sand Slag	13-30-1016		1.4E+09		140034	57100386	10/10/57	300	KGS	300 KGS/PALLET	300	KGS	PALLET	2014	10
25	Parting & Rel	13-30-1016		1.43E+09		140034	57100386	10/10/57	100		20 LITRE/DRUM	20	LITRE	DRUM	2014	10
06	Coatings	13-30-1016		1.4E+09		140034	57100386	10/10/57	90	KGS	30 KGS/DRUM	30	KGS	DRUM	2014	10
14	Adhesive Pro	13-30-1016		1.4E+09		140034	57100386	10/10/57	60	PCS	30 PCS/BOX	30	PCS	BOX	2014	10
03	Refractories I	13-10-3250		1.41E+09		140041	57100388	11/10/57	5000	KGS	25 KGS/BAG	25	KGS	BAG	2014	10
03	Refractories I	13-20-3277		1.41E+09		140040	57100390	11/10/57	250	KGS					2014	10
20	Sand Slag	13-20-5404		1.4E+09		140044	57100392	11/10/57	500	KGS	20 KGS/BAG	20	KGS	BAG	2014	10
03	Refractories I	13-10-8830		1.41E+09		140045	57100393	13/10/57	1000	KGS	25 KGS/BAG	25	KGS	BAG	2014	10
04	Ferro Alloys	13-11-1001		1.4E+09		140047	57100395	13/10/57	1000	KGS	25 KGS/BAG	25	KGS	BAG	2014	10
04	Ferro Alloys	13-10-2146		1.4E+09		140048	57100396	13/10/57	100	KGS	25 KGS/BAG	25	KGS	BAG	2014	10
04	Ferro Alloys	13-10-2146		1.4E+09		140048	57100396	13/10/57	100	KGS	25 KGS/BAG	25	KGS	BAG	2014	10
04	Ferro Alloys	13-20-3209		1.4E+09		140049	57100397	13/10/57	1000	KGS	25 KGS/CAN	25	KGS	CAN	2014	10
04	Ferro Alloys	13-11-1000		1.4E+09		140051	57100398	10/10/57	150	KGS	25 KGS/BAG	25	KGS	BAG	2014	10

Figure 3.27: Invoice Data

3.5.2 Stock data

The company checks stock at the end of every month. The measurement of products are in many units, i.e., weight (ton), the number (piece), length (metre), volume (litre) and set. Figure 3.28 presents the example of stock data.

Adhesive Product	1	2	3	4	5	6	7	8	9	10	11	12
	4517	2580	3245	1537	6857	4676	3813	2153	3131	2377	4049	1365
	1338	578	2898	2418	3018	2418	2098	1738	1278	818	100	2700
	1523	3497	2687	2689	4461	3475	2457	1594	4225.5	3386.5	2735.5	2260
	3390	2190	3210	6210	3990	3300	3240	2940	4830	2370	570	5730
	39	39	39	39	39	39	36	36	33	32	28	25
	21	13	2	2	2	2	0	0	0	0	0	48
	0	1	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	1	0
Ceramic Product	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	32387	32387	31587	31587	30993	30993	30300	29500	28906	28906	28506	28105
	24789	24789	24789	24789	24789	24789	25190	25190	25190	25090	25090	24390
	12	8	2	35	31	30	26	22	22	21	17	9
	0	117	308	308	222	546	408	330	241	161	260	260
	12	112	131	131	113	293	218	158	144	144	203	203
	31	31	181	181	175	415	490	490	485	485	485	490

Figure 3.28: Stock Data

3.5.3 Product size data

The dimensions of the products are required in order to design the spaces for the products. The product size data contain 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 (max overlay), and the maximum number of pallets that can be retrieved per times (max retrieve).

There are only the data of pack quantity, product units, and pack size of 109 products out of 198 products. There are no records of the dimension of products, dimension of pallets, the number of products per pallet, the maximum number of pallets per stack, and the maximum number of products. Therefore, the product size collecting form is developed. Table 3.5 presents the form of product size data. All required data will be collected and completed.

The warehouse supervisors collected 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. Table 3.6 presents an example of Product Size Data.

Table 3.5: 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			

Table 3.6: An Example of 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			
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

3.5.4 Storage Data

Since each product should be located in different storage areas. It is important to know and understand the storage areas of Warehouse 8 and Ware house 10. The details of storage areas of Warehouse 8 and Warehouse 10 are described in this section.

For Warehouse 8, there are 2 storage areas, i.e., floor stack area and single-deep selective rack area. For floor stack area, we separate the area into 3 zones, i.e., zone A, zone B1, and zone B2. There are 17 rows in zone A and each row can locate up to 7 pallets. For zone B1 and zone B2, there are 20 rows in each zone. Each row of zone B1 and zone B2 can locate up to 6 pallets of products. Consequently, the maximum capacities of zone A and zone B are 119 stacks and 240 stacks (calculating from multiplying the number of rows by the number of stacks per row). Figure 3.29 presents the floor stack area of Warehouse 8.

Figure 3.29: Floor Stack Area in Warehouse 8

There are 7 single selective racks in Warehouse 8, i.e., rack A, rack B, rack C, rack D, rack E, rack F, and rack G. Rack A has 110 locations. Rack B and rack C have 92 locations. Rack D, rack E, rack F, and rack G have 100 locations. Figure 3.30 presents the single-deep selective rack area of Warehouse 8.

Figure 3.30: Single-deep Selective Rack Area of Warehouse 8

Figure 3.31 presents the storage areas of Warehouse 8. The number in each zone represents the number of stacks (for stack area) and the number of locations (for selective rack area). The reserved rack is for locating rarely ordered products. For single-deep selective rack, there are 25 location in reserved rack.

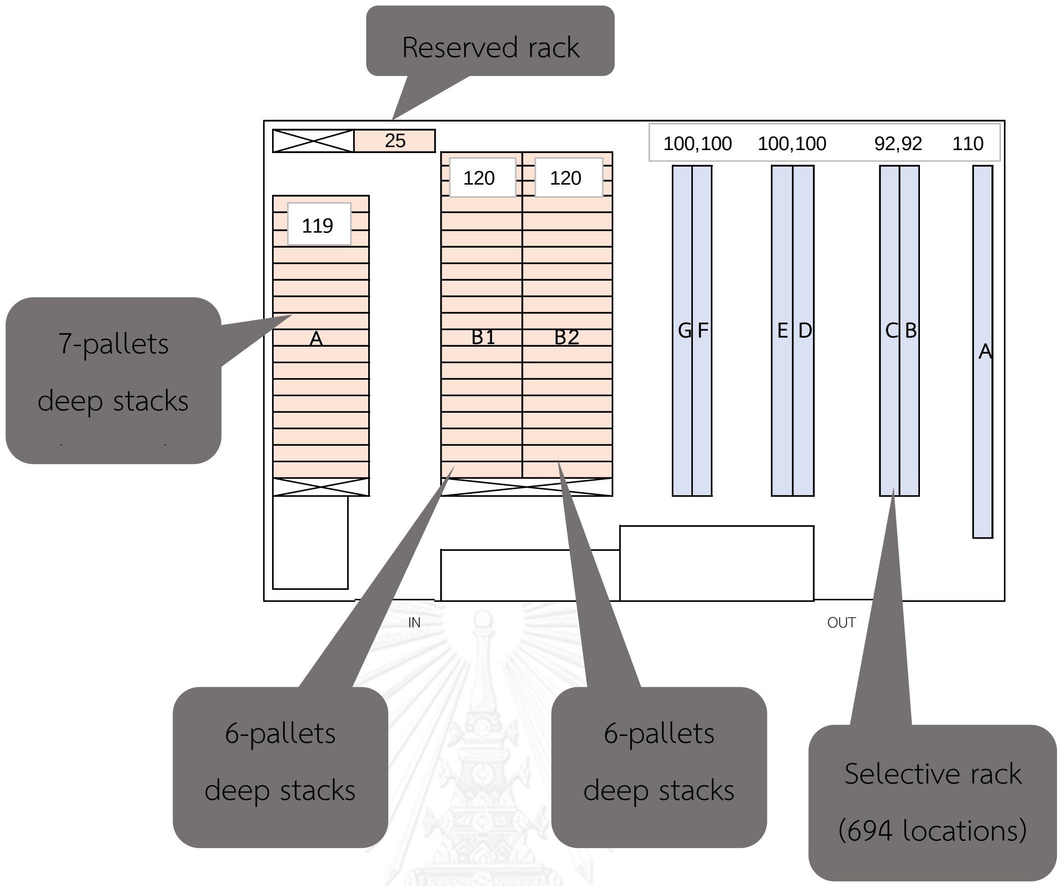


Figure 3.31: Storage Areas of Warehouse 8

For Warehouse 10, we divide the storage area into 3 zones, i.e., zone A, zone B, and zone C. Zone A and zone B are floor stack areas. Each row in both zones can locate 7 stacks. There are 21 rows in zone A and 23 rows in zone B, so the maximum capacities of zone A and zone B are 147 stacks and 161 stacks, respectively (calculating from multiplying the number of rows by the number of stacks per row). Figure 3.32 presents the floor stack area of Warehouse 10.

Figure 3.32: Floor Stack Area of Warehouse 10

Zone C is flow rack. There are 20 lanes of flow rack in zone C. Since flow rack can store 18 pallets per lane, the maximum capacities of flow rack is 360 pallets (calculating from multiplying the number of lanes by the number of pallets per lane.). Figure 3.33 presents the flow rack area of Warehouse 10.

Figure 3.33: Flow Rack Area of Warehouse 10

Figure 3.34 presents the storage areas of Warehouse 10. The number in each zone represents the number of stacks (for stack area) and the number of locations (for selective rack area).

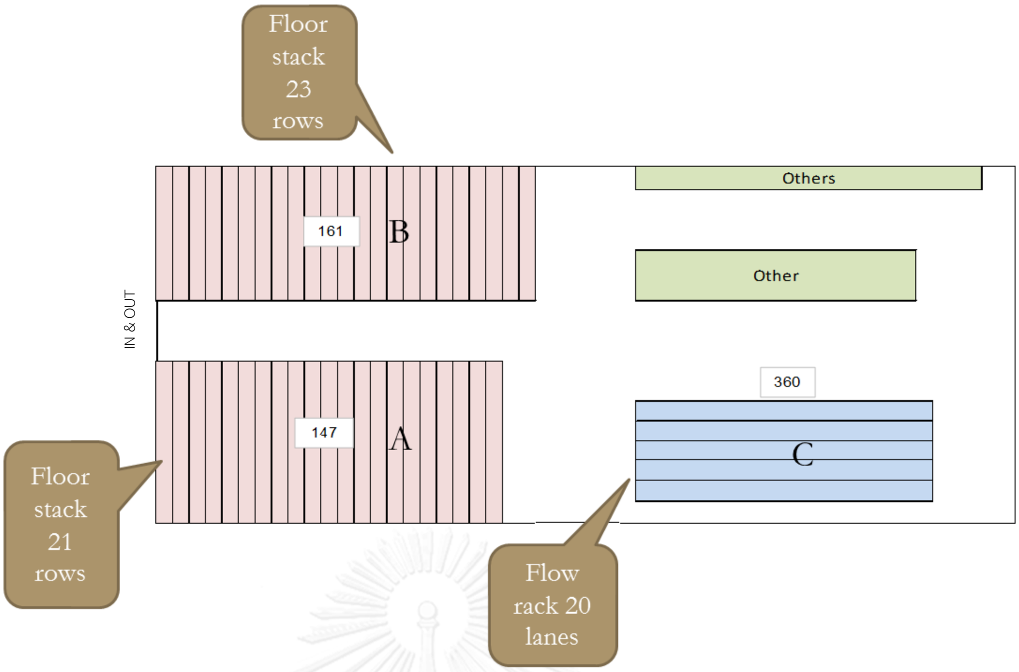


Figure 3.34: Storage Area of Warehouse 10

3.6 Conclusion of Company Data and Analysis

In order to design the layouts for Warehouse 8 and Warehouse 10, the warehouse and product information are required for developing the layouts. There are many types of product categories, e.g., sell-in-bulk and sell-in-piece products etc. Different types of product categories require different types of storages. For, the warehouse information, there are three types of storage areas, i.e., single selective rack, floor stack and flow rack. Flow rack is only available in Warehouse 10, while single-deep selective racks are only available in Warehouse 8. This research will consider the product characteristics and assign the products in the proper locations.

CHAPTER 4:
Research Methodology

This chapter describes the research methodology. The chapter starts from the conceptual design and overview of the methodology. Then, the two phases of the research are described and explained. The first phase is grouping product categories into two groups for the two warehouses. The second phase is designing layout for Warehouse 8 and Warehouse 10. The research methodology conclusion is concluded at the end of the chapter.

4.1 Conceptual Design and Overview of the Research Methodology

The studied products used to be located in Warehouse 3A, Warehouse 4, Warehouse 5, and Warehouse 8 before being relocated to Warehouse 8 and Warehouse 10. Consequently, all of the products have to be assigned to either Warehouse 8 or Warehouse 10. Therefore, the first phase of the methodology is product grouping for Warehouse 8 and Warehouse 10. After grouping, the products are assigned to their locations. Thus, the second phase is layout designing for Warehouse 8 and Warehouse 10. Briefly, there are two phases in methodology, i.e., group product categories into two groups for Warehouse 8 and Warehouse 10, and design layout for Warehouse 8 and Warehouse 10. Figure 4.1 presents the framework of the research methodology.

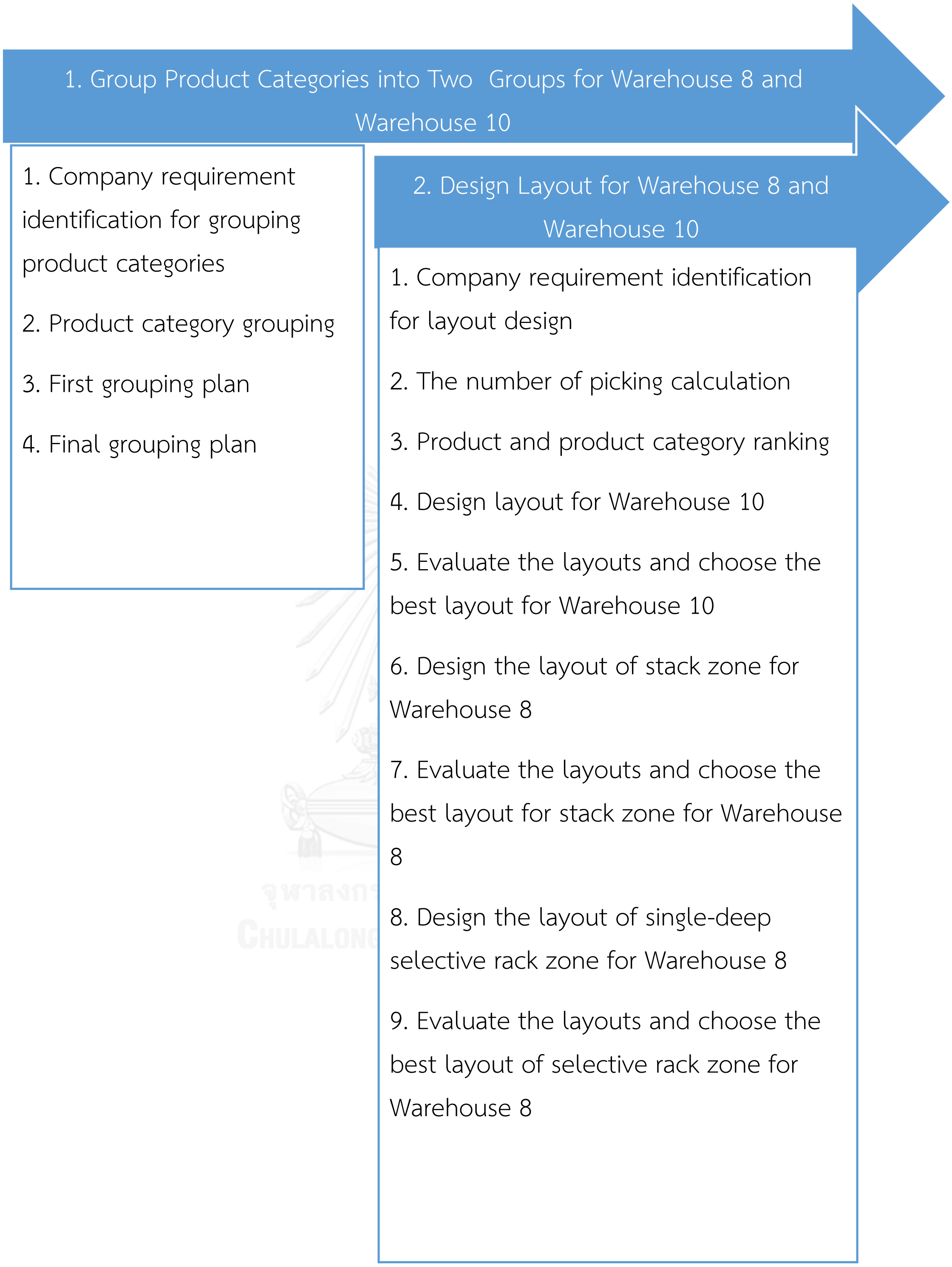


Figure 4.1: Framework of the Methodology

4.2 Group Product Categories into Two Groups for Two Warehouses

Since the company has inventory policy which is storing the same product category in the same warehouse, we have to separate the product categories into 2 groups for Warehouse 8 and Warehouse 10.

First step is understanding the company requirements and nature of the products. Then, we develop a grouping logic. After that, we have to compare the grouping plans to the warehouses' capacities. The product size data is analysed in order to calculate the space for each product category. After that the members in the groups will be adjusted. The final grouping plan is developed. Final part is the conclusion of product category grouping for Warehouse 8 and Warehouse 10. 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. Figure 4.2 summarises the product category grouping process. Figure 4.3 presents the flow process chart of each step in the grouping phase.

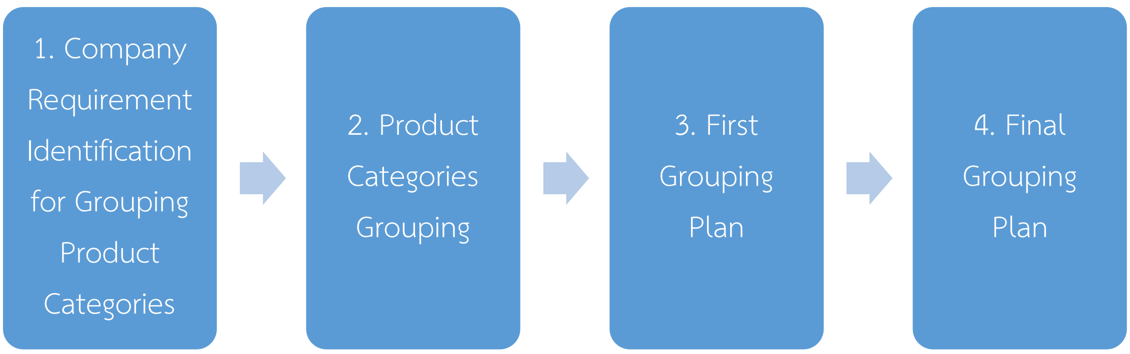


Figure 4.2: Product Category Grouping Process

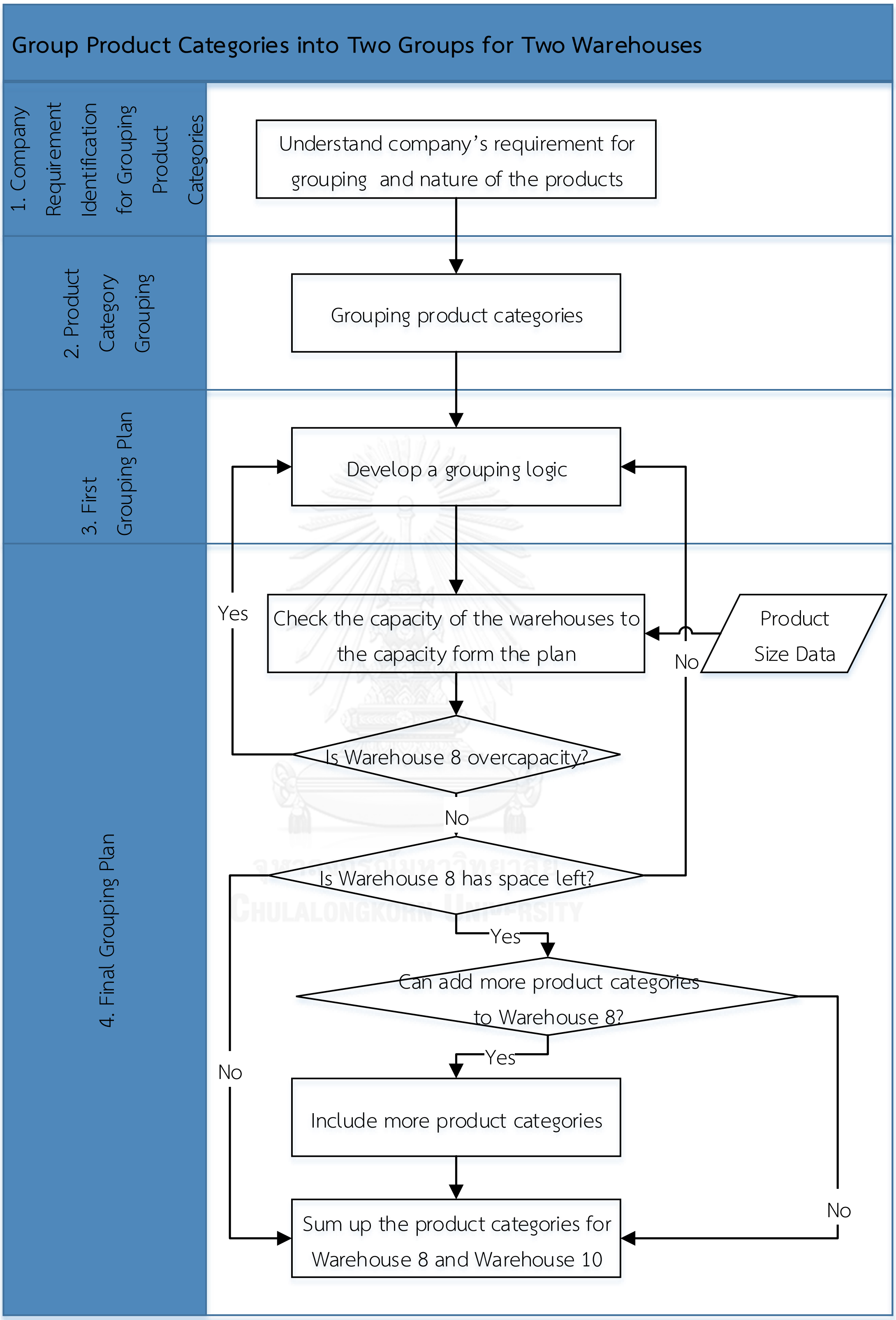


Figure 4.3: Flow Process Chart of Product Category Grouping for Two Warehouses

4.2.1 Company Requirement Identification for Grouping Product Categories

Before grouping the product categories, it is important to understand the company requirements. First requirement is storing products in the safe location. This requirement is the most important requirement of the company. The company requires to locate fragile products and sell-in-piece products in Warehouse 8. For fragile products, locating them on rack can reduce the chances of accidental breaks. For sell-in-piece products, specifying the products' locations can decrease the picking time. The picker will not waste time finding the products. Second requirement is storing in-house products in Warehouse 8. Since, the production warehouse is close to the Warehouse 8, the company also requires to locate in-house products in Warehouse 8. Third requirement is locating as many product as possible in Warehouse 8. Because Warehouse 8 is the main warehouse of the company, it is close to the shipping area. Storing many products in Warehouse 8 can facilitate warehouse activities for the warehouse manager and warehouse supervisors.

4.2.2 Product Category Grouping

According to the company requirements and product category characteristic, we categorise product categories into 4 groups, i.e., Fragile Products, In-house Products, Sell-in-piece Products, and Sell-in-bulk Products. The product categories are categorised by the characteristic of the majority products in the product category. Exothermic Sleeves & Powder, Mica Product & Insulation, Temperature & CE Products & Service, Non-Ferrous Product & Other Fluxes, and Ceramic Product mainly contain fragile products, so these product categories are defined as Fragile Products. The company produces some of products from Refractor Castable and Refractor Plastic & Other, so these two product categories are In-house Products. Product categories that are sold individually can be defined as Sell-in-piece Products. Consequently, Adhesive Products and Parting & Release Agent are Sell-in-piece Products. The others, i.e., Refractories Lining, Coatings, Special Alloys-Inoculant/ Magnesium, Sand Slag, Other Chemical, Raw Material for Refractory Production, and Fluxes are Sell-in-bulk Products. Table 4.1 presents the four groups of product categories.

Table 4.1: 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

4.2.3 First Grouping Plan

After dividing product categories into 4 groups, third step is to plan product categories for both warehouses. This plan is the first grouping plan. This plan groups product categories based on the company requirements. Fragile

Products, In-house Products and Sell-in-piece Products are planned to be located in Warehouse 8. In-house Products are planned to be located in Warehouse 8, because Warehouse 8 is close to the production warehouse. Since there are single-deep selective racks in Warehouse 8, single-deep selective racks can protect the Fragile Products and Sell-in-piece Products from any damages. Sell-in-bulk Products are planned to be located in Warehouse 10. Table 4.2 presents the first grouping plan.

Table 4.2: First Grouping Plan

Warehouse 8		Warehouse 10	
CID	Product Category	CID	Product Category
07	Exothermic Sleeve	23	Other Chemical
3	Refractories Lining	13	Fluxes
22	Refractory Plastic	20	Sand Slag
25	Parting & Releasing Agent Product	6	Coating
8	Mica	26	Raw Material for Refractories
14	Adhesive Product	12	Special Alloy
9	Temperature & CE Product	2	Foundry Sand
18	Ceramic Product		
17	Non-ferrous Product		
21	Refractor Castable		

4.2.4 Final Grouping Plan

Warehouse 8 is the main warehouse of the company. Consequently, the company requires to store product categories as many as possible in Warehouse 8. In order to store many product categories as possible. After planning, we have to compare the capacity from first plan to the full capacities of the warehouses. If there are any remaining locations for any product categories which are firstly planned to be located in Warehouse 10, that product categories will be located in Warehouse 8 instead. If the capacity from the first plan required more capacity than the full capacity of the Warehouse 8, the product categories which are least important to be located in Warehouse 8, in-house product categories, will be located in Warehouse 10 instead. There are 5 steps to compare the capacities from the first plan to the full capacity of the warehouses. Figure 4.4 presents the five steps in order.

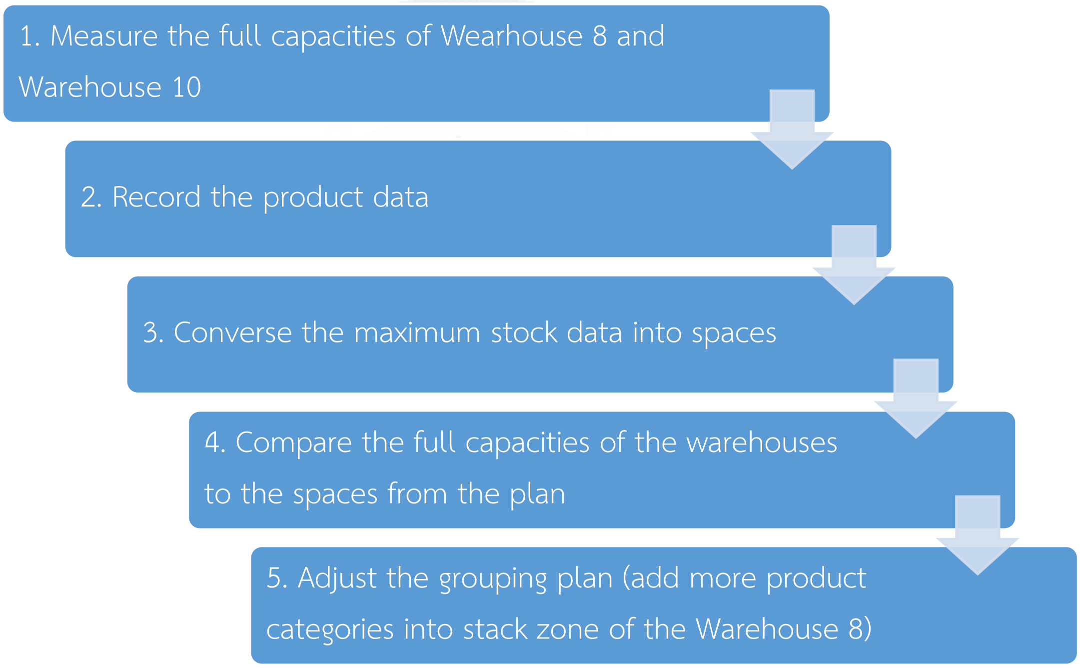


Figure 4.4: Five Steps for Comparing the Capacity of First Plan to the Full Capacity of Warehouse 8

4.2.1 <u>Measure the full capacities of Warehouse 8 and Warehouse 10</u>

Since there is no warehouse capacities data of Warehouse 8 and Warehouse 10, so this research measures the full capacities of both warehouses.

Full capacity of Warehouse 8 is 359 stacks (floor stack area) and 694 pallets (single-deep selective rack). For Warehouse 10, full capacity is 308 stacks (floor stack area) and 270 pallets (flow rack). Figure 4.5 and Figure 4.6 present internal layouts and storage options of Warehouse 8 and Warehouse 10, respectively.

For Warehouse 8, the pink area is the floor stack area and the blue area is the single-deep selective rack. For Warehouse 10, the pink area is the floor stack area and the blue area is the flow rack area.

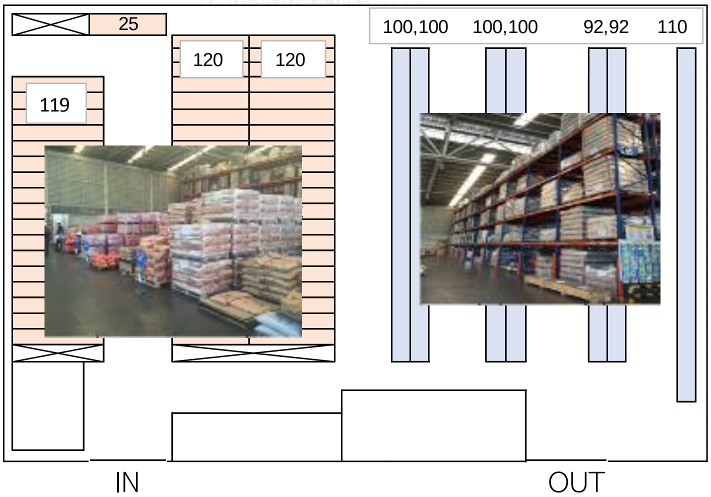


Figure 4.5: Internal Layout and Storage Options of Warehouse 8

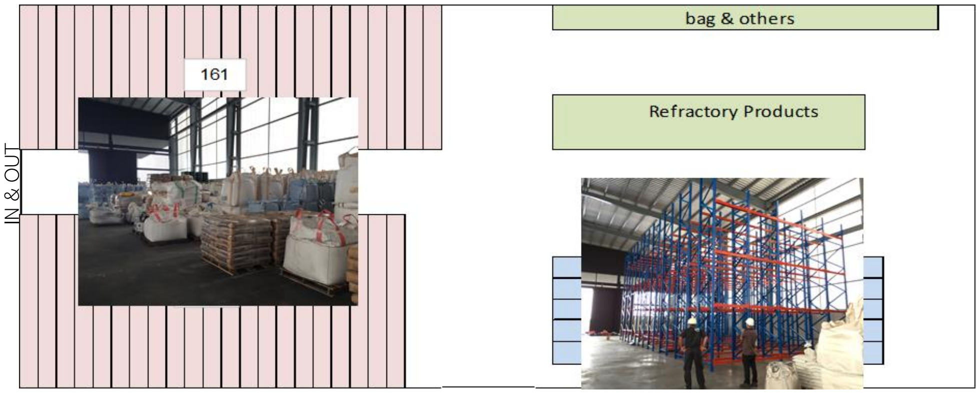


Figure 4.6: Internal Layout and Storage Options of Warehouse 10

4.2.2 Record the product data.

In order to calculate the required space for each product category, stock data and product size data are required. Since the company does not have product size data, this research involves collecting product size data. We develop the collecting form in order to collect all product size data. Product size collecting form and example of completed form are presented in Table 3.5 and Table 3.6 in CHAPTER 3: Company Data and Analysis.

4.2.3 Converse the maximum stock data into space

This research uses the product size data for calculating the required space for each product. The maximum stock data of 2014 are the representatives of maximum holding stock.

There are two methods of space calculation. First method is dividing the maximum stock data by units/pallet. This method is for non-sell-in-bulk products, i.e., Fragile Products, In-house Products, and Sell-in-piece Products, because these products are stored on pallets. The number of units per pallet affects the number of picking. Second method is dividing the maximum stock data by units/stack. This method is for Sell-in-bulk Products. Since we can overlay the products in stack, the maximum units/stack affects the number of picking.

Both methods result in maximum individually required spaces for holding stocks. We calculate the required spaces of all 198 products.

Figure 4.7 demonstrates how to calculate space for a non-sell-in-bulk product. We divide maximum stock data of the product (6,857 units) by units/pallet of the product (2,240 units) and round up the number. The result is the required spaces of the non-sell-in-bulk product (4 pallets).

Figure 4.8 demonstrates how to calculate space for a sell-in-bulk product. We divide maximum stock data of the product (76,504 kg) by units/stack of the product (2,000 kg) and round up the number. The result is the required spaces of the non-sell-in-bulk product (39 stacks).

$$\frac{6,857}{2,240} = 3.061 \approx 4 \text{ Pallets}$$

Figure 4.7: An Example of Space Calculation of a Non-sell-in-bulk Product

$$\frac{76,504}{2,000} = 38.25 \approx 39 \text{ Stacks}$$

Figure 4.8: An Example of Space Calculation of a Sell-in-bulk Product

4.2.4 <u>Compare the full capacities of the warehouses to the spaces from the plan</u>

We sum up the total space requirement for each product category by adding required spaces of all products in the same product category together.

Table 4.3 is the summary of space requirement of all product categories. Then, we can conclude the first plan's space requirement for Warehouse 8 and Warehouse 10 as presented in Table 4.4 and Table 4.5, respectively.

Table 4.3: Space Requirement of All Products

CID	Product Category	# of Stacks	# of Pallets
7	Exothermic Sleeve	15	247
3	Refractories Lining	210	13
22	Refractory Plastic	36	77
25	Parting & Releasing Agent Product	0	52
8	Mica	0	35
14	Adhesive Product	0	18
9	Temperature & CE Product	0	43
18	Ceramic Product	0	34
17	Non-ferrous Product	13	44
21	Refractor Castable	21	0
23	Other Chemical	13	0
13	Fluxes	4	0
20	Sand Slag	135	0
6	Coating	55	0
26	Raw Material for Refractories	63	0
12	Special Alloy	55	0
2	Foundry Sand	64	0
Total		684	563

Table 4.4: First Plan's Space Requirement for Warehouse 8

Warehouse 8			
CID	Product Category	# of Stacks	# of Pallets
7	Exothermic Sleeve	15	247
3	Refractories Lining	210	13
22	Refractory Plastic	36	77
25	Parting & Releasing Agent Product	0	52
8	Mica	0	35
14	Adhesive Product	0	18
9	Temperature & CE Product	0	43
18	Ceramic Product	0	34
17	Non-ferrous Product	13	44
21	Refractor Castable	21	0
Total		295	563

Table 4.5: First Plan's Space Requirement for Warehouse 10

Warehouse 10			
CID	Product Category	# of Stacks	# of Rows
23	Other Chemical	13	2
13	Fluxes	4	1
20	Sand Slag	135	23
6	Coating	55	9
26	Raw Material for Refractories	63	11
12	Special Alloy	55	9
2	Foundry Sand	64	11
Total		389	66

Since Warehouse 8 is the main warehouse and close to the shipping area, Warehouse 8 should contain as many product categories as possible. The plan requires 563 locations of single-deep selective racks and 295 stacks, while the full capacity of Warehouse 8 is 694 single-deep selective rack locations and 359 stacks. Therefore there are some vacant spaces in Warehouse 8; 131 single-deep selective rack locations and 64 stacks.

4.2.5 Adjust the grouping plan (Add more product categories into stack zone of the Warehouse 8)

Since there are left spaces in Warehouse 8, we can add more product categories to Warehouse 8. The plan has already located all products that are suitable for single-deep selective racks in warehouse 8, so we will add only Sell-in-bulk Products into the stack zone of Warehouse 8. We will move the product categories from Warehouse 10 which are fit to the vacant spaces of Warehouse 8.

There are two stack zones in warehouse 8, i.e., stack zone A and stack zone B (zone B1 and zone B2) as presented in Figure 4.9.Stack zone A contains 17 rows (7 stacks/row), while stack zone B contains 40 rows (6 stacks/row). Reserved rack is not in the scope of this research. We locate products which are not in the scope of this research to the reserved rack.

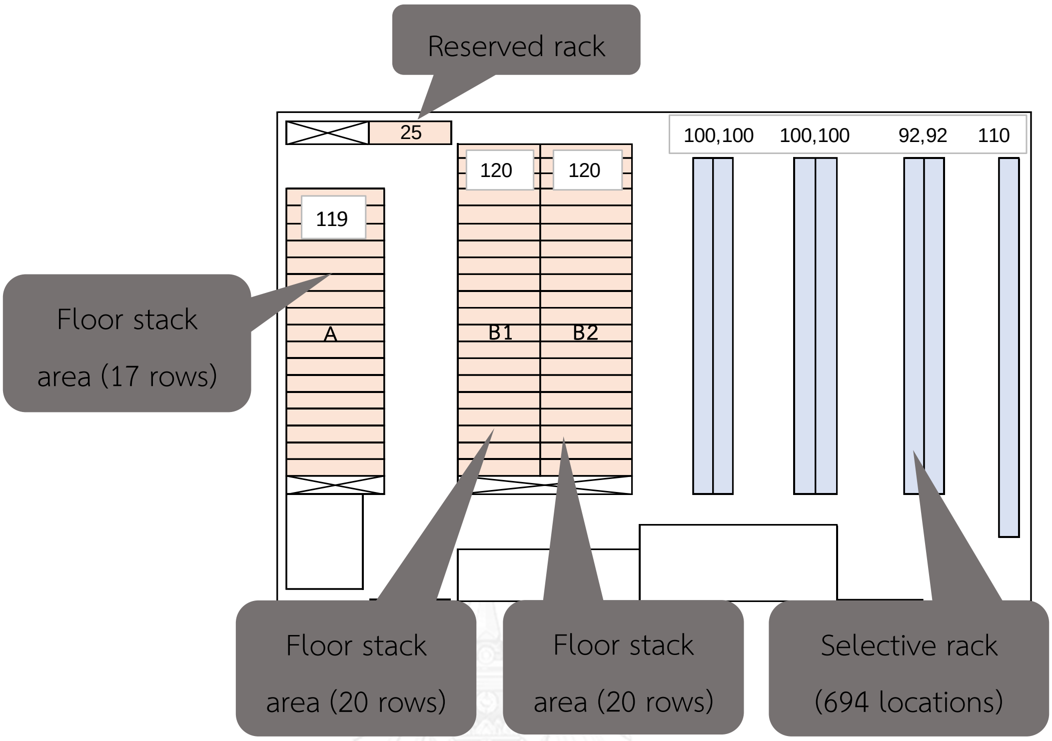


Figure 4.9: Stack Zones of Warehouse 8

Before adding more product categories into stack zone, we have to converse 295 stacks of products into the number of rows. We assign 1 row for 1 type of product. The products in Warehouse 8 from the first plan are called first priority products.

Since the products in first plan have priority over the new-coming products, we will assign the locations for the first priority products in space-saving locations without concerning the product category constraints (locating the same product category in the same storage area). The products which gives the higher number of differences rows between 6-stacks-deep rows and 7-stack- deep rows will be temporarily assign to the 7-stacks-deep rows (Zone A) without concerning the product category. This process will give the maximum possible number of vacant rows.

We divide the number of the stacks by the number of stacks in a row for zone A and zone B. Then, we round up the number of required rows and compare the number of rows. For example, the product requires spaces of 56 stacks. If we locate the product in Zone A, it requires 8 rows, it requires 10 rows in zone B. We locate this product in zone A, because zone A requires less number of rows than zone B. The calculation for zone A and zone B are presented in Figure 4.10 and Figure 4.11, respectively.

$$\frac{56}{7} = 8 \text{ Rows}$$

Figure 4.10: An Example of Number of Rows in Zone A Calculation

$$\frac{56}{6} = 9.33 \approx 10 \text{ Rows}$$

Figure 4.11: An Example of Number of Rows in Zone B Calculation

After locating first priority products in space-saving locations, it is found that there are 8 vacant rows as shown in Figure 4.12 (the blue colour rows are the assigned rows while the pink rows are the vacant rows).

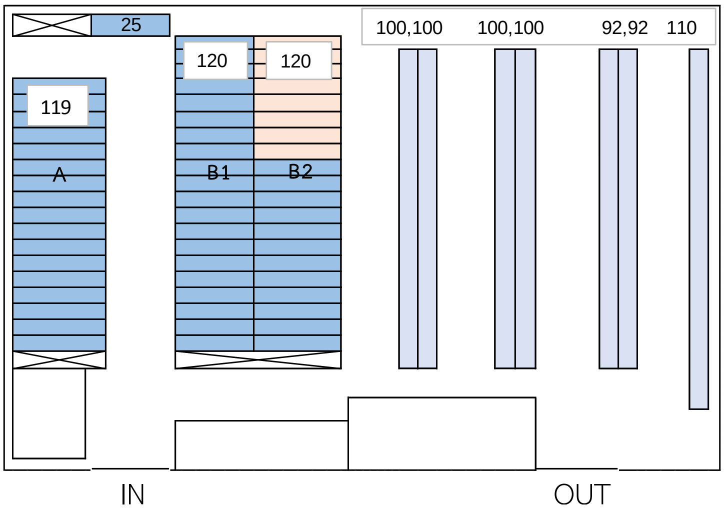


Figure 4.12: First Floor Stack Layout of Warehouse 8

After that, we consider the product categories which are firstly planned to be located in Warehouse 10. The number of required stacks for products are conversed into the number of required rows (6-stacks-deep rows). It is found that there are two product categories which required not more than 8 rows of floor stacks.

As presented in Table 4.6, Other Chemical and Fluxes require 2 and 1 rows of floor stacks, respectively. The total required rows of Other Chemical and Fluxes are less than the available rows, while other possible cases will require more rows than the left rows. Therefore, Other Chemical and Fluxes are additionally added into Warehouse 8. Table 4.6 also presents the number of required rows for all product categories which are firstly planned to be located in Warehouse 10 (Sell-in-bulk Products). For Warehouse 10, Warehouse 10 is a new warehouse. It is flexible and able to expand the storage space. So, there is enough storage space for Warehouse 10.

Table 4.6: The Number of Required Rows of Sell-in-bulk Products

CID	Product Category	# of Required Rows (6-stacks-deep rows)
23	Other Chemical	2
13	Fluxes	1
20	Sand Slag	23
6	Coating	9
26	Raw Material for Refractories	11
12	Special Alloy	9
2	Foundry Sand	11

As a result, there are twelve product categories located in Warehouse 8, i.e., Exothermic Sleeve, Refractories Lining, Refractory Plastic, Parting & Releasing Agent Product, Mica, Adhesive Product, Temperature & CE Product, Ceramic Product, Non-ferrous Product, Refractor Castable, Other Chemical, and Fluxes. There are five product categories located in Warehouse 10, i.e., Sand Slag, Coating, Raw Material for Refractories, Special Alloy, and Foundry Sand. The summary of product categories for both warehouse is presented in Table 4.7.

Table 4.7: Product Categories for Warehouse 8 and Warehouse 10

Warehouse 8		Warehouse 10	
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		

4.2.5 Conclusion of Product Category Grouping

In order to group product categories into 2 groups for Warehouse 8 and Warehouse 10, we have to understand the company requirements and product characteristics. We develop the first grouping plan by assigning the Fragile Products, In-house Products, and Sell-in-piece Products to Warehouse 8. Then, we add some Sell-in-bulk Products to Warehouse 8. The Final Grouping plan is the final result of this research methodology phase. The process in all steps of Product category Grouping and the results of each step are concluded in Table 4.8.

Table 4.8: Conclusion of Steps in Product Category Grouping

No.	Step	Process	Result
1.	Company Requirement Identification for Grouping Product Categories	1) Identify the company requirements for grouping product categories	1) Understand company requirements; • Store products in safe locations • Store in-house products in Warehouse 8 • Store as many products as possible in Warehouse 8
2.	Product Category Grouping	1) Group product categories into 4 groups based on the product category characteristics	1) Four groups of product categories • Fragile Products • In-house Products • Sell-in-piece Products • Sell-in-bulk Products
3.	First Grouping Plan	1) Assign the 4 groups of product categories to Warehouse 8 and Warehouse 10	1) Warehouse 8; Fragile Products, In-house Products, and Sell-in-piece Products

			2) Warehouse 10; Sell-in-bulk Products
4.	Final Grouping Plan	1) Measure the full capacities of Warehouse 8 and Warehouse 10 2) Record the product data 3) Converse the maximum stock data into spaces 4) Compare the full capacities of the warehouses to the spaces from the plan 5) Adjust the grouping plan (Add more product categories into stack zone of the Warehouse 8)	1) Full capacities of Warehouse 8 and Warehouse 10 2) Completed product size Data 3) The required spaces for all products and product categories 4) Required spaces from the first plan 5) The vacant spaces from the first plan 6) The final plan

4.3 Design Layout for Warehouse 8 and Warehouse 10

After dividing product categories into two groups for Warehouse 8 and Warehouse 10, second phase is designing the layouts of Warehouse 8 and Warehouse 10.

The methodology starts from identifying company's layout requirements. Then, we rank the number of picking of product categories and products. After that, we design the layouts of Warehouse 10, stack zone of Warehouse 8, and single-deep selective rack zone of Warehouse 8. The layouts are evaluated from the qualitative and quantitative results. Finally, the best layouts are chosen. Figure 4.13 summarise the layout designing process. Figure 4.14 presents the flow process chart of designing layout for Warehouse 8 and Warehouse 10.

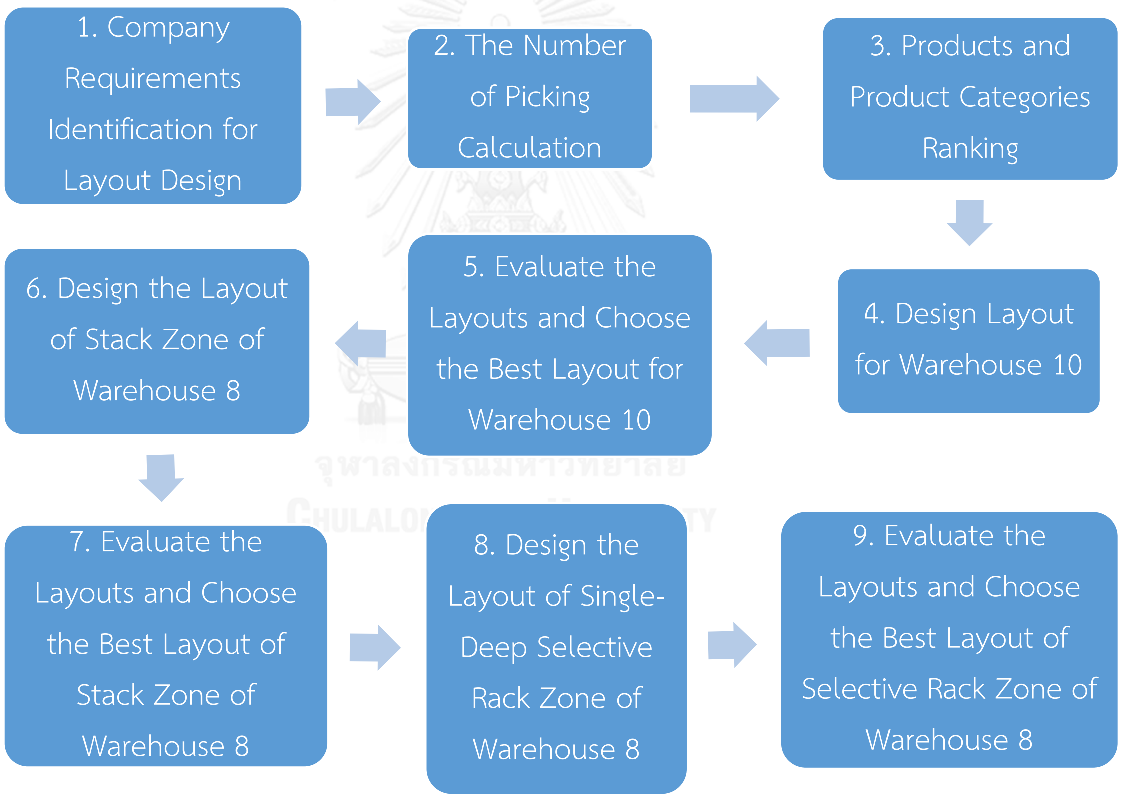


Figure 4.13: Layout Designing Process

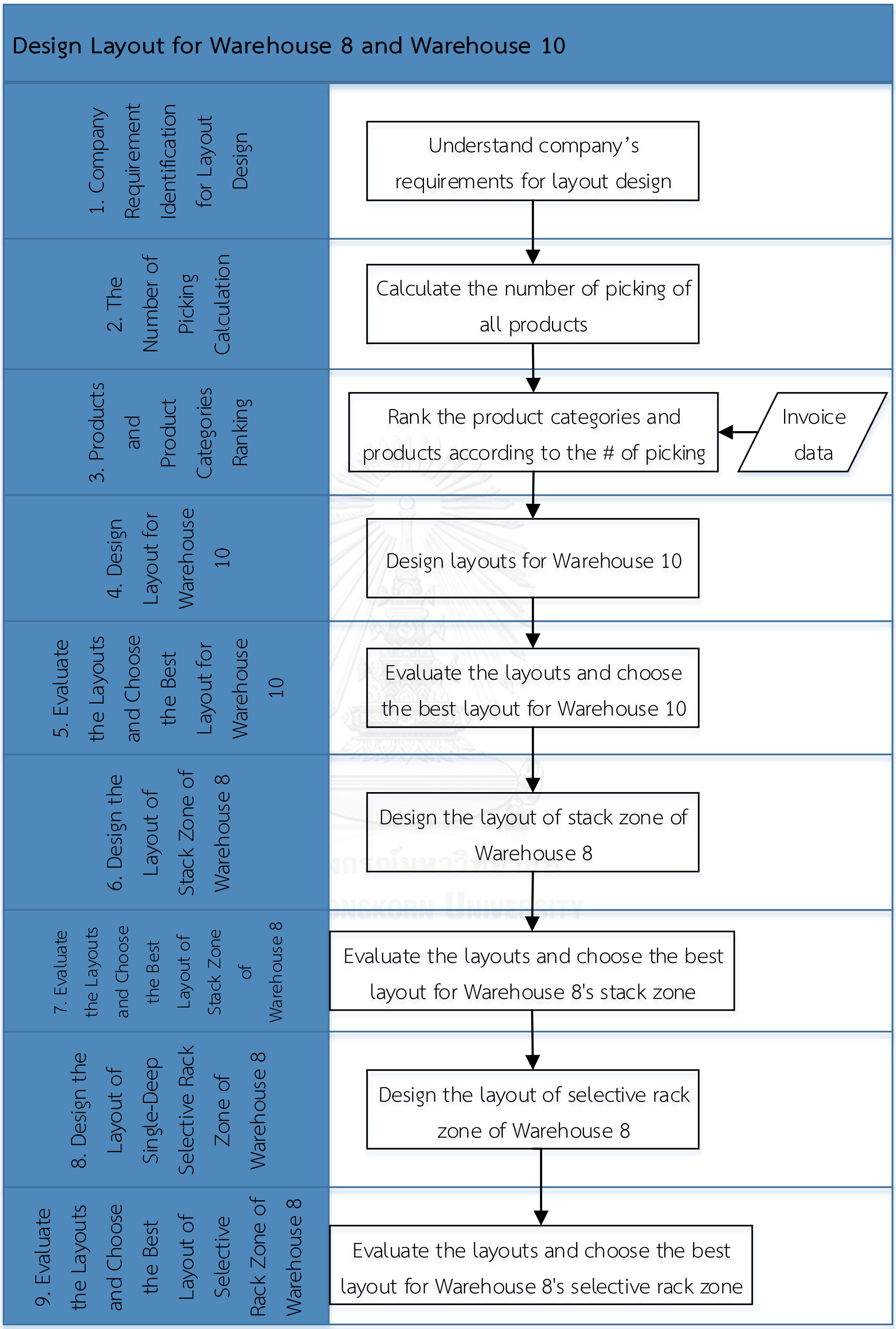


Figure 4.14: Flow Process Chart of Designing Layout for Warehouse 8 and Warehouse 10

4.3.1 Company Requirements Identification for Layout Design

It is important to understand the layout requirements of the company. First requirement is storing same product category in the same area, so we separated locations of all product categories into 3 locations, i.e., Warehouse 10, stack zone of Warehouse 8, and single-deep selective rack of Warehouse 8. Second requirement is determining the products' locations according to the frequency of picking. Third requirement is maximizing space utilization. Space utilization is to locate products under to theirs constraints and in space-saving locations. Some product categories have specific constraints depending on the characteristics of the products. Table 4.9 presents the layout constraints of all product categories. We have to take these requirements and constraints into account when we develop the layouts for Warehouse 8 and Warehouse 10.

Table 4.9: Layout Constraints of Product Categories

	CID	Product Category	Constraint
Warehouse 8	7	Exothermic Sleeve	1. Sort by product family and size
	3	Refractories Lining	-
	22	Refractory Plastic	1. Sort by product family
	25	Parting & Releasing Agent Product	-
	8	Mica	1. Sort by product family. 2. Some products have to be stored on the floor
	14	Adhesive Product	1. Sort by product family
	9	Temperature & CE Product	-
	18	Ceramic Product	1. Sort by product family and size

	17	Non-ferrous Product	1. A product has to be stored on the floor
	21	Refractor Castable	-
	23	Other Chemical	-
	13	Fluxes	-
Warehouse 10	20	Sand Slag	-
	6	Coating	-
	26	Raw Material for Refractories	-
	12	Special Alloy1 (Non-Pack)	-
	2	Foundry Sand	-

4.3.2 The Number of Picking Calculation

In order to calculate the number of picking, we have to request invoice data from IT department and change the order quantity into number of picking. The invoices in 2014 are the representatives. Number of picking depends on maximum load of handling equipment and maximum number of retrieved products per picking. Reach trucks are used in picking process. The maximum load of the reach trucks is 2,000 kg. Most of non-sell-in-bulk products are not heavier than 2,000 kg, consequently, the number of picking of non-sell-in-bulk product depends on the maximum number of retrieved products per picking.

Figure 4.15 is an example of conversing an invoice of non-sell-in-bulk product into number of picking. The invoice requests 800 units of product. Maximum number of retrieved products per picking is 2,240 units. After dividing 800 by 2,240 and rounding up the number, the result is the number of picking for that invoice.

$$\frac{800}{2,240} = 0.36 \approx 1 \text{ Pick}$$

Figure 4.15: An Example of Conversing Invoice into Number of Picking for a Non-sell-in-bulk Product

For sell-in-bulk products, the maximum load limits the number of picking. For instance, the product weights 1,200 kg per pallet. The maximum number of pallets per picking of this product is 1 pallet, because the reach truck cannot lift heavier than 2,000 kg. Two pallets of this product will heavier than the limit of the reach truck. Figure 4.16 is an example of conversing an invoice of a sell-in-bulk product into number of picking. The invoice requests 6,000 kg of the product. Maximum pallet per picking is 1 pallet (1,200 kg) as mentioned. Dividing 6,000 by 1,200 and rounding up the number, the result is the number of picking of for this invoice. We calculate the number of picking for every invoice.

$$\frac{6,000}{1,200} = 5 \text{ Picks}$$

Figure 4.16: An Example of Conversing Invoice into Number of Picking for a Sell-in-bulk Product

To sum up, the number of picking of non-sell-in-bulk products and sell-in-bulk products can be calculated differently. For non-sell-in-bulk products, we divide the number of products from the invoice by the number of units in a pallet. For sell-in-bulk products, we divide the number of products from invoice by the maximum number of units per retrieving. Table 4.10 presents the conclusion of the number of picking calculation.

Table 4.10: Conclusion of the Number of Picking Calculation

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

4.3.3 Products and Product Categories Ranking

We sum the number of picking from all of invoices in 2014 for each product and product category. Then, we rank products and products categories of Warehouse 8 and Warehouse 10 from highest number of picking to least number of picking.

For Warehouse 8, the most frequently picked product is Exothermic Sleeve. It is found that although Refractory Plastic has higher number of invoices than Refractories Lining, Refractories Lining has higher number of picking than Refractory Plastic. Because Refractories Lining is likely to be sold in large scale. Consequently, Refractories Lining has higher frequency of picking than Refractory Plastic. Fluxes is the lowest number of picking product category in Warehouse 8.

For Warehouse 10, Sand Slag is the most frequently picked product, while Foundry Sand is the least frequently picked product.

Table 4.11 and Table 4.12 show the number of invoices and number of product category picking in Warehouse 8 and Warehouse 10, respectively. The product categories are ranked from the highest number of picking to the least number of picking. The products in each category are ranked in order similarly to product categories. Table 4.13 is an example of ranking in product level (Temperature & CE Product).

Table 4.11: Rank of Product Category in Warehouse 8

Warehouse 8			
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 4.12: Rank of Product Category in Warehouse 10

Warehouse 10			
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

Table 4.13: Rank of Temperature & CE Product

Temperature & CE Product	# of picking	Rank
Temperature-SKU-1	179	1
Temperature-SKU-2	144	2
Temperature-SKU-3	94	3
Temperature-SKU-4	90	4
Temperature-SKU-5	55	5
Temperature-SKU-6	27	6
Temperature-SKU-7	15	7
Temperature-SKU-8	5	8
Temperature-SKU-9	1	9
Total	610	

To sum up, we rank the product categories of Warehouse 8 and Warehouse 10 using the number of picking from the last step. We also rank the number of picking of products for every product category. Figure 4.17 presents the conclusion of products and product categories ranking process.

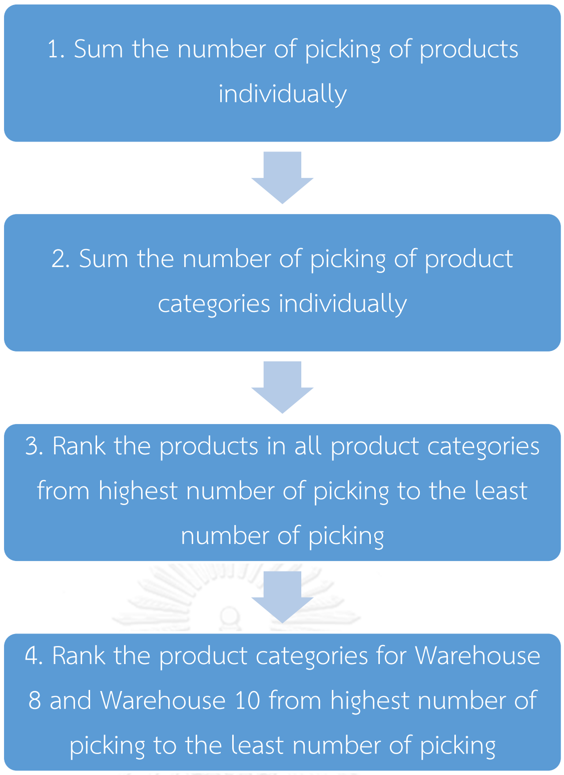


Figure 4.17: Conclusion of Products and Product Categories Ranking

4.3.4 Design Layout for Warehouse 10

We design the layout of Warehouse 10 based on the ranking of product categories and products. For Warehouse 10, there are 3 zones of storage as presented in Figure 4.18. Zone A and zone B are floor stack areas. Zone A and zone B can line up 23 and 21 rows of 7-stacks-deep, respectively. For zone C, there is 20 lanes of 18-pallets-deep flow rack.

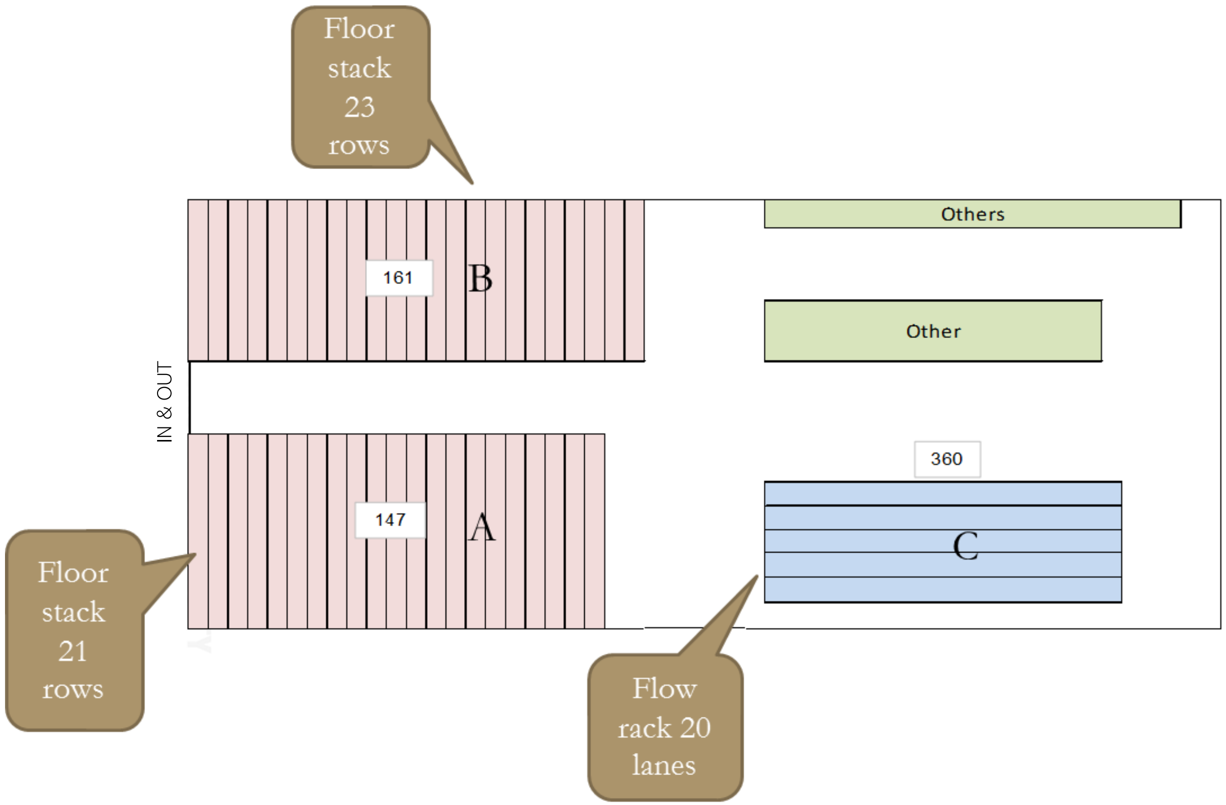


Figure 4.18: Three Zones of Warehouse 10

The required space for each product is calculated in stacks and lanes. For row calculation, we have to divide the number of stacks by the number of stacks per row. For lane calculation, we have to divide the number of pallets by the number of pallets per lane.

Figure 4.19 is an example calculation of the number of required rows. Maximum holding stocks of product A equals to 96 pallets. The maximum pallet per 1 stack is 5 pallets. For, the number of required row, we divide 96 by the maximum number of pallets per stack. The result is the number of stacks of product A. Then, we divide the result by 7, which is the number of stacks per row, and round the number. The final result is the number of required rows for product A.

$$\frac{96}{5} = 19.2 \approx 20 \text{ Stacks}$$

$$\frac{20}{7} = 2.86 \approx 3 \text{ Rows}$$

$\therefore$Product A requires 3 rows

Figure 4.19: Example of the Number of Required Rows of Product in Warehouse 10 Calculation

For the flow rack's lane, we assign 1 lane for 1 type of product. Figure 4.20 shows an example calculation of the number of required lanes. The maximum pallets per lane is 18 pallets. We divide the maximum holding stocks (in pallets) by 18 pallets and round up the number. The result is the number of required lanes for product A.

$$\frac{96}{18} = 5.33 \approx 6 \text{ Lanes}$$

∴Product A requires 6 lanes

Figure 4.20: Example of the Number of Required Lanes of Product in Warehouse 10 Calculation

The products within each product category are ranked from the highest picking frequency to the lowest picking frequency. Then, we sum up the number of picking of products in the same product categories. The order of product categories are ranked from the highest number of product category picking to the lowest number of product category picking. Table 4.14 summarises the number of picking, the number of stack rows, and number of flow rack lanes for each product and product category. Sand Slag has the highest number of picking, while Foundry has the least number of picking.

Table 4.14: The number of stack's rows and flow rack's lanes of Product Categories in Warehouse 10

NO	Sand Slag	# of picking	# of stacks	# of rows	# of lanes
1	Sand Slag-SKU-1	1182	90	13	15
2	Sand Slag-SKU-2	112	30	5	3
3	Sand Slag-SKU-3	109	15	3	2
NO	Coating	# of picking	# of stacks	# of rows	# of lanes
1	Coating-SKU-1	409	15	3	2
2	Coating-SKU-2	121	22	4	3
3	Coating-SKU-3	77	9	2	1

4	Coating-SKU-4	52	9	2	1
NO	**Raw Material for Refractory**	**# of picking**	**# of stacks**	**# of rows**	**# of lanes**
1	Raw Material-SKU-1	649	63	9	11
NO	**Special Alloy**	**# of picking**	**# of stacks**	**# of rows**	**# of lanes**
1	Special Alloy-SKU-1	109	12	2	4
2	Special Alloy-SKU-2	79	10	1	3
3	Special Alloy-SKU-3	69	12	2	4
4	Special Alloy-SKU-4	67	4	1	2
5	Special Alloy-SKU-5	60	2	1	1
6	Special Alloy-SKU-6	34	2	1	1
7	Special Alloy-SKU-7	29	2	1	1
8	Special Alloy-SKU-8	17	4	1	2
9	Special Alloy-SKU-9	16	2	1	1
10	Special Alloy-SKU-10	5	5	1	1
NO	**Foundry Sand**	**# of picking**	**# of stacks**	**# of rows**	**# of lanes**
1	Foundry Sand-SKU-1	155	34	5	10
2	Foundry Sand-SKU-2	91	14	2	4
4	Foundry Sand-SKU-3	70	16	3	5

The candidate layouts for Warehouse 10 are developed using the results from the calculation. For both Warehouse 8 and Warehouse 10, we want to reduce the total picking distance and locate products in the space-saving space.

Class-Based Turnover Assignment concept is adopted in this research. Products and 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.

In this research, we start from developing Layout#1 of Warehouse10. Then, we find alternative ways to improve the layouts. Thus, Layout#2, Layout #3, and Layout#4 of Warehouse 10 is developed. There are 4 candidate layouts of Warehouse 1. We describe Layout#1 and Layout#2 in this chapter. We describe Layout#3 and Layout#4 in Appendix A.

Layout#2 is the best layout, the other three layouts are not as better as Layout#2. The concepts of all candidate layouts are different. The difference between Layout#1 and Layout#2 is how to locate products in flow rack. Layout#1 firstly locates the least number of picking products in flow rack, while Layout#2 locates the least number of pallets/stack products in flow rack. The concept of Layout#2 is to locate the same product category in the same location, while Layout#3 and Layout#4 separate one product category at the beginning of designing. Layout#4 locates one product in one row, while Layout#2 locates product in space-saving location, e.g., locate product in the last row transversely. Table 4.15 presents the layout designing concepts of all candidate layouts of Warehouse 10.

Table 4.15: The Layout Designing Concepts of Warehouse 10

Layout#1

- Firstly, we locate least picking number product categories which have less than 4 pallets/stack to flow rack.
- Secondly, we try to utilize all lanes in the flow rack.
- Thirdly, we locate the higher number of picking products closer to the warehouse gate and locate the products in the same product category together. We allow to locate products in last row transversely.

↓

Layout#2

- Firstly, we locate the products that have less than 4 pallets/stack to flow rack without considering the number of picking.
- Secondly, we locate the product categories in stack area and flow rack in space-saving location. The higher number of picking products are located closer to the gate. We allow to locate product in last row transversely.

↓

Layout#3

- Firstly, we locate the products that have less than 4 pallets/stack to flow rack without consider the number of picking.
- Secondly, we separately locate two Sand Slag products in two zone of stack area (Sand Slag-SKU-1 in Zone A and locate Sand Slag-SKU-2 in Zone B)

- Thirdly, we locate the higher number of picking products and product categories close to the gate. We allow to locate products in last row transversely.

Layout#4
• Firstly, we locate the products that have less than 4 pallets/stack to flow rack without consider the number of picking. • Secondly, we separately locate two Sand Slag products in two zone of stack area (Sand Slag-SKU-1 in Zone B and locate Sand Slag-SKU-2 in Zone A) • Thirdly, we locate the higher number of picking products and product categories close to the gate. We assign 1 type of product in 1 row. We do not allow to locate products in last row transversely.

1) Layout#1 of Warehouse 10

The designing concept of this layout is locating the least number of picking products to the flow rack and considering the space-saving condition at the same time. We consider from the least 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 stack area.

First, we consider Foundry Sand, because it is the least number of picking product category. However, we locate just 1 out of 3 products in the flow rack. We locate the 2 products in the stack area because their maximum pallets per stack are 4 and 5 pallets. It will save the spaces if we choose other products which have lower maximum pallets per stack to be located in the flow rack.

Second, we consider the second least number of picking product category, Special Alloy. All of Special Alloy products can be overlaid by 4 - 5 pallets, so we will locate this product category in the stack area. Some of the products require just 4 pallets, so it is not worth to keep these products in the flow rack.

Third, we consider Raw Material for Refractory. This product category contains 1 product. This product can be overlaid by 3 pallets, so we locate this product in the flow rack.

Since, there are 6 lanes left. Six lanes are not sufficient for the whole Coating. Fourth, we will compare Coating and Sand Slag. Then, we will choose the products which have lower number of picking. We compare the number of picking between the maximum number of possible Coating products to be located in the 6 lanes (3 products) to the maximum number of possible Sand slag products to be located in the 6 lanes (2 products). The 2 products of Sand Slag have lower number of picking. Consequently, we locate 2 product of Sand Slag in the flow rack.

Finally, we locate the products according to the number of picking and locate the same product category products in the same location as possible. We adopt Class-Base Assignment concept in designing the layout. Coating and Foundry Sand are located in zone B, while Sand Slag and most of Special Alloy are located in zone A. Since some Special Alloy products require small spaces, some products are located transversely. There is only one product from Special Alloy which is located in zone B. Figure 4.21 presents Layout#1. The designing process is summarised in flow process chart. Figure 4.22 presents the flowchart of designing layout#1 of Warehouse 10. The number in the Figure 4.21 represents product categories' products.

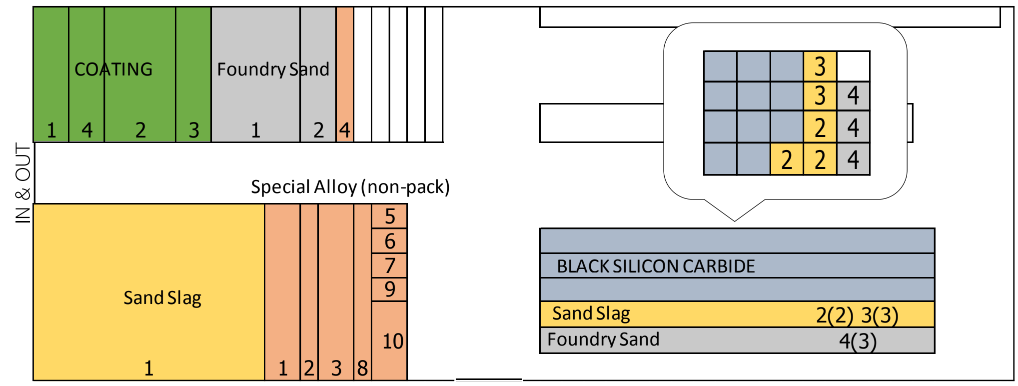


Figure 4.21: Layout#1 of Warehouse 10

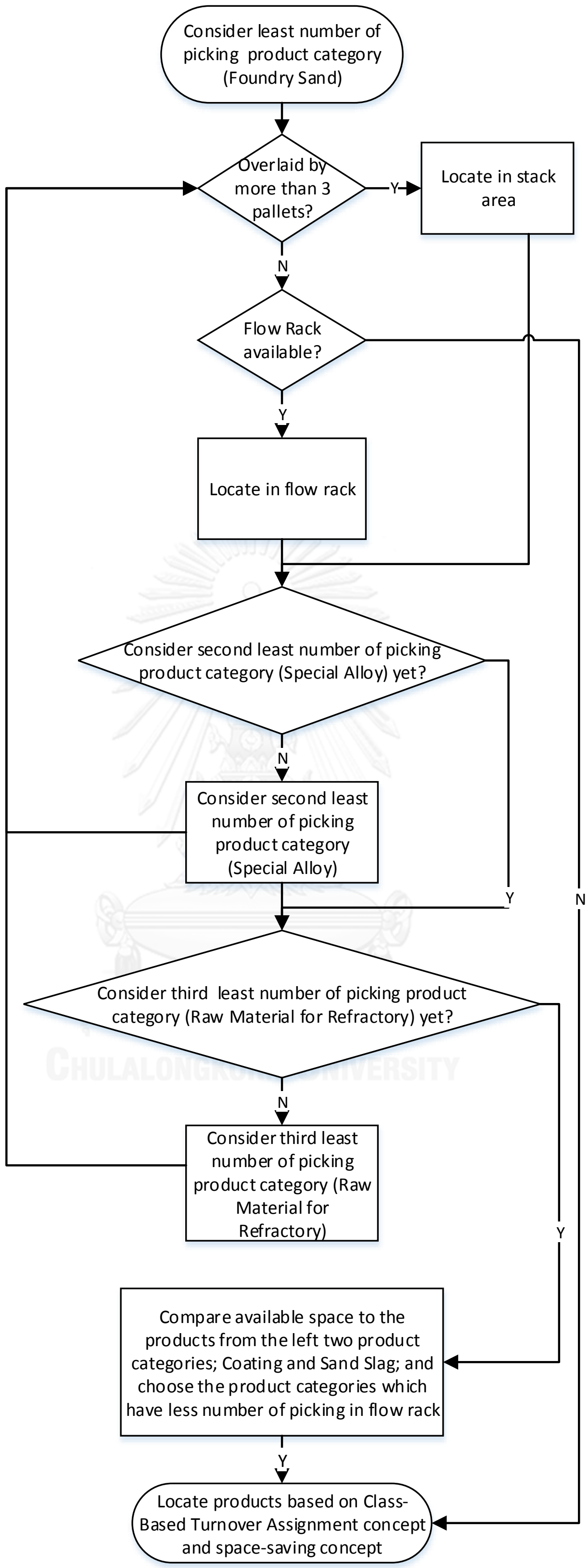


Figure 4.22: Layout#1 Designing Process for Warehouse 10

1) Layout#2 of Warehouse 10

The designing concept of this layout is locating products which have low number of pallets per stack (2 and 3 pallets) in the flow rack. Then, we will consider the space-saving condition in the stack area.

First we identify the products that have least number of pallets per stack. Foundry Sand-SKU-3 of Foundry Sand, Special Alloy-SKU-10 of Special Alloy, All products of Coating, Sand Slag-SKU-2, and Sand Slag-SKU-3 of Sand Slag are considered, since they have the least number of pallets per stack (2 pallets). Table 4.16 summarises the number of pallets per stack for the products in Warehouse 10.

Table 4.16: Maximum Number of Pallets per Stack of Products in Warehouse 10

NO	**Sand Slag**	# of pallets/stack
1	Sand Slag-SKU-1	3
2	Sand Slag-SKU-2	2
3	Sand Slag-SKU-3	2
NO	**Coating**	# of pallets/stack
1	Coating-SKU-1	2
2	Coating-SKU-2	2
3	Coating-SKU-3	2
4	Coating-SKU-4	2
NO	**Raw material for refractory**	# of pallets/stack
1	Raw Material-SKU-1	3
NO	**Special Alloy**	# of pallets/stack
1	Special Alloy-SKU-1	5
2	Special Alloy-SKU-2	4
3	Special Alloy-SKU-3	5
4	Special Alloy-SKU-4	5

5	Special Alloy-SKU-5	5
6	Special Alloy-SKU-6	5
7	Special Alloy-SKU-7	5
8	Special Alloy-SKU-8	5
9	Special Alloy-SKU-9	5
10	Special Alloy-SKU-10	2
NO	**Foundry Sand**	# of pallets/stack
1	Foundry Sand-SKU-1	5
2	Foundry Sand-SKU-2	4
4	Foundry Sand-SKU-3	2

Second, we consider the product characteristics of the focused products. Special Alloy-SKU-10 is not appropriate to be stored in the flow rack, since it is fragile (It is the only fragile product in the category). Consequently, we will locate this product in the stack area.

Third, we evaluate the space and locate the product in the flow rack. We decide to locate Foundry Sand-SKU-3 of Foundry Sand and all products of Coating in the flow rack. They require 9 lanes of the flow rack, so there are 11 lanes of the flow rack available. If we locate more products (Sand Slag-SKU-2 Sand Slag-SKU-3) of Sand Slag in the flow rack there will be 6 lanes left which is not fit for locating any other 3-pallet-stacked products. Since Raw Material for Refractory product which is the lowest frequently picked product of 3-overlaid-pallet products requires 11 lanes of the flow rack, we decide to locate the product in the flow rack together with Foundry Sand-SKU-3 of Foundry Sand and all products of Coating. According to trial & error, this decision results in maximum available space in the stack area, since it locates all suitable and possible products which have low number of pallets per stack in the flow rack.

Fourth, we will design the locations for products in the flow rack according to the number of picking. Products which have higher number of picking are located closer to the main aisle as presented in Figure 4.23.

Finally, we design layout of the stack area based on the picking rank and suitability. Two products of Sand Slag are placed closest to the shipping area on one side of the warehouse. Opposite to the Sand Slag, there are Special Alloy. Since there are 3 rows left on the Sand Slag side, we locate some products of Special Alloy in these rows. Some products are located transversely as same as layout#1. This decision will not separate Foundry Sand to many locations and gather the free rows in just one side of the warehouse as presented in Figure 4.23. Designing process is summarised in flow process chart as presented in Figure 4.24.

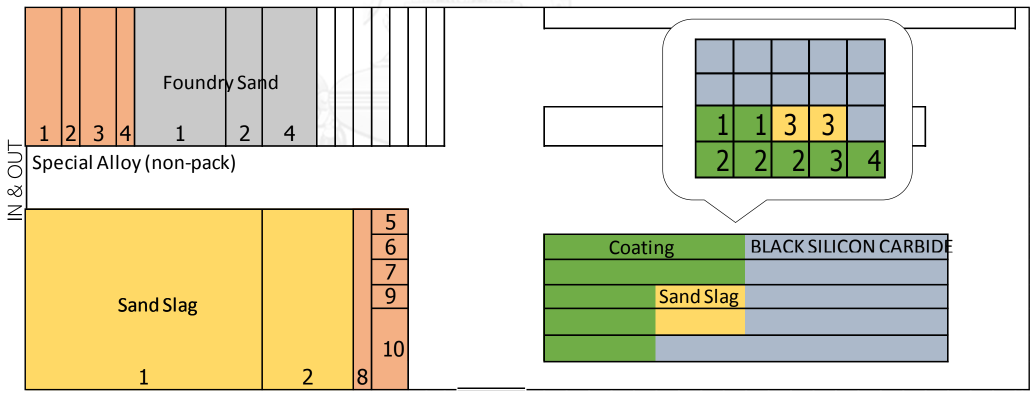


Figure 4.23: Layout#2 of Warehouse 10

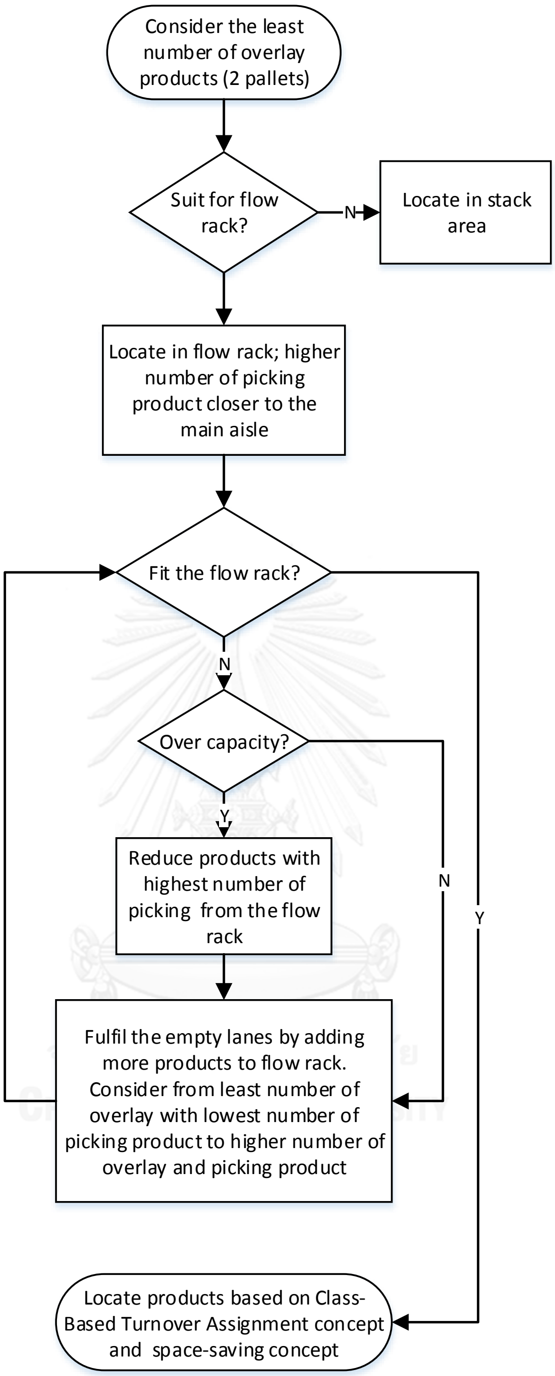


Figure 4.24: Layout#2 Designing Process for Warehouse 10

To sum up, we calculate the required number of stacks and lanes of all products in Warehouse 10 by using the number of pallets of the product (calculated in Final Grouping Plan). Table 4.17 concludes the number of rows and lanes calculation. Then, we design the candidate layouts. There are 4 candidate layouts for Warehouse 10.

Table 4.17: Conclusion of Number of Rows and Lanes Calculation for Warehouse 10

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

4.3.5 Evaluate the Layouts and Choose the Best Layout for Warehouse 10

We compare the total picking distances of all layouts, vacant spaces, and appropriateness for works of the 4 layouts. We firstly calculate the total picking distances of all layouts.

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 10 will be transferred to Warehouse 8 via the gate.

Figure 4.25 shows an example of distance measurement. The distance is measured from the middle location of the Coating products to the gate. We concern not only the distance in horizontal plane, but also the height of the products. The average height of the products is the representative of the height of the Coating products. We sum up the distance in horizontal plane and height. We multiply the calculated distance by the number of picking of Coating products. Then, we multiply it by 2 again, the result is the total picking distance of Coating (including back and forth). The calculation is shown in Figure 4.26.

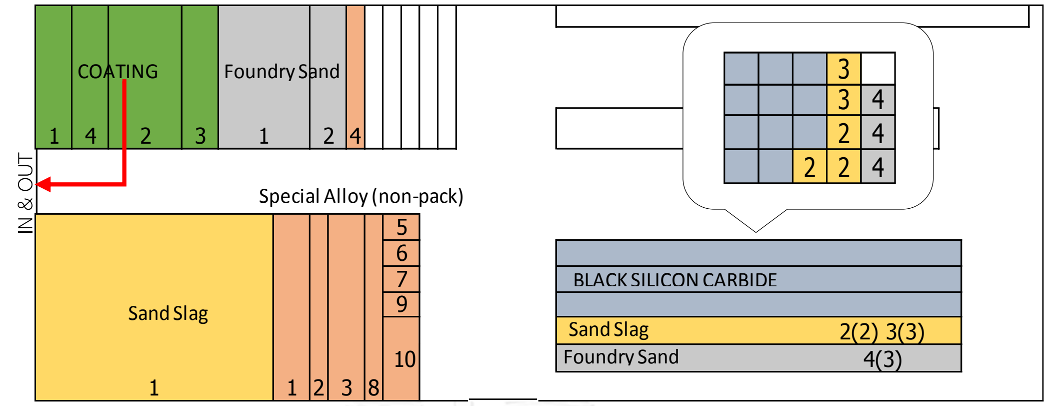
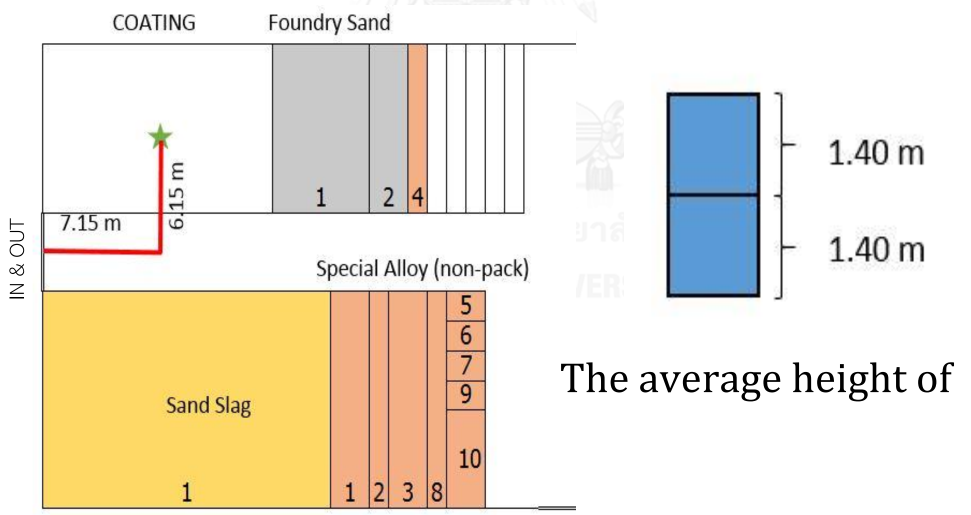


Figure 4.25: An Example Distance Measurement of Warehouse 10



$Distance = 7.15 + 6.15 + 1.4 = 14.7$

$The\ total\ picking\ distance = 14.7 \times 2 \times 643 = 9{,}687.3\ m$

- *is from travelling back and fourth*
- *643 is the number of picking of Coating*

Figure 4.26: An Example of Distance Calculation

We separately calculate the distances of product categories for each layout. If the layout locates the same product category at more than 1 location, we separately calculate the total picking distance for all groups of the product category. Then, we sum up the distance for each layout

There are different number of vacant space from each layout. Layout#1 has 5 rows of stacks and 1 lane of flow rack left. Layout#2 and Layout#3 have 7 rows of stack left. Layout#4 has 4 rows of stack left. Table 4.18 summarises the total picking distance and left spaces of all layouts.

Table 4.18: Candidate Layouts for Warehouse 10

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

The best layout gives the best trade-off between the distance, space and usability. Comparing layout#2 to Layout#4, Layout#4 gives the lower total picking distance, but it is not significantly different. However, Layout#2 gives better trade-off. Layout#2 gives higher number of remaining space which is more important.

Comparing 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. Layout#2 is more practical than. Layout#2 store higher number of product categories together 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 least 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 distance of Layout#1 and Layout#2 are not significantly different and Layout#2 give the highest number of remaining rows. Accordingly, Layout#2 is the best layout of Warehouse 10.

To sum up, we calculate the total picking distance of all candidate layout for Warehouse 10. Then, we analyse and choose the best layout for Warehouse 10. We choose the best trade-off between the total picking distance, the left spaces, and number of product categories that locate in more than 1 location in the stack area. Layout#2 is the best layout of Warehouse 10.

4.3.6 Design the Layout of Stack Zone for Warehouse 8

For floor stack zone of Warehouse 8, we have divided products and product categories which are suitable for floor stack in Product Category Grouping phase. Consequently, we have to calculate the required space for each product.

Figure 4.27 is an example of the number of required row calculation. Maximum holding stock of product B equals to 13 pallets. The maximum pallets per 1 stack is 3 pallets. For, the number of used rows, we divide 13 by the maximum number of pallets per stack. The result is the number of stacks of product B. Then, we divide the result by 6, which is the number of stacks per row, and round the number. The final result is the number of required rows for product B.

$$\frac{13}{3} = 4.33 \approx 5 \text{ Stacks}$$

$$\frac{5}{6} = 0.83 \approx 1 \text{Row}$$

$\therefore$Product B requires 1 row

Figure 4.27: An Example of the Number of Required Rows of Product in Warehouse 8 Calculation

We calculate the number of required rows of all products. Table 4.19 presents the number of picking and number of required rows of the ranked product categories. Tale 4.20 is an example of calculation in product level. It is the rank of products from Refractor Castable.

Table 4.19: Rank of Product Categories in Floor Stack Zone of Warehouse 8

Rank	Product Category	# of picking	# of rows
1	Refractories Lining	1,642	33
2	Refractor Castable	182	5
3	Exothermic Sleeves & Powder	171	2
4	Refactor Plastic & Other	148	7
5	Flux	75	1
6	Non-ferrous Product & Other Fluxes	72	2
7	Other Chemical	59	3

Table 4.20: Rank of Products from Refractor Castable

Rank	Product Category	# of picking	# of rows
1	Castable-SKU-1	51	1
2	Castable-SKU-2	46	1
3	Castable-SKU-3	36	1
4	Castable-SKU-4	25	1
5	Castable-SKU-5	24	1

We have divided the stack area into 3 zones; zone A, zone B1, and zone B2. We found that Refractories Lining requires largest space, so 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 the different aisle. The capacities of zone A and zone B1 are sufficient and practical, so this location is the most appropriate location for Refractories Lining. Refractories Lining is located in zone A and zone B1 as presented in Figure 4.28. According to this decision, we calculate the number of required rows for all product categories as presented in Table 4.20.

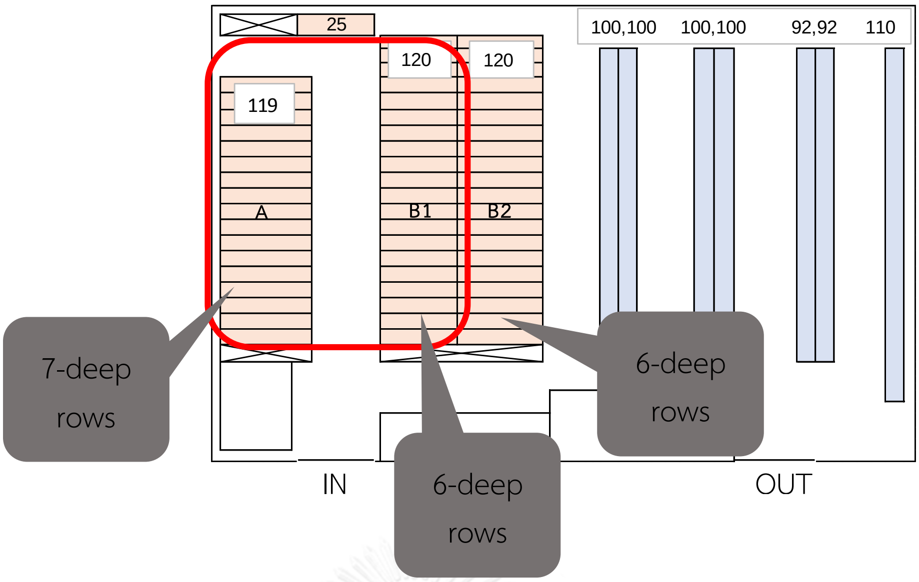


Figure 4.28: Assigned location for Refractories Lining

The number of required rows presented in Table 4.20 are from assigning all product categories in 6-stacks-deep rows (zone B1 and B2) except Refractories Lining. Since it is impossible to locate Refractories Lining in just 1 zone, the number of rows are calculated after assigning the products in zone A and zone B1.

We assign 1 colour for 1 product category as shown in Table 4.21. We rank the products. The number in each colour represents a product in that product category.

Table 4.21: Product Categories for Stack Zone of Warehouse 8

Rank	Product Category	colour
1	Refractories Lining	
2	Refractor Castable	
3	Exothermic Sleeves & Powder	
4	Refactor Plastic & Other	
5	Flux	
6	Non-ferrous Product & Other Fluxes	
7	Other Chemical	

In this research, we start from developing Layout#1 for stack zone of Warehouse 8. Then, we develop the other candidate layouts for stack zone of Warehouse 8 based on the product category constraints. There are 7 candidate layouts for the stack zone of Warehouse 8. We describe Layout#1 and Layout#2 in this chapter. We describe Layout#3 - Layout#7 in Appendix B.

Layout#2 is the best layout, the other six layouts are not as better as Layout#2. The concept of all candidate layouts are different. Layout#2 concept is to gather the vacant rows in only zone B2 which is the furthest from the packing area in Warehouse 8, while Layout#1, Layout#3, and Layout#4 gathers vacant rows in zone B1, A, and B1, respectively. Concept of Layout#3, Layout#4, and Layout#5 are to locate the higher number of frequently picked products of Refractory Lining closer to the preparing area, while Layout#2 locates higher frequently picked Refractory Lining products in zone A and zone B1, respectively. The concept of Layout#6 and Layout#7 is to gather the vacant row in zone B2 as same as the concept of Layout#2, but the locations of product categories are different from the Layout#2. Both layouts locate Fluxes in zone

B1, while Layout#2 locates Fluxes in zone B2. Table 4.22 concludes the layout designing concepts of all candidate layouts of stack zone of Warehouse 8.

Table 4.22: The Layout Designing Concepts of Stack Area of Warehouse 8

Layout	Gather vacant rows in			Locate higher # of picking Refractory products in zone A and zone B1	Locate higher # of picking Refractory products in zone A firstly, the locate in zone B1	Locate Fluxes in zone B1
	Zone A	Zone B1	Zone B2			
Layout#1		√			√	
Layout#2			√		√	
Layout#3	√			√		√
Layout#4		√		√		
Layout#5			√	√		
Layout#6			√		√	√
Layout#7			√		√	√

1) Layout#1 of stack zone of Warehouse 8

The concept of this layout is to locate Refractories Lining products in order and gather vacant rows in zone B1. This layout locates Refractories Lining in order from zone A to zone B1 and locates other product categories according to the product categories' rank and products' rank in zone B2. As presented in Figure 4.29, products in each product category are arranged from high number of picking to low number of picking. There are 4 vacant rows in the back of zone B1.

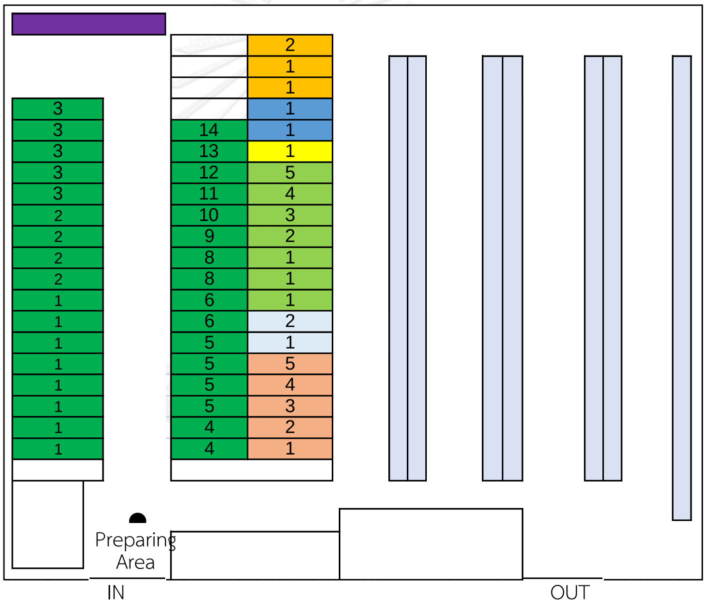


Figure 4.29: Layout#1 of Stack Zone of Warehouse 8

2) Layout#2 of stack zone of Warehouse 8

The concept of this layout is to locate Refractories Lining products in order and gather vacant rows in zone B2. Refractories Lining is located in zone A and zone B1. Then, other product categories are located in order. We also have to determine the required space. Although the 4 back rows in zone B1 is closer to the preparing area, Refractor Castable (the second frequently picked product category) required 5 rows. Consequently, we have to locate Refractor Castable in front rows of zone B2 instead. Exothermic Sleeves & Powder the third frequently picked product category required 2 rows, so we locate this product category next to the Refractories Lining. After locating other products in order, there are 4 vacant rows in the back of zone B1. Figure 4.30 presents the layout#2 of stack zone of Warehouse 8.

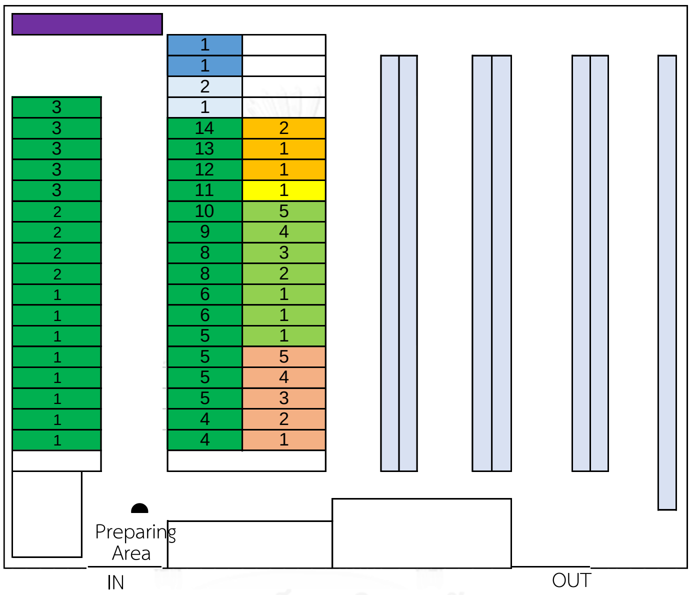


Figure 4.30: Layout#2 of Stack Zone of Warehouse 8

To sum up, we calculate the number of required rows for all products in the stack area of Warehouse 8. We find the number of required rows. Table 4.23 concludes the calculation of the number of required rows. Then, we design the layouts for the stack area of Warehouse 8. Seven candidate layouts are developed.

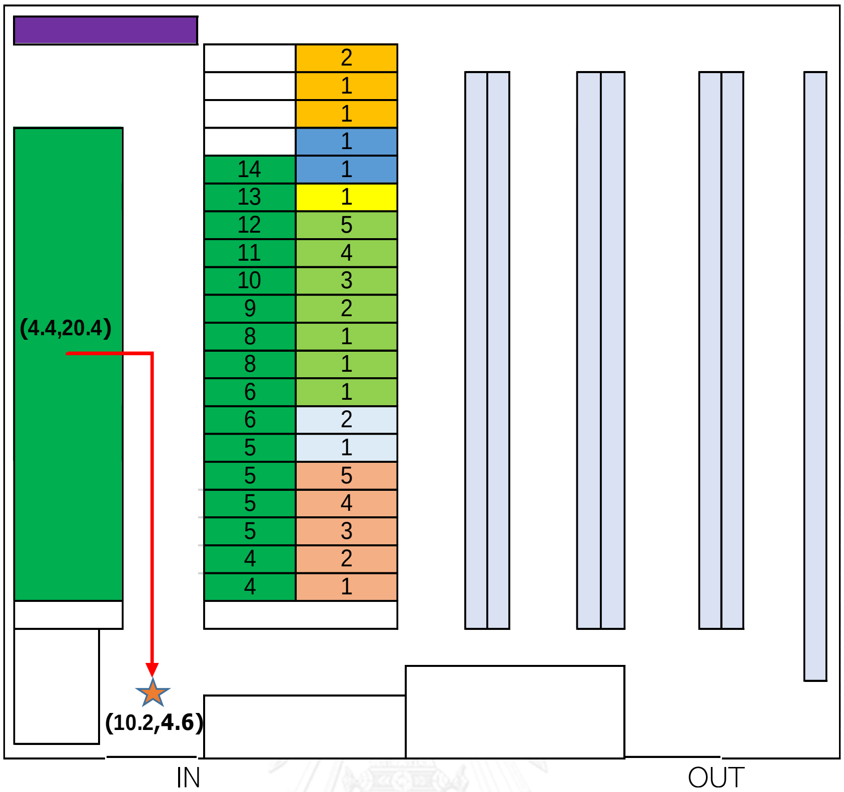
Table 4.23: Conclusion of Number of Rows Calculation for Warehouse 8

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

4.3.7 Evaluate the Layouts and Choose the Best Layout of Stack Zone for Warehouse 8

We compare the total picking distances of all layouts, vacant space, and appropriateness for works of 7 layouts. Total picking distance is calculated by multiplying the number of picks to the distance from preparing area to a particular product and from product to the preparing area. Preparing area is the area that all products will be prepared to be packed. Total picking distances are calculated by the same method as evaluating the layout for Warehouse 10. We consider not only horizontal distance, but also vertical distance.

Figure 4.31 presents the example of distance calculation. We sum up the distance in horizontal axis and vertical axis. Then, we time the sum by the number of picking and 2 (the picker has to go to the product location and return to the preparing area.) The preparing area is at the star in Figure 4.31.



- $Average\ height = 0.82\ m$
- $The\ number\ of\ picking = 1{,}042$
- $The\ number\ of\ picking = 534$
- $Multiply\ by\ 2\ from\ go\ back\ and\ fourth$

$$The\ total\ distance = [\{(10.2 - 4.4) + (20.4 - 4.6) + 0.82\} \times 534] \times 2$$

Figure 4.31: Example Distance Measurement of Stack Area in Warehouse 8

We calculate all total picking distances of the 7 candidate layouts. Table 4.24 presents the summary total distances and vacant spaces of all candidate layouts. Layout#2 is considered as the best layout since it gives the best trade-off between the distance and left spaces.

Table 4.24: Candidate Layouts for Stack Zone of Warehouse 8

Layout	Total picking distance (km)	Left space		
		Zone A	Zone B1	Zone B2
#1	135.19	0	4	0
#2 (Best Layout)	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

Gathering vacant rows in 1 zone is more practical for the warehouse supervisors to use the space for other purposes. The total picking distance of Layout#2 is the least compared to candidate layouts which gathering vacant rows in 1 zone. The vacant space in zone B2 is the best. The company can use the space for other purposes with less interfere from warehouse activities. The location is close to the wall of the warehouse, so the company can use to the space from the location to the wall to keep old machine, dead stock, or manufacturing tools. Other candidate layouts do not give more left spaces, so this layout is the best layout for stack zone of Warehouse 8.

To sum up, we calculate the total picking distance of all products in the stack area of Warehouse 8. Then, we choose the best layout. We consider the total picking distance, the vacant space, and the zone of the vacant space. The best layout of the stack area in Warehouse 8 is Layout#2. Layout#2 has the highest vacant space in best zone (zone B1) and gives the least total picking distance under this condition.

4.3.8 Design the Layout of Single-Deep Selective Rack Zone for Warehouse 8

For stack zone, we have to rank products and product categories from high frequency of picking to low frequency of picking in order to assign location for each product and product category.

There are 7 racks named as presented in Figure 4.32. 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 capacities at 100 pallets/rack. Rack C and B have maximum capacities at 92 pallets/rack. Rack A has maximum capacity at 110 pallets/rack. The company firstly uses first floor to fourth floor of the racks (80% of the capacity). First floor to fourth floor of racks are the first priority locations. Therefore, we will consider the capacities of rack G, F, E, and D at 80 pallets/rack, rack C and B at 72 pallets/rack, and rack A at 86 pallets/rack in first place. The top floor is the reserved location. In case that the first floor to fourth floor are full, the company will locate products on the top floor of the rack. However, we can adjust the locations of products depending on the product characteristics and company requirements.

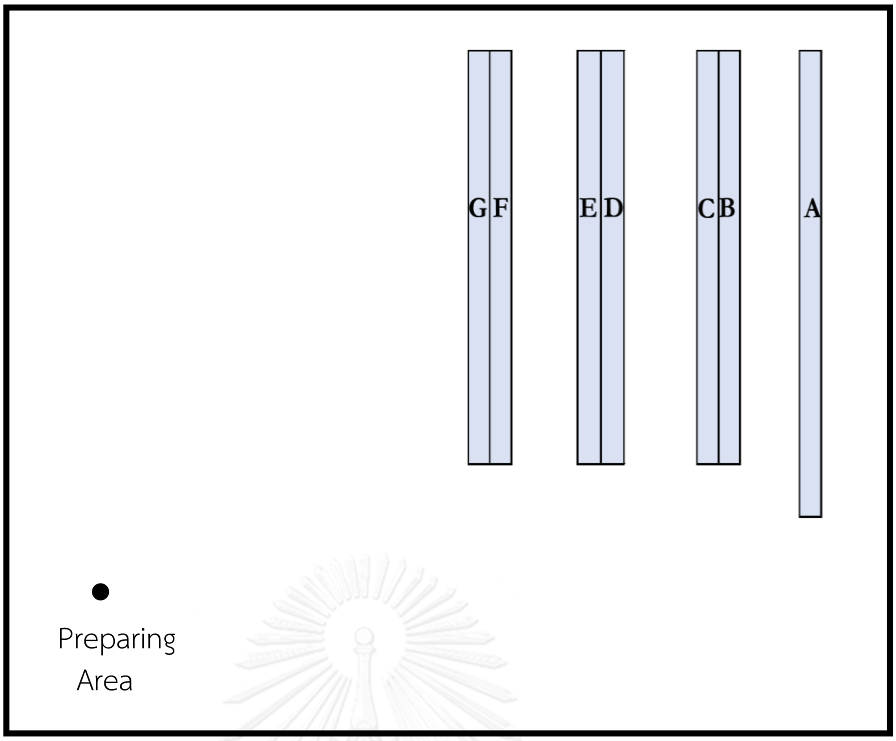


Figure 4.32: Selective Rack Zone of Warehouse 8

Table 4.25 presents the number of required pallets for each product category and the number of picking. The number of pallets which is the maximum holding stocks of the products is also shown in Table 4.25. The product categories are ranked from highest number of picking to least number of picking. Exothermic Sleeve has the highest number of picking and requires highest number of pallet locations.

Table 4.25: Rank of Product Categories in Selective Rack Zone of Warehouse 8

Rank	Product Category	# of picking	# of pallets
1	Exothermic Sleeve	1,699	247
2	Refractories Lining	1,661	13
3	Refractory Plastic	1,559	77
4	Parting & Releasing Agent Product	1,119	52
5	Mica	832	35
6	Adhesive Product	782	18
7	Temperature & CE Product	610	43
8	Ceramic Product	360	34
9	Non-ferrous Product	343	44

We also rank the products in all product categories. Table 4.26 is an example ranking of products from Adhesive Product. Then, we develop the candidate layouts for the selective rack zone of Warehouse 8 based on the product category constraints and company requirements. We assign 1 colour for 1 product category as shown in Table 4.27. The number in each colour represents a product in that product category.

Table 4.26: Rank of Products from Adhesive Product

Rank	Product Category	# of picking	# of pallets
1	Adhesive-SKU-1	347	4
2	Adhesive-SKU-2	218	6
3	Adhesive-SKU-3	108	2
4	Adhesive-SKU-4	97	4
5	Adhesive-SKU-5	7	1
6	Adhesive-SKU-6	5	1

Table 4.27: Product Categories for Selective Rack Zone of Warehouse 8

Rank	Product Category	colour
1	Exothermic Sleeve	
2	Parting Releasing Agents	
3	Refractories Plastic	
4	Mica	
5	Adhesive Products	
6	Temperature Products	
7	Ceramic Product	
8	Non-Ferrous Product	
9	Refractory Lining	

We design 4 layouts for the selective rack zone of Warehouse 8. We firstly design Layout#1, then we improve the layouts by adding more constraints into the layouts. Concept of Layout#1 is to locate highest frequently picked product categories closer to the preparing area. We try to locate the products from 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 Sleeve A, subgroup of Exothermic Sleeve, in to 2 locations. Figure 4.33 conclude the concepts of designing single-deep selective rack of Warehouse 8. The constraints are gradually added as the layouts are designed.

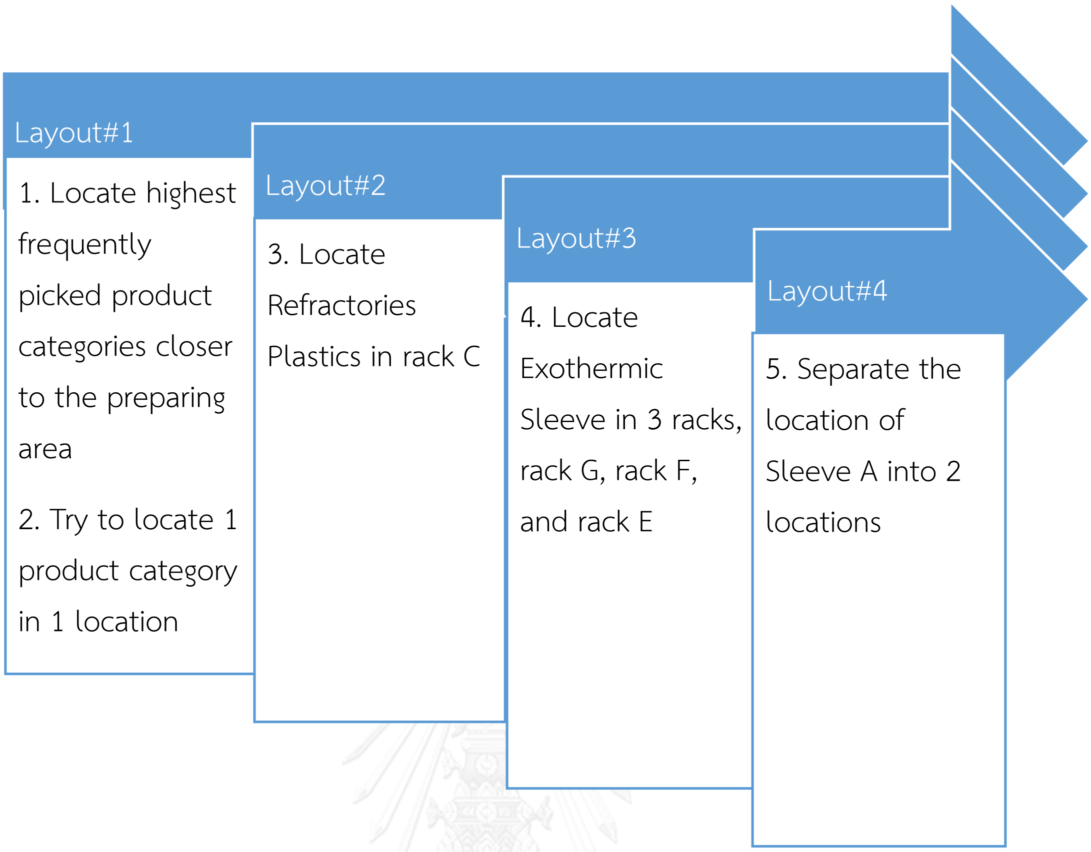


Figure 4.33: The Layout Designing Concepts of Single-deep Selective Rack of Warehouse 8

1) Layout#1 of selective rack zone of Warehouse 8

We located products according to the product categories' rank, products' rank, and the product category requirements. The concept of this layout is to locate products and product categories according to the ranks in the efficient spaces. The product in same product category will be located in the same location. We firstly locate Exothermic Sleeve in rack G, rack F, and rack E, since this product category has highest number of picking.

There are 5 product families in Exothermic Sleeve, i.e., Sleeve P, Sleeve F, Sleeve CE, Sleeve A, and Sleeve FO, this sequence arrange the product family from the highest number of picking to the least number of picking. We locate the product families according to the product family's rank. Sleeve P is located in rack G. Since the left spaces in rack G is not sufficient for any family, we locate Sleeve F in rack F, Sleeve EC in rack E, Sleeve A in rack E. The left spaces in rack E is also not sufficient, so we locate Sleeve FO in rack D.

We have to consider the spaces of the locations before locating any product categories. Refractories Plastic requires more than 72 pallets, so we have to separate the locations of Refractories plastic into rack C and rack D. we continue to locate product categories according to the picking frequency and space availability.

After locating Mica, we have to locate Adhesive Products next to Mica and locate Temperature Products oppositely. Because the remaining locations in rack A is only sufficient for required spaces from Adhesive Products and Ceramic Product. The last product category is Refractory Lining. Refractory Lining is assigned to rack G because the available spaces in rack G is sufficient. Figure 4.34 presents the Layout#1 for the selective area of Warehouse 8.

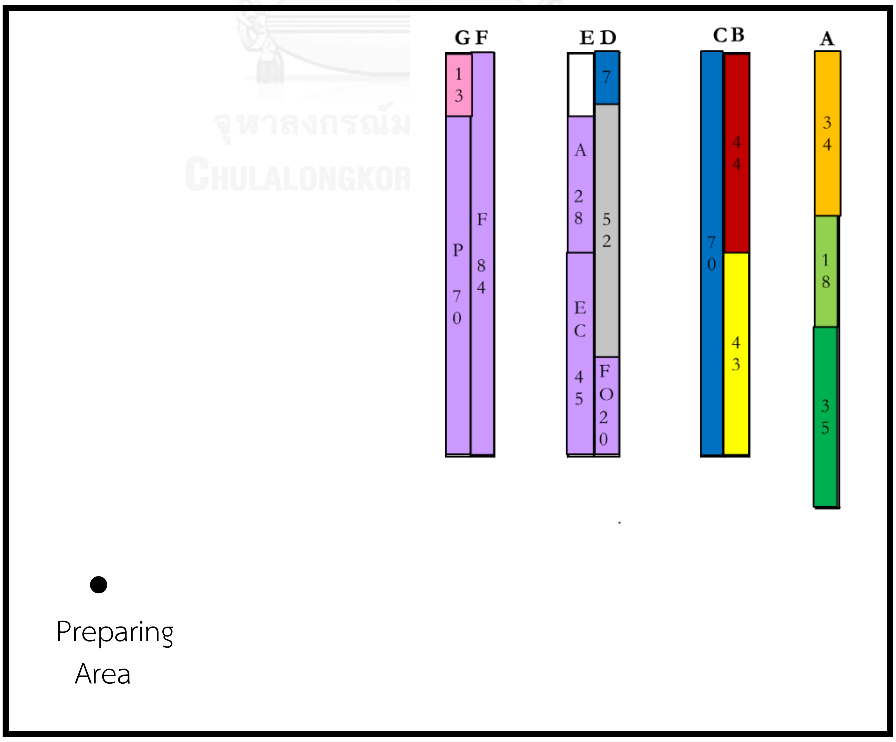


Figure 4.34: Layout#1 of Selective Rack Zone of Warehouse 8

2) Layout#2 of selective rack zone of Warehouse 8

The concept of this layout is similar to Layout#1's concept; locating products and product categories according to the ranks in the efficient space, but we will locate Refractories Plastic in just 1 row of the selective rack.

We start as same as Layout#1. Since rack D has capacity at 80 pallets and Refractories Plastic requires 77 location of pallets, rack D is sufficient for Refractories Plastic. We decide to change the location of Refractories Lining from rack C to rack D and locate other product categories in order. Since Refractories Plastic is located in rack D, we have to locate Sleeve A in rack C instead of rack E and locate Sleeve FO in rack E instead of rack C. If we don't swap the location of the both product families, there will be not sufficient space. Figure 4.35 presents the Layout#2 for the selective area of Warehouse 8.

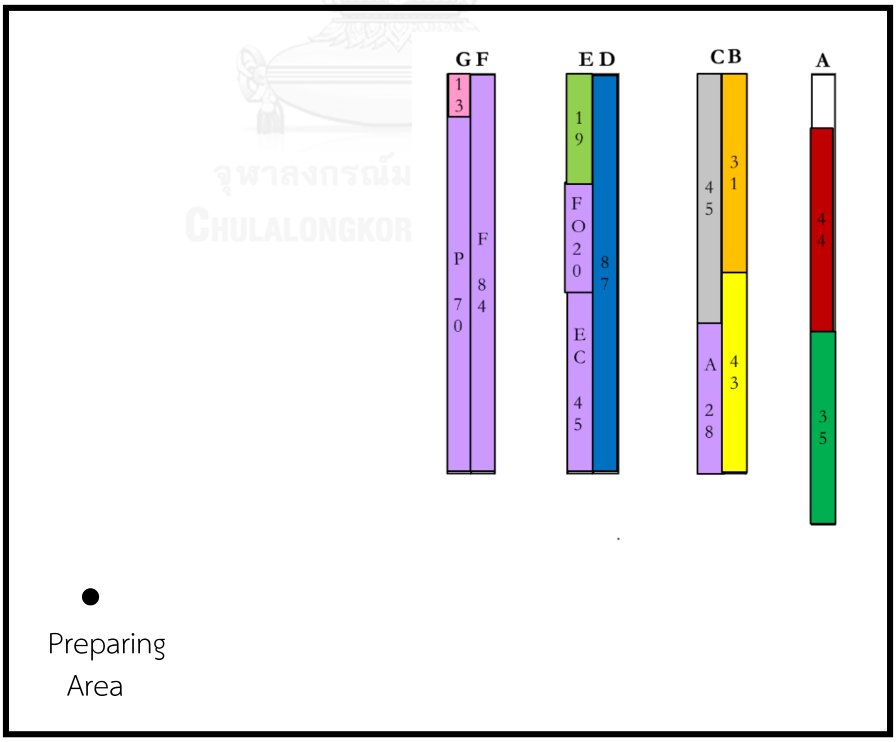


Figure 4.35: Layout#2 of Selective Rack Zone of Warehouse 8

3) Layout#3 of selective rack zone of Warehouse 8

The concept of this layout is similar to previous layouts' concept, but we will locate Refractories Lining and Exothermic Sleeve in 1 row and 3 rows, respectively.

We firstly locate Exothermic Sleeve in rack G, F, and E. Sleeve A is added into rack E. Sleeve EC, Sleeve FO, and Sleeve A require 93 location of pallets. The capacity of rack E is 80 locations of pallets, so we have to locate some products in the reserved spaces in the top of rack E. We remain locating Refractories Lining in rack D and other product categories according to the order and space constraints. Figure 4.36 presents the Layout#3 for the selective area of Warehouse 8.

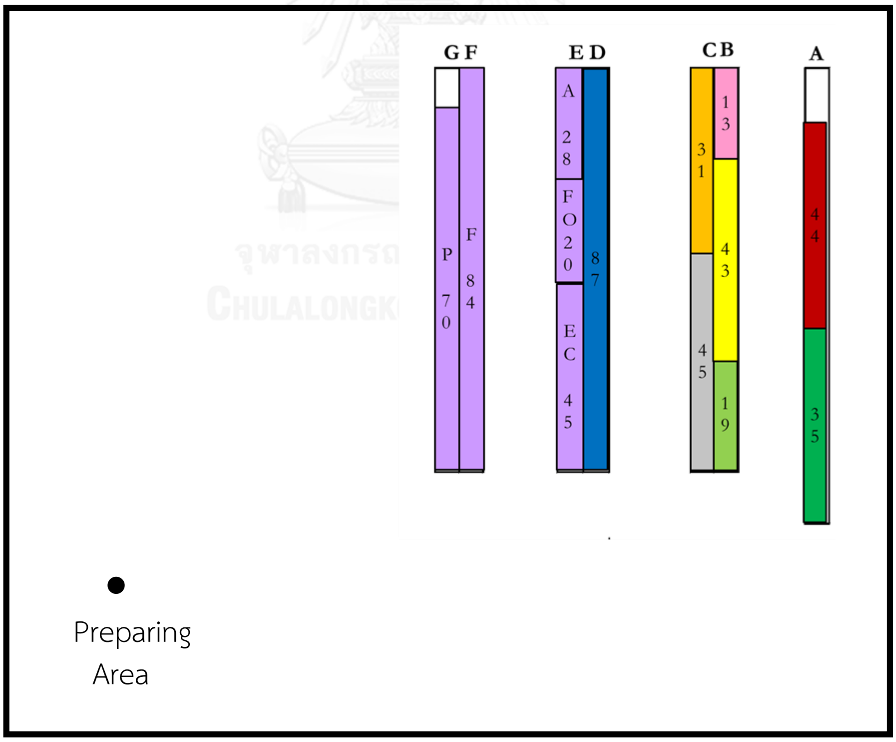


Figure 4.36: Layout#3 of Selective Rack Zone of Warehouse 8

4) Layout#4 of selective rack zone of Warehouse 8

The concept of this layout is similar to previous layouts' concept, but we will efficiently use all the locations in level 1 – 4 of the selective rack.

We firstly change the location of Sleeve F and Sleeve P. We want to separate the location of Sleeve A into 2 locations as presented in Figure 4.37, since we have known that the rack E cannot handle the Sleeve EC, Sleeve FO, and Sleeve A without locating in the top floor of rack. This plan will balance the number of sleeves in Rack E and rack F. This plan separate some of Sleeve A to rack F and located them next to the Sleeve P. If we do not alter the location of Sleeve P and Sleeve F, there will be not sufficient locations of pallets in rack F to support this plan. After locating Exothermic Sleeve, we locate Refractories Lining in rack D and locate other product categories following the order. Figure 4.37 presents the Layout#4 for selective area of Warehouse 8.

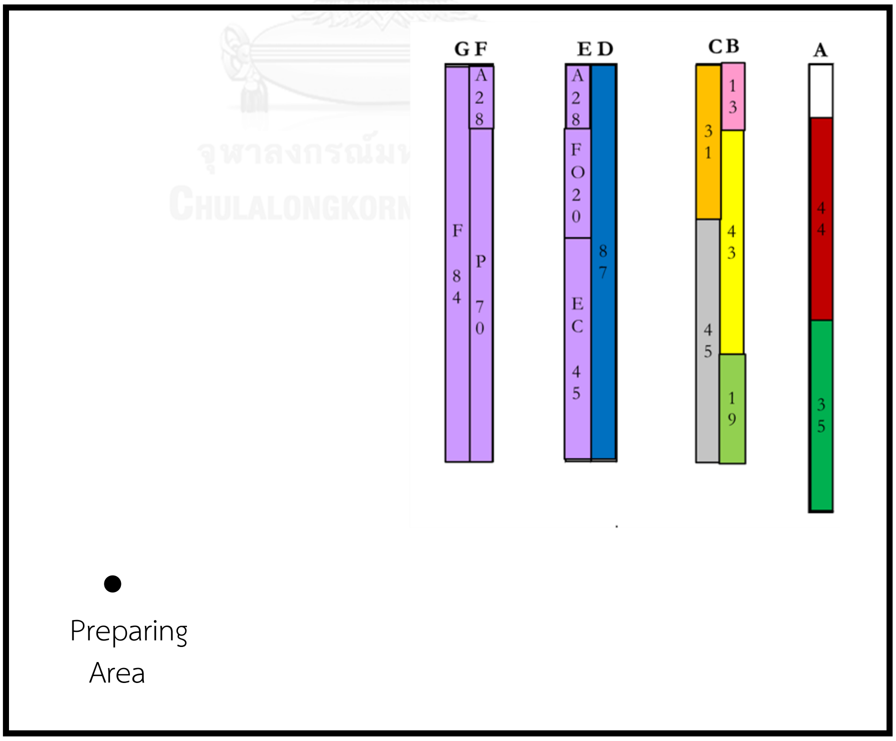


Figure 4.37: Layout#4 of Selective Rack Zone of Warehouse 8

To sum up, we design the location of product in selective rack area of Warehouse 8. Four candidate layouts are developed in order. The location of products and product categories are designed based on the company requirement and product constraints

4.3.9 Evaluate the Layouts and Choose the Best Layout of Selective Rack Zone for Warehouse 8

We compare the total picking distances of all layouts, vacant space, and appropriateness for works of 4 layouts. Total picking distances are calculated from the same method as evaluating the layout for Warehouse 10 and layout of stack area for Warehouse 8. Total picking distance is calculated by multiplying the number of picking to the distance from preparing area to product and from product to the preparing area. We consider horizontal and vertical distance. As we developing the candidate layouts, Layout#4 gives the best trade-off between usability and total distance.

As mentioned in the scopes, the company requires storing the same product category in the same location. Comparing the best layout to other layouts, the best layout well allocate all product categories. We locate Exothermic Sleeve by balancing Sleeve A in rack F and E. This layout can locate the same product category together while Layout#1 and Layout#2 have at least 1 product category in separated locations. This layout uses full capacity of the 1- 4 levels of selective racks and rarely locate products in the fifth floor of the selective rack, while Layout#3 required to store some products on the fifth floor. The total distance of the best layout is also the least among all layouts. Table 4.28 presents the disadvantages and total distances of all candidate layouts.

Table 4.28: Candidate Layouts for Rack Zone Layouts of Warehouse 8

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 location 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 (Best Layout)	• Sleeve A has to be stored in 2 locations	609.55

To sum up, 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. Layout#4 gives the least total picking distance and locate main of Exothermic Sleeve products in first floor to fourth floor of the racks.

4.3.10 Conclusion of Layout Designing for Warehouse 8 and Warehouse 10

In order to design layout for Warehouse 8 and Warehouse 10, we have to understand the layout requirements of the company. We change the invoices into the number of picking for all products. Then, we rank the products and product categories from highest number of picking to the least number of picking. After that, we design the layout of Warehouse 10, stack area of Warehouse 8, and selective rack area of Warehouse 8. We evaluate the layouts using the total picking distance, vacant space, and other qualitative issues. The process in all steps of layout design and the results of all step are concluded in Table 4.29.

Table 4.29: Conclusion of Steps in Layout Design

No.	Step	Process	Result
1.	Company Requirements Identification for Layout Design	1) Identify the company requirements for layout design	1) Understand company requirements; • Store the same product category in the same location • Determine the locations of products based on the picking frequency • Maximize space utilization • Locate products based on the product constraints

2.	The Number of Picking Calculation	1) Calculate the number of picking of all products (non-sell-in-bulk products and sell-in-bulk products-	1) The number of picking of all products
3.	Products and Product Categories Ranking	1) Rank products and product categories from highest number of picking to least number of picking	1) The ranked product categories of Warehouse 8 2) The ranked product categories of Warehouse 10 3) The ranked products of all product categories
4.	Design Layout for Warehouse 10	1) Calculate the number of required rows and lanes 2) Develop the candidate layouts of Warehouse 10	1) Number of required rows and lanes of all products in Warehouse 10 2) 4 candidate layouts of Warehouse 10
5.	Evaluate the Layouts and Choose the Best Layout for Warehouse 10	1) Calculate the total picking distance of all products and product categories 2) Evaluate the total picking distance, vacant space, and the number of product categories with more than 1 location in the stack area	1) Total picking distance, vacant space, and the number of product categories with more than 1 location in the stack area of all layouts 2) Choose Layout#2

		3) Choose the best layout that gives the best trade off	
6.	Design the Layout of Stack Zone of Warehouse 8	1) Calculate the number of required rows 2) Develop the candidate layout of stack zone of Warehouse 8	1) Number of required rows for all products 2) 7 candidate layouts for Stack Zone of Warehouse 8
7.	Evaluate the Layouts and Choose the Best Layout of Stack Zone of Warehouse 8	1) Calculate the total picking distance of all products and product categories 2) Evaluate the total picking distance, vacant space, and zone of the vacant space 3) Choose the best layout that gives the best trade off	1) Total picking distance, vacant space, and zone of the vacant space 2) Choose Layout#2
8.	Design the Layout of Single-Deep Selective Rack Zone of Warehouse 8	1) Develop the candidate layout of single-deep selective rack zone of Warehouse 8	1) 4 candidate layouts for Single-Deep Selective Rack Zone of Warehouse 8
9.	Evaluate the Layouts and Choose the Best Layout of Selective Rack	1) Calculate the total picking distance of all products and product categories 2) Evaluate the total picking distance, vacant space, and	1) Total picking distance, vacant space, and appropriateness for product of all layouts 2) Choose Layout#4

	Zone of Warehouse 8	the appropriateness of the products location 3) Choose the best layout that gives the best trade off	

4.4 Conclusion of Methodology

There are 2 main phases in the research methodology. First phase is grouping the product categories for Warehouse 8 and Warehouse 10. We have to understand the company requirements, understand the nature of the products, and evaluate the used space before grouping product categories. The spaces in the warehouses should enough for the required spaces for the product categories. Second phase is design the layouts. We consider the picking frequency of product categories and products together with the appropriateness in order to assign the locations for the product categories and products. It is important to understand the nature of the products before assigning the appropriate location to the products. Different products require different locations, e.g., some products should be store on selective rack, some products should store on the floor etc. These constraints have to be considered together with the picking frequency.

CHAPTER 5:

Result

After grouping and designing layout both warehouse, both layouts will be validated, implemented, and evaluated. Since we use the product data of 2014, there might be new products that should be located in Warehouse 8 and Warehouse 10. We start from validating, then we will implement. Finally, we will evaluated the layouts by comparing to the old layouts and layouts from the warehouse department.

5.1 Validate the layouts

We have to validate the layout to response the current stock volume. For Warehouse 10, as mentioned in implementation, the demand in this year is followings the company forecasting. Consequently, the assigned spaces are enough for the stocks. However, there is a new product (product#0) in Special Alloy that the company wants to locate in Warehouse 10. According to the number of picking, we found that this product has the highest picking frequency. The company also wants to locate the same product category together. Product#0 is a Special Alloy product. Consequently, we locate the product#0 together with other Special Alloy products. The four layouts are revaluated. Table 5.1 presents the new total picking distance and left spaces. Layout#1 and Layout#4 have less left space compare to Layout#2 and Layout#3, so we will compare just Layout#2 and Layout#3.

Table 5.1: Validated Layouts for Warehouse 10

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

The total picking distance of Layout#2 and Layout#3 are not significantly different. The total picking distance of Layout#3 is 1.11 km less than the distance of Layout#2.

In warehouse processes, Layout#2 performs better than Layout#3. As presented in Figure 5.1 and Figure 5.2, Layout#3 have separated locations for 2 product categories in the stack area. It is easier for the warehouse supervisors to prepare storage area if two products of Sand Slag are located next to each other. Accordingly, the adjusted Layout#2 is chosen and implemented.

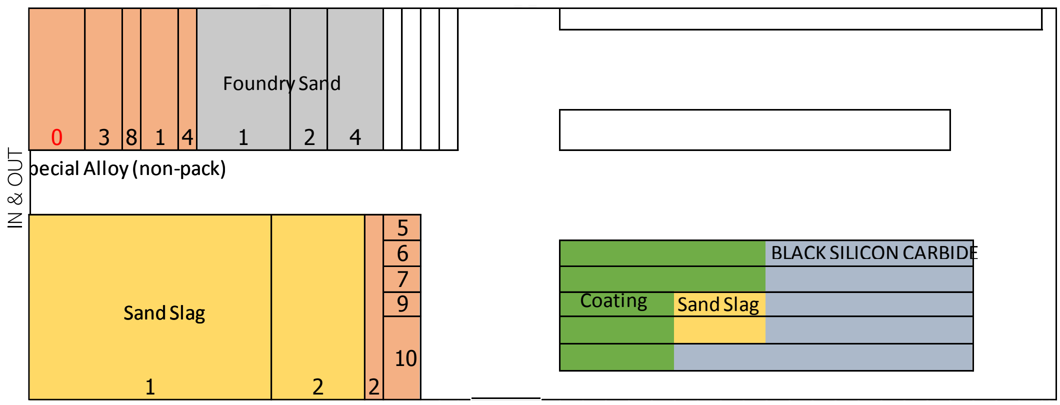


Figure 5.1: Validated Layout#2 of Warehouse 10

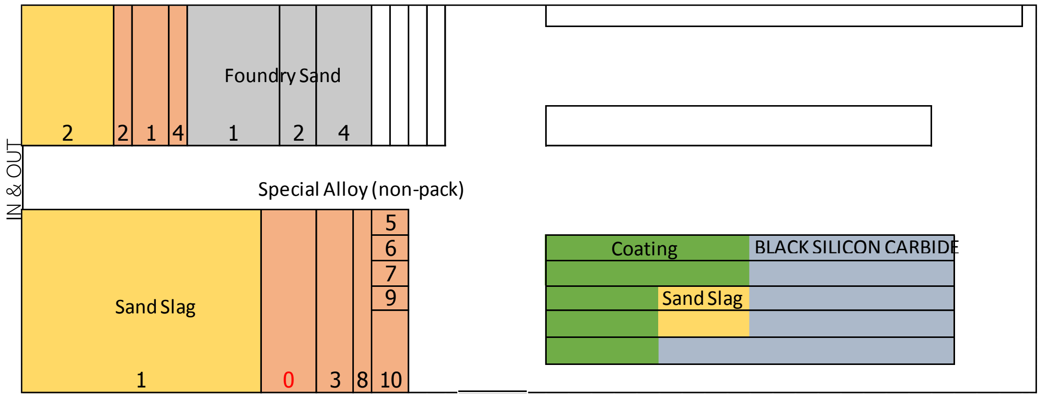


Figure 5.2: Validated Layout#3 of Warehouse 10

For Warehouse 8, 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 allocate products to every rack, there are left spaces in the top level of all selective racks. Some products require spaces more than the forecasting (20.7% of all products). We have to assigned more locations for that products in the top level of the selective racks. The products which increase in number of stocks are the Exothermic Sleeve and Ceramic Product.

For Exothermic Sleeve, the spaces in the top level of selective rack are sufficient for higher volume of products. Figure 5.3 presents rack G as an example of Exothermic Sleeve's rack before validating and Figure 5.4 presents the validated rack G. The number in each location represent products. Each colour presents a product category. The green colour in Figure 5.3 and Figure 5.4 represents Sleeve F. The numbers represent the products within product category.

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

Figure 5.3: Rack G

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

Figure 5.4: Validated Rack G

For the increasing in Ceramic Product, Ceramic Product is located in rack C together with Parting & Releasing Agent Product. On the contrary, the demand of Parting & Releasing Agent Product is decreasing. Then, we decrease the spaces for Parting & Releasing Agent Product equals to the highest stock volume in the first 6 months of 2015 and increase the locations of Ceramic Product. We increase the volume of Ceramic Product equal to the maximum volume in the first 6 months of 2015. Figure 5.5 presents rack C before validating and Figure 5.6 presents rack C after validating.

C

Ceramic Product　　Parting & Releasing Agent Product ←

				22	21	20	1	2	2	2	1	1	1	1	1	1	1		
19	18	16	13	12	4	2	1	2	2	2	1	1	1	1	1	1	1	1	1
18	11	9	5	8	4	3	1	2	2	2	1	1	1	1	1	1	1	1	1
18	11	10	5	4	2	3	2	2	2	2	1	1	1	1	1	1	1	1	1
18	17	15	7	4	2	6	2	2	2	1	1	X	X	X	X	X	X	X	X

Figure 5.5: Rack C

C

Ceramic Product — Parting & Releasing Agent Product

									3		2	2	2	1	1	1	1	1	1
	20	18	17	15	7	4	4	2	3	1	2	2	2	1	1	1	1	1	1
	19	18	16	13	12	4	2	3	6	2	2	2	2	1	1	1	1	1	1
22	18	11	9	5	8	4	2	3	1	2	2	2	2	1	1	1	1	1	1
21	18	11	10	5	8	4	2	3	1	2	2	X	X	X	X	X	X	X	X

Figure 5.6: Validated Rack C

5.2 Implementation

After choosing the best layouts for Warehouse 10, stack zone of Warehouse 8, and selective rack zone of Warehouse 8, we implement the plans.

5.2.1 Warehouse 10

For Warehouse 10, we have located the products according to the plan; Layout#2 of warehouse. The space for each product is enough and there are also left space. This because there are not many products in Warehouse 10 (20 bulk products) and the stocks are as same as we planned. Table 5.2 to Table 5.4 present before and after layouts of the Warehouse 10 in the three zones, A, B, and C.

Table 5.2: Implementation of Zone A of Warehouse 10

Zone A (Before)	Zone A (After)
	

Table 5.3: Implementation of Zone B of Warehouse 10

Zone B (Before)	Zone B (After)
	

Table 5.4: Implementation of Zone C of Warehouse 10

Zone C (Before)	Zone C (After)
	

5.2.2 Warehouse 8

For Warehouse 8, we have located the products according to the plans, Layout#2 of stack zone and Layout#4 of selective rack zone. The spaces for products in stack zone are sufficient, but the spaces in rack zone are not enough. The over capacity products will be located in the top floor of the selective rack as present in Table 5.8. Table 5.5 to Table 5.8 present the before and after layout of the Warehouse 8.

Table 5.5: Implementation of Zone A of Warehouse 8

Zone A (Before)	Zone A (After)
	

Table 5.6: Implementation of Zone B1 of Warehouse 8

Zone B1 (Before)	Zone B1 (After)
	

Table 5.7: Implementation of Zone B2 of Warehouse 8

Zone B2 (Before)	Zone B2 (After)
	

Table 5.8: Implementation of Selective Rack Zone of Warehouse 8

Stack Zone (Before)	Stack Zone (After)
	

5.3 Evaluate the layouts

First, we will evaluate the layout of Warehouse 8. There is no fix location in the old layout of warehouse 8. The products in same product category are located separately. The products can be located in any space, so it takes time to find the products. The old layout of Warehouse 8 is presented in Figure 5.7. The new layout of Warehouse 8 provide the fixed location of all products. The method locates products and product categories according to the frequency of picks, so it facilitate warehouse processes. The new layout is also efficient to use, since the products are assigned based on space-saving condition. The new layout Warehouse 8 reduce the total picking distance from 1068 km to 1034 km (34 km). This distance is measure from the total picking time and compare just the products which are currently located in Warehouse 8. The new layout of Warehouse 10 is shown in Figure 5.8.

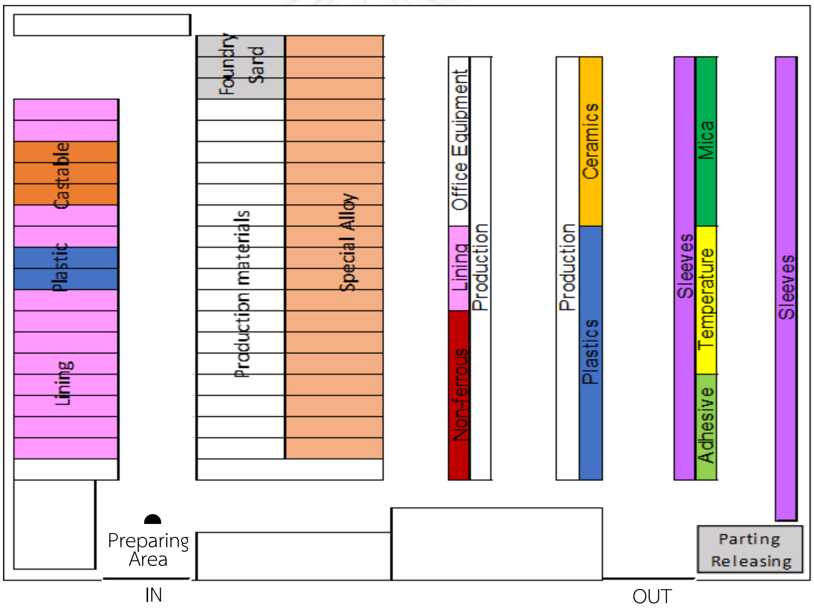


Figure 5.7: Old Layout of Warehouse 8

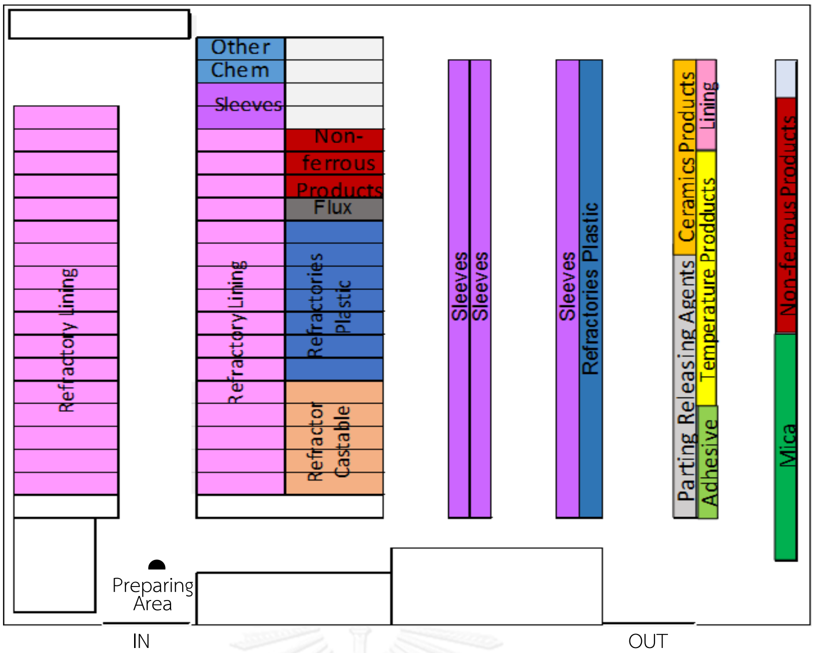


Figure 5.8: New Layout of Warehouse 8

We compare the layout to the plan from warehouse department. 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 concern 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 practical and very useful for the company. The layout from the warehouse department is shown in Figure 5.9.

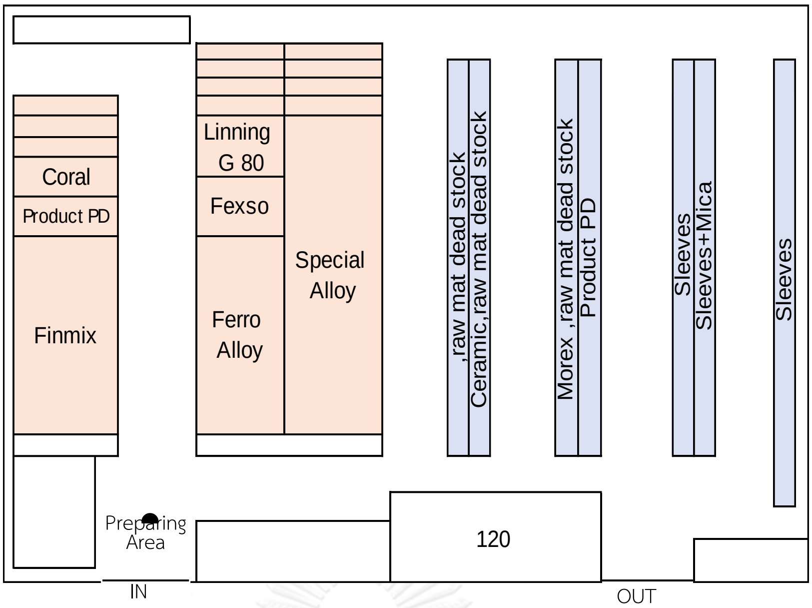


Figure 5.9: New Layout of Warehouse 8 from Warehouse Department

Second, we evaluated the layout of Warehouse 10. Since Warehouse 10 is the new warehouse which has not been assigned the location for any products, there is no compared old layout for Warehouse 10. However, we will evaluate the layout using the plan from the warehouse department. 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. The products are assigned in the appropriate places of their characteristics. As presented in Figure 5.10, there are non-selling products located in zone B which is closer to the preparing area than the locations of Foundry Sand and Special Alloy (green colour area). However, the planned spaces are too large. For example, the plan assign all of the flow rack lanes for Raw Material. It is too many lanes for this product category. Accordingly, the layout of Warehouse 10 from this research is more appropriate and well designed. Figure 5.11 presents the layout of Warehouse 10 from this research.

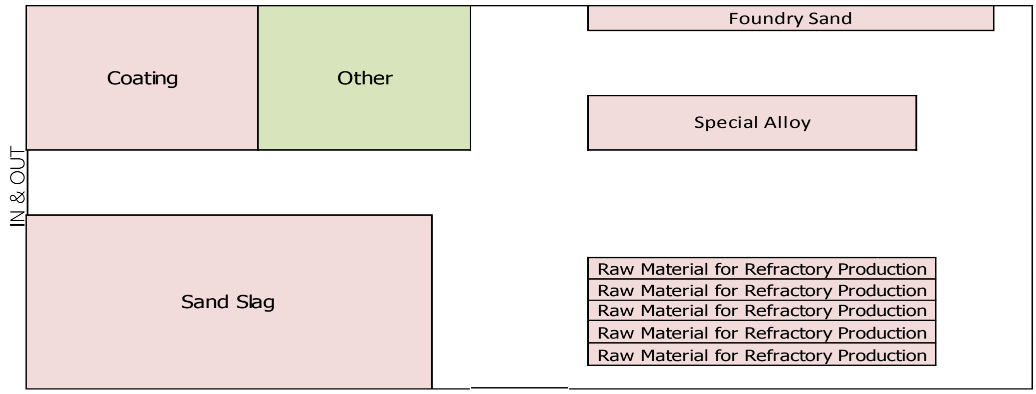


Figure 5.10: New Layout of Warehouse 10 from Warehouse Department

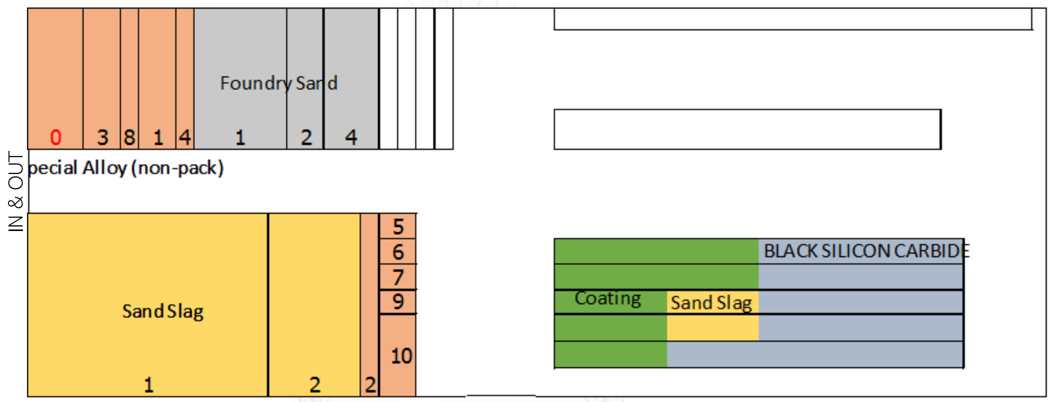


Figure 5.11: New Layout of Warehouse 10

CHAPTER 6:

Conclusion

6.1 Conclusion

The objective of this thesis is designing the layouts of the existing warehouse (Warehouse8) and the new warehouse (Warehouse 10) so that the space can be efficiently used and the picking distance from all invoices in 2014 is low. According to the company policy, Warehouse 10 is constructed and products in temporary warehouses (Warehouse 3A, Warehouse 4, and Warehouse 5) will be located in permanent warehouses. The company wants to divide product categories for the two warehouses and assign the location for each products. Total picking distance, saving space, and product characteristics are the constraints of developing layouts for both warehouses. Many layouts are developed. The best layouts give the best trade-off between, using space, total picking distance, and warehouse processes. The layout should encourage the warehouse processes and proper for products' qualification and limitation which the research have to study all of the details of the warehouse processes and nature of the products. After deciding the layout for both warehouse, adjusting and implementing is proceeded.

There are three main phase in developing layouts. First phase is grouping product categories for each warehouse. In order to group product categories, understanding and identifying company requirements are important. Then, product categories will be divided using the constraints. This is the first grouping plan. Next step is calculating the space requirements from the first grouping plan and comparing to the warehouse capacity. After that, the plan will be adjust and the final grouping plan is developed. Warehouse capacity, stock size, and Product size are all required data for this phase.

Second phase is designing the layout for Warehouse 8 and Warehouse 10. It starts from identifying and understanding the special requirements of the layout and products. Then, we calculate the number of picking of products and products categories. The rank of picking is used in developing all layouts. This phase required the invoice data in order to calculate the number of picking. After that, the layouts for both warehouse are developed and compared. Layouts are developed based on the number of picking and suitability of the location for each product. Warehouse processes are considered during developing. The best layouts give the best trade-off between left space, total picking distance, and usability of the layout. The thesis develops layout logically by looking at all possibility.

Third phase is implementation. Warehouse 8 and Warehouse 10 are implemented. Before implementing, the layouts have to be validated. To be up-to-date, this research has to look at the current information and adjusts the layouts.

When comparing the new layout (Warehouse 8) to the old layout, the new layout Warehouse 8 reduce the total picking distance of the same products from 1068 km to 1034 km (reduce the total distance 34 km). Since this research considers the stock data, the provided spaces from the developed layouts are sufficient. The provided spaces of 79.3% of all studied products are sufficient. The planed layout without considering the spaces for individual product cannot well design the location for products correctly. This research also design warehouses based on the characteristics of the products. We assign the location for Fragile Products, Sell-in-piece Products, and In-house Products in Warehouse 8 which is the main warehouse of the company (close to the shipping area and production warehouse). We design the locations in product category level and product level under the company constraints and product constraints. For example, some products have to locate in the first floor of the rack. We assign these product on the first floor of the rack. It is important to understand the products and locate them in the appropriate locations.

This research proposes the systematic and practical layout designing method for automotive industry. This method uses the past data together with the constraints and observed data in order to develop the layouts. The layout is adaptive for any company since the method consider the product constraints and company requirements.

6.2 Recommendation

The objective of this research is designing the layout of warehouses in order to efficiently use the space and have low total picking distance. ABC analysis and class-based storage are applied in for developing the methodology. The total picking distance is the sum of all products' picking distances in 1 year (2014). In the future, the rank of products and product categories may change. It is important to revise the invoice data and revise the layouts of the warehouses.

This research focuses on the designing the layouts of the warehouses. For the next step, the company should study the operational design of order picking, i.e., picking policy and the picking route etc. Since the company does not have the standard picking time, developing standard picking time is also recommended of the next step. The company should also measure and develop the standard time. The standard picking time is useful in efficiency measurement, e.g., it evaluating the warehouse officials' performances.

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APPENDICES

Appendix A:

Candidate Layouts of Warehouse 10

Appendix A describes two concepts of layout designing for Warehouse 10 in details. The concepts of Layout#3 and Layout#4 are described.

1) Layout#3 of Warehouse 10

The designing concept of this layout is similar to Layout#2's concept (locating products which have low number of pallets per stack in flow rack and considering the space-saving condition in stack area.) The different between Layout#2 and Layout#3 is the logics of locating Sand Slag in stack area. We assign the same product as Layout#2 in the flow rack, since this decision results in maximum available space (as mentioned in previous layout designing process.)

We follow the process from first process to fourth process. All Coating products, Raw Material for Refractory products, and one product of Sand Slag are assigned in the flow rack. We continue the final process. Finally, we design the layout of products in stack area. We decide to locate Sand Slag separately as presented in Figure A.1. Sand Slag-SKU-1 is in zone A and Sand Slag-SKU-2 is in zone B.

Total number of picking of Foundry Sand is higher than the left Special Alloy products. Accordingly, we locate Foundry Sand next to Sand Slag-SKU-2. There is limited space in zone A, so we locate some Special Alloy products transversely and Special Alloy-SKU-4 is located in another zone (zone B.)

Figure A.2 presents Layout#3 of Warehouse 10. . Designing process is summarised in flow process chart as presented in Figure A.2.

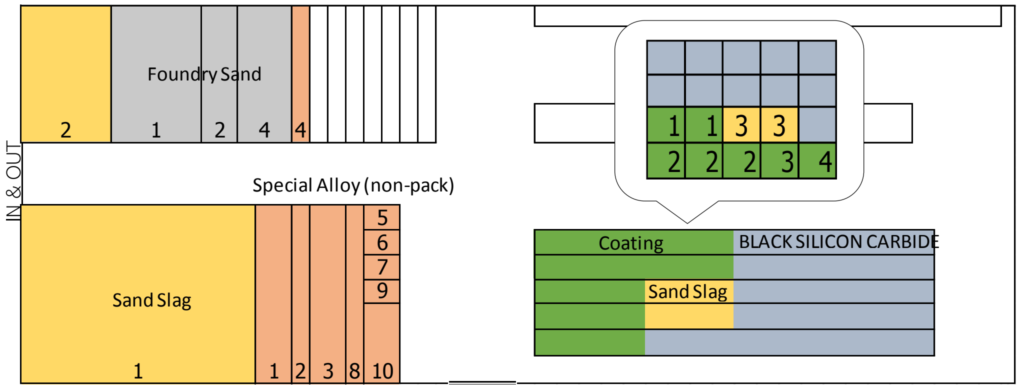

Figure A.1: Layout#3 of Warehouse 10

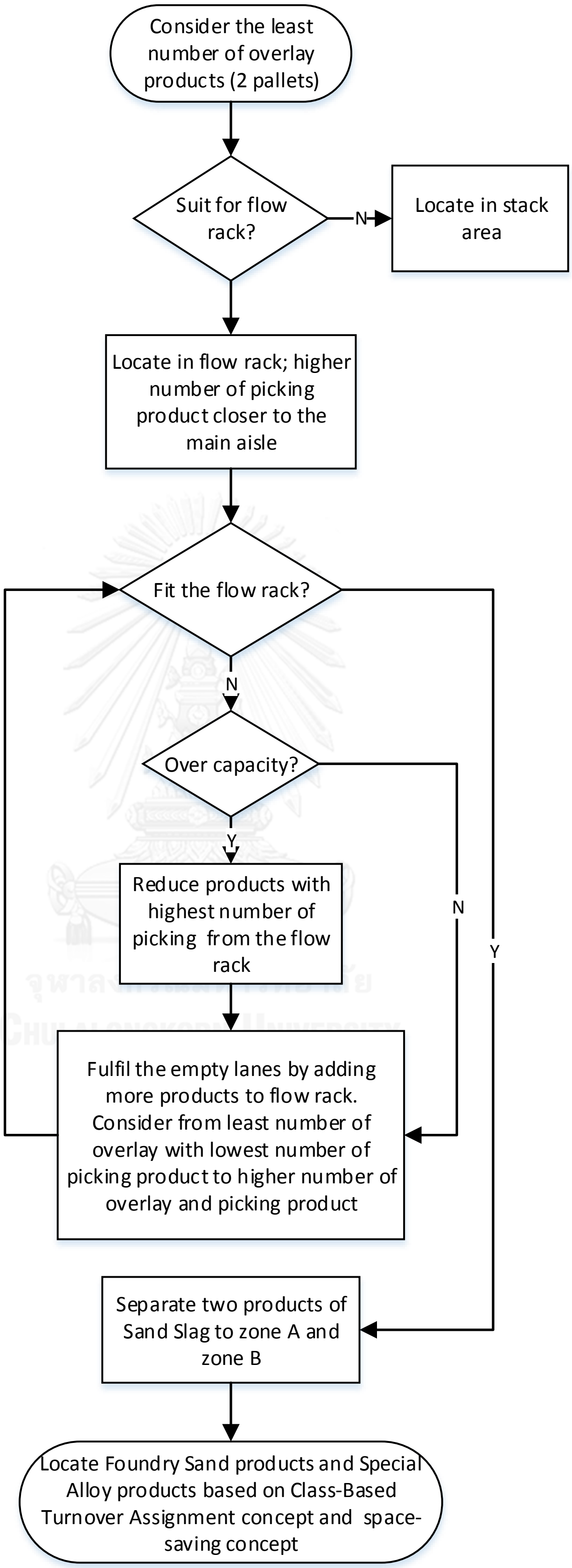

Figure A.2: Layout#3 Designing Process for Warehouse 10

2) Layout#4 of Warehouse 10

The designing concept of this layout is to locate products which have low number of pallets per stack in flow rack and assign 1 row for 1 product in stack area. The selected products and locations in flow rack are as same as the Layout#2 and Layout#3, since this decision results in maximum available space.

We locate products in flow rack using the same logic as designing Layout#2. We follow the process from first process to fourth process. All Coating products, Raw Material for Refractory products, and one product of Sand Slag are assigned in the flow rack. Then, we continue the final process.

Finally, we design the layout of products in stack area. We decide to locate Sand Slag separately as presented in Figure A.3. We located the second high number of picking; special Alloy; in zone A next to Sang Slag-SKU-2. Then, we locate Foundry Sand in zone B as presented in Figure A.3. Figure A.3 presents Layout#3 of Warehouse 10. Designing process is summarised in flow process chart as presented in Figure A.4.

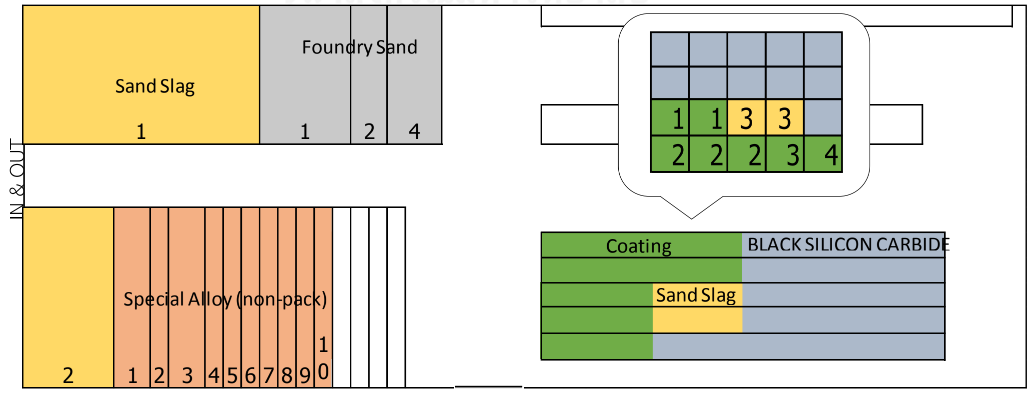

Figure A.3: Layout#4 of Warehouse 10

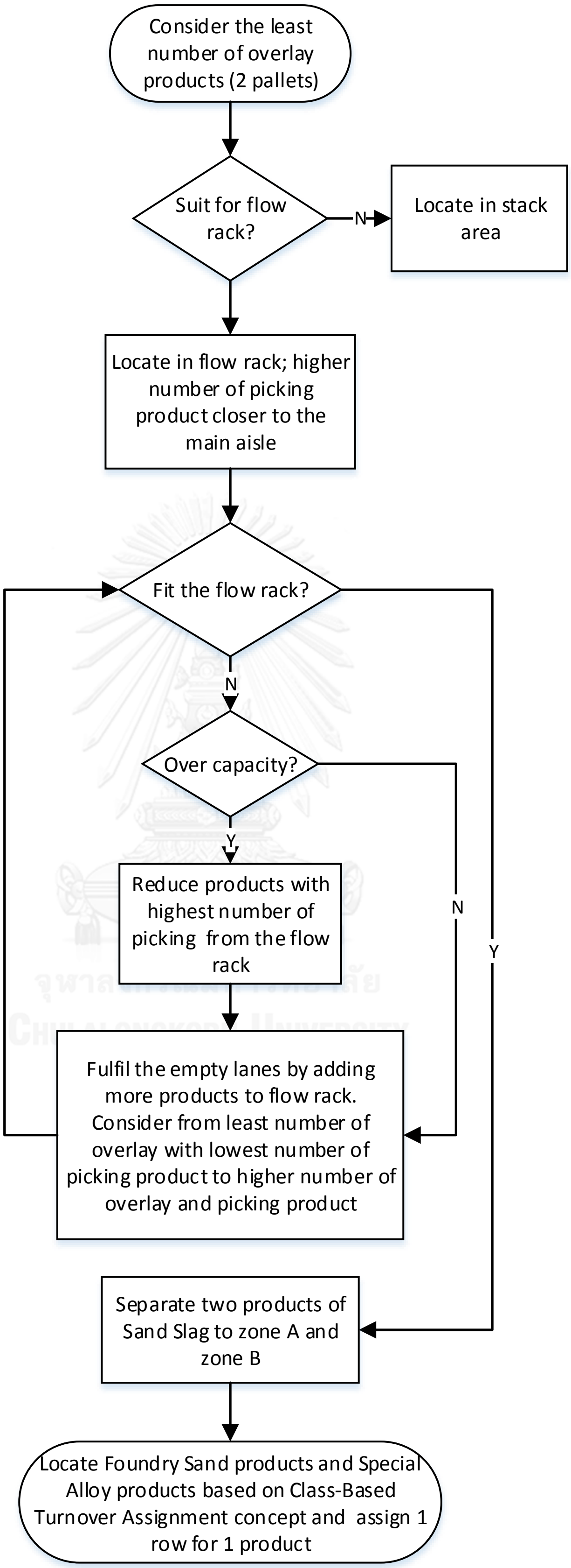

Figure A.4: Layout#4 Designing Process for Warehouse 10

Appendix B:

Candidate Layout of Stack Area of Warehouse 8

Appendix B describes five concepts of layout designing for stack area of Warehouse 10 in details. The concepts of Layout#3 to Layout#7 are described.

1) Layout#3 of stack zone of Warehouse 8

The concept of this layout is to locate products of Refractory Lining with higher number of picking closer to the preparing area and gather vacant rows in zone A.

We choose the shortest distance location for each Refractories Lining product and remain vacant rows in zone A as many rows as possible. After that, we locate other product categories in zone B2 and B1 in order. There are 2 vacant rows left in zone A and 1 vacant row in zone B2. Figure B.1 presents the layout#3 of stack zone of Warehouse 8.

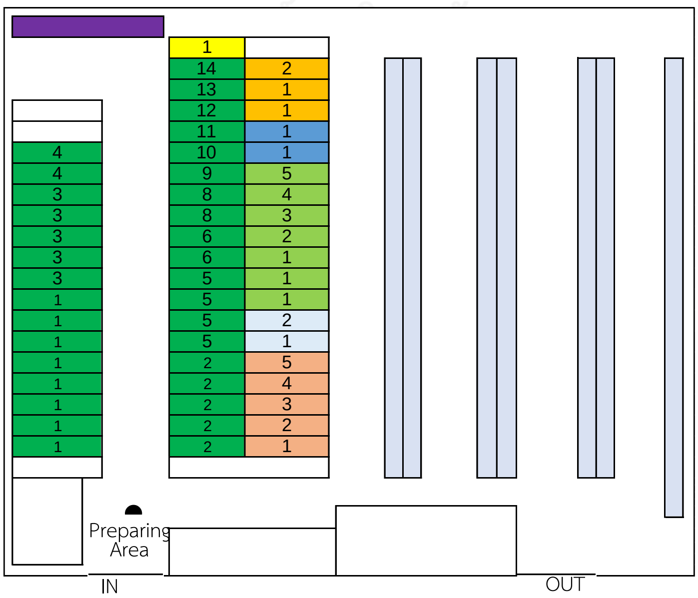

Figure B.1: Layout#3 of Stack Zone of Warehouse 8

2) Layout#4 of stack zone of Warehouse 8

The concept of this layout is to locate products of Refractories Lining with higher number of picking closer to the preparing area and gather vacant rows in zone B1.

We choose the shortest distance location for each Refractories Lining product and remain vacant rows in zone B1 as many rows as possible. After that, we locate other product categories in zone B2. There are 1 vacant rows in zone A and 3 vacant rows in zone B1. Figure B.2 presents the layout#4 of stack zone of Warehouse 8.

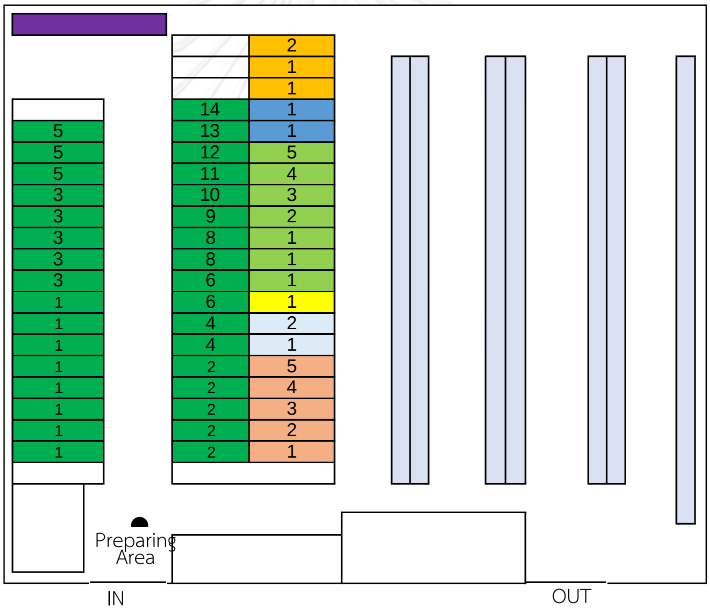

Figure B.2: Layout#4 of Stack Zone of Warehouse 8

3) Layout#5 of stack zone of Warehouse 8

The concept of this layout is to locate products of Refractories Lining with higher number of picking closer to the preparing area and gather vacant rows in zone B2.

We choose the shortest distance location for each Refractories Lining product and remain vacant rows in zone B2 as many rows as possible. After that, we locate other product categories in zone B1 and B2, respectively. There are 1 vacant rows in zone A and 3 vacant rows in zone B2. Figure B.3 presents the layout#5 of stack zone of Warehouse 8.

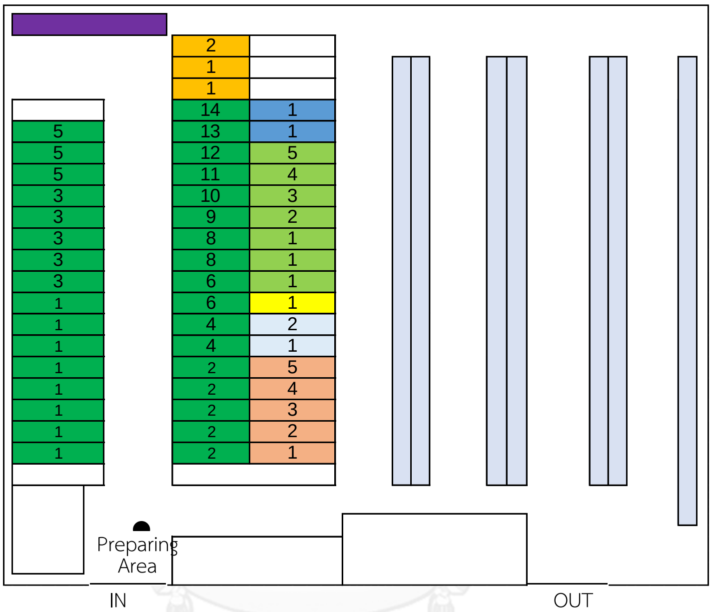

Figure B.3: Layout#5 of Stack Zone of Warehouse 8

4) Layout#6 of stack zone of Warehouse 8

The concept of this layout is similar to the concept of layout#2, locate Refractories Lining products in order and gather vacant rows in zone B2. However, this layout swaps the location of Exothermic Sleeves & Powder and Other Chemical with Flux and Non-ferrous Product & Other Fluxes. There are 4 vacant rows in zone B2. Figure B.4 presents the layout#6 of stack zone of Warehouse 8.

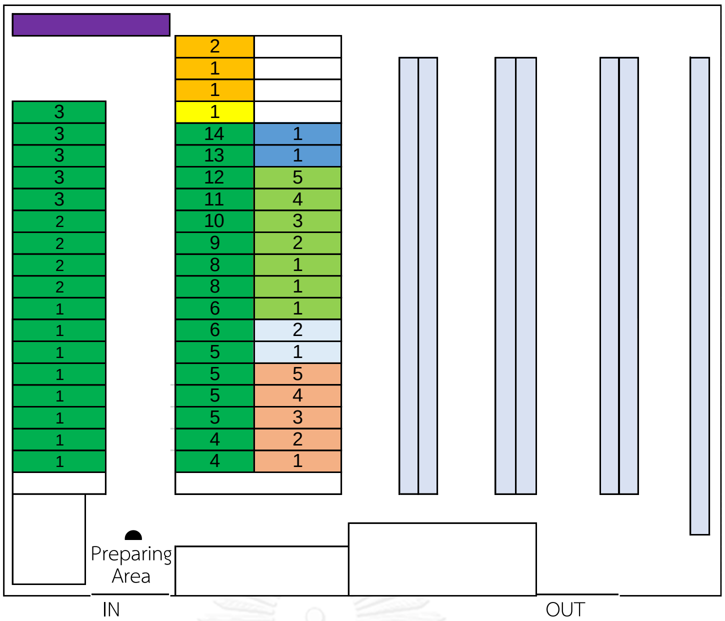

Figure B.4: Layout#6 of Stack Zone of Warehouse 8

5) Layout#7 of stack zone of Warehouse 8

The concept of this layout is also similar to the concept of layout#2; locate Refractories Lining products in order and gather vacant rows in zone B2. This layout changes the location of Other Chemical with Flux. There are 1 vacant rows in zone B1 and 3 vacant rows in zone B2. Figure B.5 presents the layout#7 of stack zone of Warehouse 8.

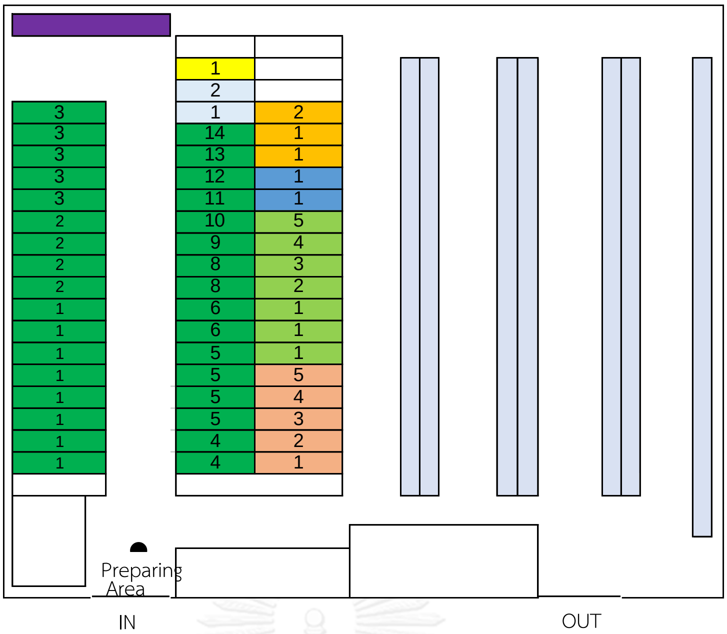

Figure B.5: Layout#7 of Stack Zone of Warehouse 8

VITA

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