STORAGE LOCATION ASSIGNMENT PROBLEM IN WAREHOUSE OPTIMIZATION BY OPENSOLVER

BY

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AN INDEPENDENT STUDY SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
ACADEMIC YEAR 2024

THAMMASAT UNIVERSITY

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

INDEPENDENT STUDY

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ENTITLED

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was approved as partial fulfillment of the requirements for
the degree of Master of Engineering (Logistics and Supply Chain Systems Engineering)

on November 23, 2024

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Academic Years	2024

ABSTRACT

Effective storage location assignment within warehouses is a critical determinant of operational efficiency, cost savings, and customer satisfaction. This independent study explores the intricate challenges posed by the Storage Location Assignment Problem (SLAP) and delves into the application of OpenSolver, a powerful optimization tool, to enhance distance optimization within warehouse operations.

The central objective of this research is to design and evaluate innovative strategies for optimizing storage location assignments in a way that minimizes travel distances. The study will begin by conducting an extensive literature review to assess existing storage location assignment approaches and the role of optimization tools in the warehousing context. Subsequently, developing mathematical models and algorithms, leveraging OpenSolver's capabilities, to tackle SLAP.

This investigation aims to address the complexity of warehouse operations by accounting for factors such as product placement, retrieval paths, order picking, and the interplay of these elements. The study will evaluate various storage location assignment algorithms in terms of key performance indicators, with a primary focus on minimizing travel distances and improving overall warehouse efficiency.

In conclusion, this independent study offers a comprehensive exploration of the Storage Location Assignment Problem in warehouses, employing OpenSolver as a powerful tool for distance optimization. The findings from this research will contribute valuable insights to warehouse managers and logistics professionals, aiding them in enhancing operational efficiency and ultimately driving success in the competitive world of modern warehousing.

Keywords: Storage location assignment problem, Storage policy, Storage location assignment problem optimization

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to all those who supported me throughout the completion of this independent study. First and foremost, I would like to thank my advisor, Jirachai Buddhakulsomsiri, Ph.D , for their guidance, encouragement, and insightful feedback. Their expertise and unwavering support were invaluable to the success of this research.

I would like to acknowledge EssilorLuxottica for providing the necessary data and allowing me access to their facilities, which played a crucial role in the practical application of my research.

Lastly, I am forever grateful to my family and friends for their constant encouragement, patience, and support throughout this journey. Without their understanding and motivation, this study would not have been possible.

Burawatchara Dumnurn

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

The efficient management of warehouse operations is paramount in today's increasingly competitive and complex supply chain environments. Warehouses serve as pivotal nodes in the logistics network, responsible for the receipt, storage, and distribution of goods. Among the numerous challenges faced by warehouse managers, one problem that stands out as a critical determinant of overall efficiency is the "Storage Location Assignment Problem."

The Storage Location Assignment Problem, often abbreviated as SLAP, represents a class of optimization challenges that pertain to the allocation and assignment of products to specific storage locations within a warehouse. The goal is to maximize the utilization of available storage space, streamline order-picking processes, and minimize operational costs, all while adhering to various constraints and operational requirements.

This independent study will use the information and data from EssilorLuxottica company which currently setting up a new plant in Rayong province, Thailand. This plant will have 2 main warehouses which are the “Finished Frame Warehouse” and “Industrial Warehouse”. The finished frame warehouse will mainly focus on the storage of finished goods. On the other hand, an Industrial warehouse will be used to store raw material components. In this study, the author will use an industrial warehouse to be our storage location and focus on the picking process only.

1.1 Industrial warehouse

An industrial warehouse is a warehouse that is used for the purpose of storing raw materials. To make eyeglasses, there are 4 main categories of components which are Decoration (Screw, Plastic, and Sticker), Front, Temple, and lenses. Every component will be stored in a bin.

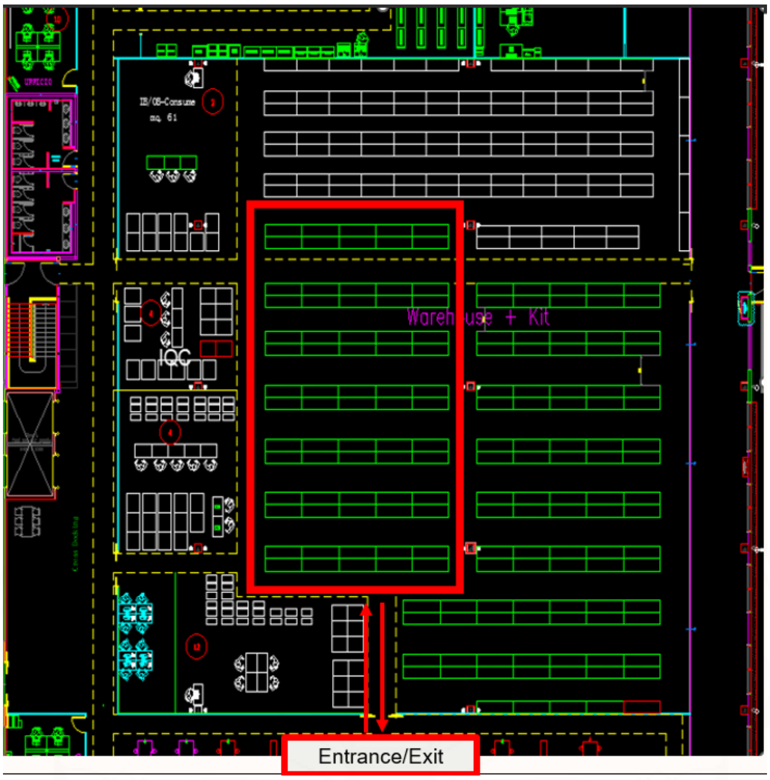


Figure 1.1 Industrial Warehouse layout and area being used in the start-up phase

From Figure 1.1, It shows the storage layout of the industrial warehouse. The area in the red box will be used in the start-up phase. The green box in the figure represents the rack, 70 racks will be used. Each rack will have 8 levels. There are 3 bins per level of each rack as shown in
Figure 1.2.

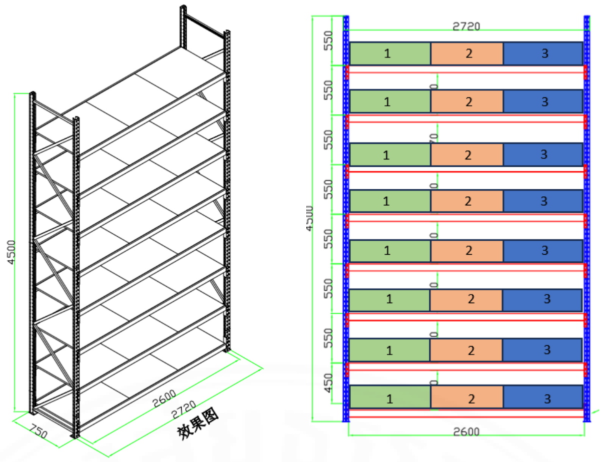


Figure 1.2 Rack drawing and bins location

To make the optimization simple but powerful, there will be 70 storage locations in total but each location will contain 24 bins which means that in total, this warehouse will have 1,680 bins. However, In this independent study, only 3 levels on each rack will be used to store the components. Total warehouse capacity will be 630 bins with 12 periods of day to store the SKUs.

The warehouse will utilize a standard unit of handling called "MasterBox" to store components. Each master can accommodate components in varying standard quantities, as represented in Figure 1.3. The item category code will be included in the SKU. name.

ITEM CATEGORY	Description	QTY/Masterbox
FM	DECORATION	200
PE	DECORATION	3,000
PM	DECORATION	400
VT	DECORATION	5,000
ZP	DECORATION	400
AL	DECORATION	2,500
GL	DECORATION	400
CR	DECORATION	200
BU	DECORATION	5,000
SL	DECORATION	180
ML	DECORATION	5,000
NS	DECORATION	5,000
FR	FRONTS	50
RB	FRONTS	50
CL	FRONTS	100
ME	FRONTS	100
LG	LENSES	50
LS	LENSES	200
AJ	TEMPLES	100
AM	TEMPLES	200
TE	TEMPLES	400

Figure 1.3 Standard Unit for each of SKU category

On each bin the maximum capacity that can keep the master box is only 50 boxes Based on this information, the total capacity for this warehouse will be 630 bins or 31,500 master boxes

1.2 Picking process flow in the warehouse

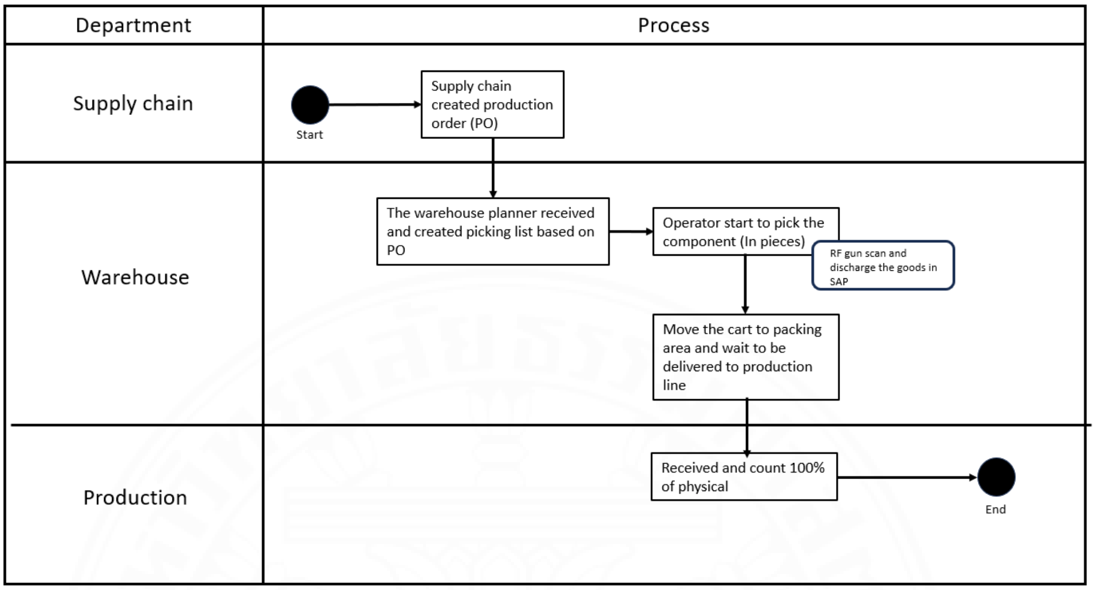


Figure 1.4 Picking process flow chart

Figure 1.4 shows the picking process flow, The process will start with the supply chain department creating a production order (PO) by SAP. The warehouse department receives the information inside the program and starts to generate a picking list based on the production order then the operator will pick the component in pieces based on the picking list and move the component to the packing area for pack and delivery to the production line. The production receives the component and starts to do the counting.

1.3 Objective

This independent study aims to focus on minimizing the total distance of the operator in the picking process. There are 2 scenarios that are used for the optimization of the total distance for the picking process. Scenario 1 will set the storage location grouping by the component. Scenario 2 will be grouped by brand.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Storage Location Assignment

The effective management of storage locations in a warehouse plays a crucial role in optimizing the efficiency and overall performance of the supply chain. Two key aspects of this management are storage assignment for newly arrived items in forward picking areas and solving the storage location assignment problem. In recent years, researchers have explored various approaches and techniques to address these challenges.

In the study by Guo et al., the authors focused on the issue of storage assignment for newly arrived items in forward-picking areas with limited open locations. This problem is particularly relevant in settings where the forward picking area is constrained, making it essential to allocate storage spaces effectively. Guo and his colleagues addressed this challenge in the context of transportation and logistics, emphasizing the importance of optimizing the allocation of storage space to ensure efficient order fulfilment. Their work is a testament to the significance of effective storage assignment in the domain of fast-moving inventories and emphasizes the need for innovative approaches to solve such problems.

On a related note, Leon et al.delved into solving the realistic storage location assignment problem using a discrete-event simheuristic approach. Their research was driven by the recognition that real-world warehousing scenarios often involve intricate complexities that require sophisticated solutions. In their study, they presented a novel simheuristic technique tailored for addressing storage location assignment problems, acknowledging the challenges posed by factors such as warehouse layout, operational constraints, and dynamic inventory profiles. Their approach reflects a real-world orientation, seeking practical solutions to the intricacies of warehouse management.

In the study by Ren-Qian Zhang, Meng Wang. , the authors focus on the new model of the storage location assignment problem considering the demand correlation pattern. The Storage Location Assignment Problem has been extensively studied due to its impact on warehouse efficiency, particularly in order-picking operations. Traditional methods often focus on item properties like popularity, volume, or turnover.

However, some studies have shown greater efficiency in correlation-based strategies, which assign items commonly picked together to nearby locations (De Koster et al., 2007). The demand correlation pattern (DCP) model, introduced by Zhang et al. (2019), offers a novel approach, considering multi-item correlations to improve travel distances during order picking. This model, along with heuristic and simulated annealing methods, has been tested against real-world data and has shown significant improvements in warehouse order-picking efficiency.

Various strategies have been explored in Storage Location Assignment Problem . Basic strategies, such as random and dedicated storage assignments, offer simplicity but can result in inefficiencies when multiple items need to be picked together. More advanced strategies, such as class-based and correlation-based assignments, seek to improve picking efficiency by clustering related items. Correlation-based strategies aim to minimize travel time by storing frequently ordered items near each other, which has been demonstrated to reduce picking times significantly (Bindi et al., 2009; Liu, 2004).

Simulated annealing is another method applied to the Storage Location Assignment Problem. It has been widely used in order-picking problems due to its ability to provide efficient solutions for complex, NP-hard problems like the Storage Location Assignment Problem (Muppani & Adil, 2008). The combination of heuristic and Simulated annealing methods has yielded competitive results in optimizing item assignments and reducing picking distances.

The effective management of warehouse storage locations is critical for optimizing supply chain performance, particularly in order-picking operations. Studies have explored various methods, from traditional item-based strategies to more advanced approaches like demand correlation patterns (DCP). Guo et al. addressed storage allocation in forward-picking areas, while Leon et al. proposed a discrete-event simheuristic for complex warehouse environments. Zhang et al. introduced a DCP model to improve picking efficiency by grouping frequently ordered items together. Simulated annealing has also proven effective for solving complex storage location assignment problems.

2.2 Optimization Techniques

Efficient warehouse management is essential for optimizing supply chain operations and improving overall business performance. In the realm of warehouse operations, two critical aspects are the optimization of route planning for order picking and solving location assignment problems. Researchers have made significant strides in developing innovative techniques to address these challenges, as evidenced in the following studies.

Shetty, Sah, and Chung (2020) conducted a study focusing on route optimization for order-picking operations within a warehouse. Their work, as described in the reference, was a multidisciplinary approach that combined concepts from vehicle routing and simulation. The authors recognized that route optimization is a central element in warehouse management, impacting the speed and efficiency of order fulfilment. To tackle this problem, they employed advanced modelling and simulation techniques to develop and validate route optimization strategies. Their approach represents a practical means of improving order picking efficiency, ultimately leading to cost savings and enhanced customer service.

In a related vein, Bolaños-Zuñiga, Salazar-Aguilar, and Saucedo-Martínez (2023) explored the challenges of solving both location assignment and order picker-routing problems within the context of warehouse management. The researchers, as detailed in reference, recognized that the allocation of products to specific storage locations, as well as the routing of order pickers, are interrelated aspects of efficient warehouse operations. By addressing these problems in tandem, they offered a comprehensive approach to warehouse optimization. Their study showcased the importance of holistic solutions that account for multiple intricacies in modern warehousing, such as dynamic inventory profiles and varying operational constraints.

Both references highlight the vital role of optimization in warehouse management. Shetty et al. employed a simulation-based approach that combined vehicle routing techniques to optimize order-picking routes, whereas Bolaños-Zuñiga et al. adopted a broader perspective, addressing both location assignment and order picker-routing issues. These studies exemplify the ongoing pursuit of innovative methodologies to streamline and improve warehouse operations, emphasizing practical implications for logistics and supply chain management.

In conclusion, these studies collectively underscore the significance of route optimization and location assignment in the warehouse management domain. The research by Shetty et al. and Bolaños-Zuñiga et al. represents an effort to develop sophisticated methodologies tailored to address the complexities of modern warehousing operations. Their work emphasizes the need for holistic and efficient solutions that consider the interplay of various factors, ultimately contributing to enhanced supply chain performance and customer satisfaction.

2.3 Research Gap and Research Opportunity

From reference research paper topic 2.1, it focuses on how to assign the storage location based on Fast-moving inventory policy, zoning and optimising the total distance from the discrete-event simheuristic approach program which is the Flexsim program. Reference research paper topic 2.2, focuses on creating a route in the warehouse and then optimizing the total distance by using an Excel open solver based on VRP logic.

By combining these two research papers, Using a discrete-event simulation program seems to be difficult. The author can see the opportunity to create a optimise the total distance by using an Excel open solver and using fast-moving product concepts to prioritize and assign the storage location.

CHAPTER 3
METHODOLOGY

To complete the objective of this independent study, it is important to organize the process of work. There are 3 main processes of this independent study. For the first data collection, 2 months of picking list will be used. The second is data analysis and warehouse profile. The third is optimization by using Opensolver.

3.1 Data collection

Figure 3.1 displays 6 columns utilized for analysis. This data accumulates over a period of 2 months. Each row includes the date, picking list, Production Order, Component, Component category, Brand, and quantity, providing sufficient information to analyze the movement trends of each SKU.

Pick date	Picking List Nr.	Pro Order	Component	Comp Cat	Brand	Quantity
6/1/2023	11844050	1833847017	1LSRX7140	LENSES	Raybans	26.000
6/1/2023	11844614	1833473124	1PE1614A00	DECORATION	Oakley	10.000
6/1/2023	11848225	1830459562	1VT0922A00	DECORATION	Raybans	600.000
6/1/2023	11848226	1830459562	1GL0232C00	DECORATION	Raybans	300.000
6/1/2023	11848226	1830459562	1GL1439001	DECORATION	Raybans	300.000
6/1/2023	11844299	1833634121	1VT291	DECORATION	Raybans	100.000
6/1/2023	11844299	1834252079	1VT0922A00	DECORATION	Raybans	8.000
6/1/2023	11844300	1833634121	1FM4086A0T	DECORATION	Raybans	4.000
6/1/2023	11844300	1833847017	1PM5853B0T	DECORATION	Raybans	2.000
6/1/2023	11844300	1834394021	1FM4086A0T	DECORATION	Raybans	13.000
6/1/2023	11844301	1834252079	1AJ7144A0T	TEMPLES	Raybans	4.000
6/1/2023	11845659	1830459645	1LSRJ9052S	LENSES	Raybans	13.000
6/1/2023	11845660	1834252585	1FR1882A00	FRONTS	Raybans	1.000
6/1/2023	11844615	1833473124	1GL3243A00	DECORATION	Oakley	5.000
6/1/2023	11844615	1834129747	1GL1439001	DECORATION	Raybans	4.000

Figure 3.1 Example table of data

3.2 Data analysis and Warehouse profile

Assigning storage locations for each component based on fast-moving and slow-moving strategies requires significant data analysis to gain insight into warehouse operations. Initially, Microsoft Excel was employed for data preparation. The results revealed 247 SKU components appearing within 2 months, totalling 7,923,512.00 pieces. To develop a warehouse profile, further analysis is essential, focusing on SKU movement trends based on two scenarios: firstly, movement by brand followed by component, and secondly, movement by component followed by brand.

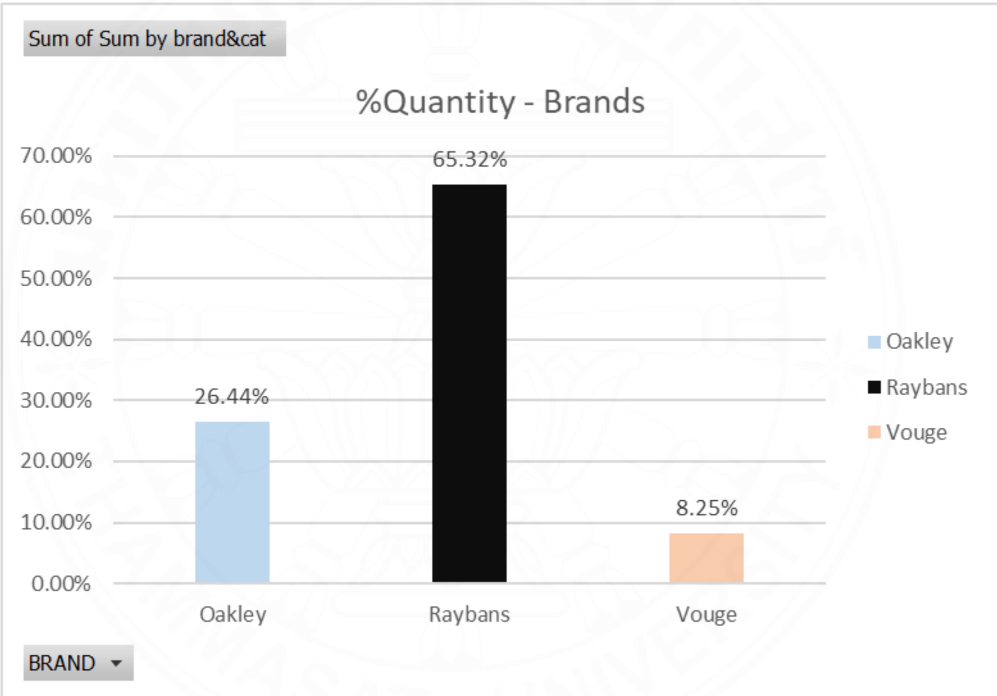


Figure 3.2 %Quantity – Brands graph

Figure 3.2 shows the analysis of the first scenario which is storage by brand and followed by component. Out of the total quantity of SKU stored in the warehouse, 65.32% is allocated for serving Raybans, followed by 26.44% for Oakley, and approximately 8.25% for Vouge as showing in figure 5. With this information, the sequence for assigning storage locations should prioritize SKU serving Raybans, followed by those for Oakley and Vouge, respectively.

Once the sequence for each brand is determined, it's crucial to consider the percentage of component categories to optimize storage location assignments for efficiency. Figure 3.3 will illustrate a graph depicting the percentage of quantity based on component categories and brands, aiding in this optimization process.

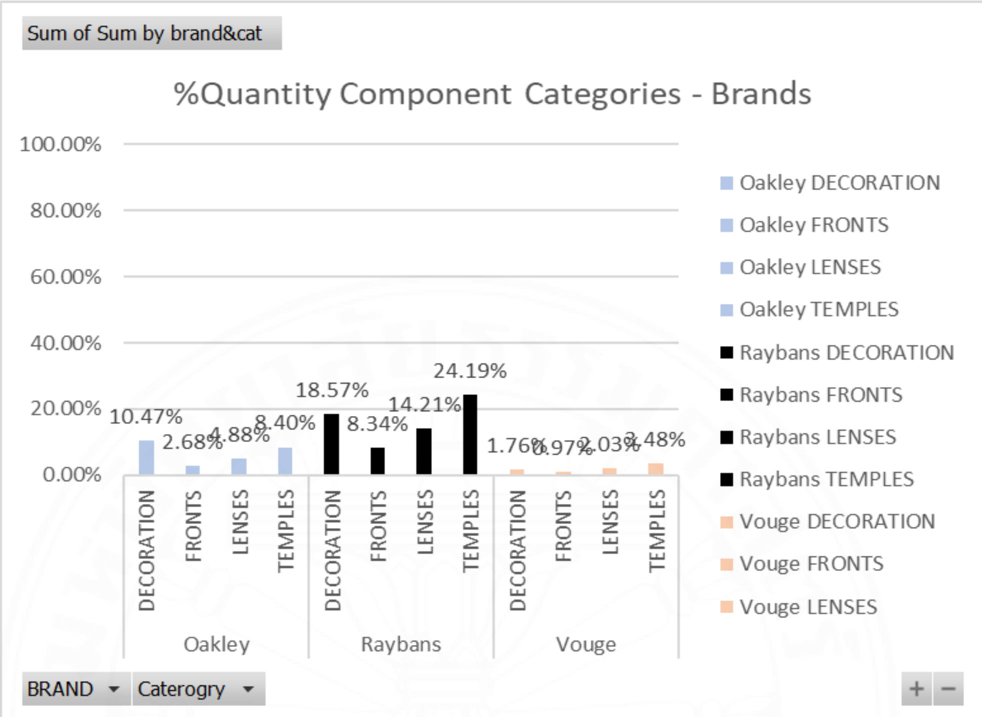


Figure 3.3 %Quantity Component Categories – Brands graph

With 65.32% allocated to Raybans, the sequence of component categories within should commence with Temples, followed by Decoration, Lenses, and Fronts. For Oakley, representing 26.44%, the sequence begins with Decoration, then Temples, Lenses, and Fronts. Finally, with Vouge at 8.25%, the sequence inside should start with Temples, followed by Decoration, Lenses, and Fronts.

In the second scenario, where storage is organized by component categories followed by brands, Figure 3.4 illustrates the total percentage of component categories stored in the warehouse. With 36.07% allocated to temples, 30.81% to decoration, 21.12% to lenses, and 12.00% to fronts, the order for arranging storage locations based on components should start with temples, followed by decorations, lenses, and fronts, respectively.

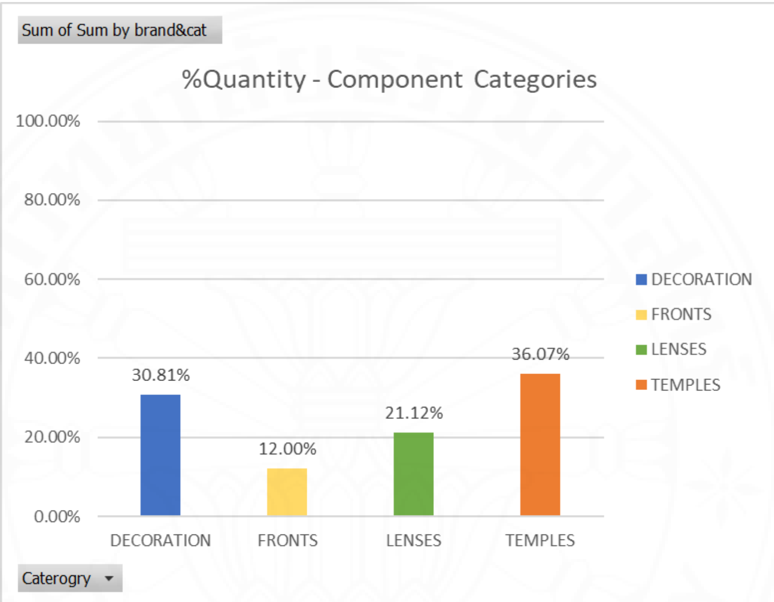


Figure 3.4 %Quantity Component Categories graph

To gain deeper insights into the movement behavior based on these four categories, brands should play a significant role in the analysis, as depicted in Figure 3.5 below. The graph indicates that within each category, the sequence should start with Raybans, followed by Oakley and Vouge.

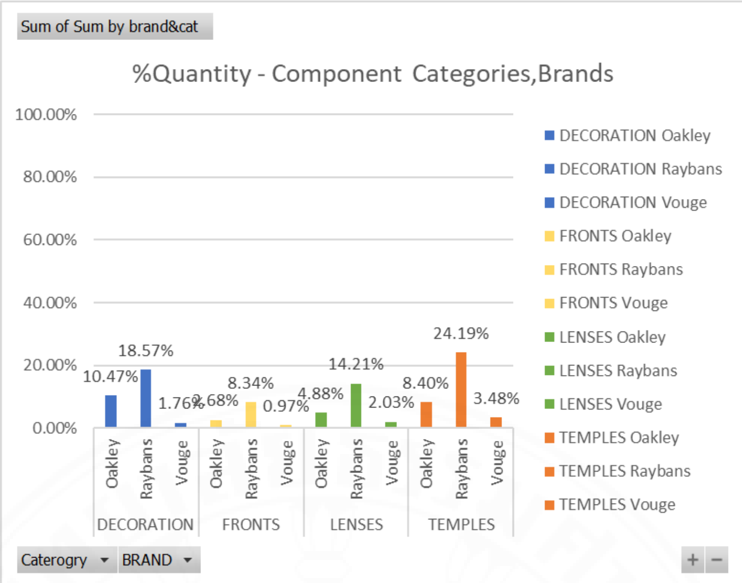


Figure 3.5 %Quantity Component Categories, Brands graph

3.3 Storage Location assigned and Layout Strategies

To assign storage locations to each SKU effectively, additional information is crucial. This includes identifying the high runners for each SKU and determining the quantity required to cover a 12-day period.

To determine the high-runner product, the sorting function in Microsoft Excel will be instrumental in facilitating analysis based on there quantity.

Component	CUT comp	Comp Cat	Brand	Quantity
1LSRB4171	LS	LENSES	Raybans	453,420.00
2AM5086A01	AM	TEMPLES	Raybans	367,260.00
1TE2130A00	TE	TEMPLES	Raybans	289,804.00
2VT0100001	VT	DECORATION	Raybans	185,193.00
1AM5086G0T	AM	TEMPLES	Raybans	176,114.00
1FR1882A00	FR	FRONTS	Raybans	162,286.00
1ZP1330B0T	ZP	DECORATION	Raybans	160,024.00
1AL1354A0T	AL	DECORATION	Oakley	154,640.00
1TE2130C00	TE	TEMPLES	Raybans	144,462.00
2RB4171A01	RB	FRONTS	Raybans	129,900.00
1TE3993A0T	TE	TEMPLES	Vouge	126,398.00
1TE0215000	TE	TEMPLES	Raybans	114,404.00
1TE3908B0T	TE	TEMPLES	Raybans	113,898.00
2GL2886C01	GL	DECORATION	Raybans	112,620.00
1AM8370B0T	AM	TEMPLES	Vouge	93,820.00
1FM4086A0T	FM	DECORATION	Raybans	92,300.00
1AJA0UUA1T	AJ	TEMPLES	Oakley	88,000.00
1LSVO5276	LS	LENSES	Vouge	83,060.00
1LSOX8046	LS	LENSES	Oakley	80,740.00
1AM7837B0T	AM	TEMPLES	Raybans	77,500.00

Figure 3.6 Table showing the high-runner SKU

After conducting sorting based on quantity using Microsoft Excel's sorting function, the resulting list, as illustrated in Figure 3.6, provides a detailed breakdown of the products according to their quantities. This information is pivotal for calculating the stock quantity necessary to adequately cover a 12-day period. For the purpose of illustration, the top 10 SKUs will be used in the example calculation.

By getting the top 10 SKUs which are high runners, The 60-day transaction will be used to see and sum the total quantity based on their daily transaction then using the percentile function, it is determined that the 90th percentile of the demand for the stock quantity at this level can cover 90% of demand. Figure 3.7 supports this determination, which indicates that the 90th percentile corresponds to the elbow point, signifying an optimal balance between quantity and coverage.

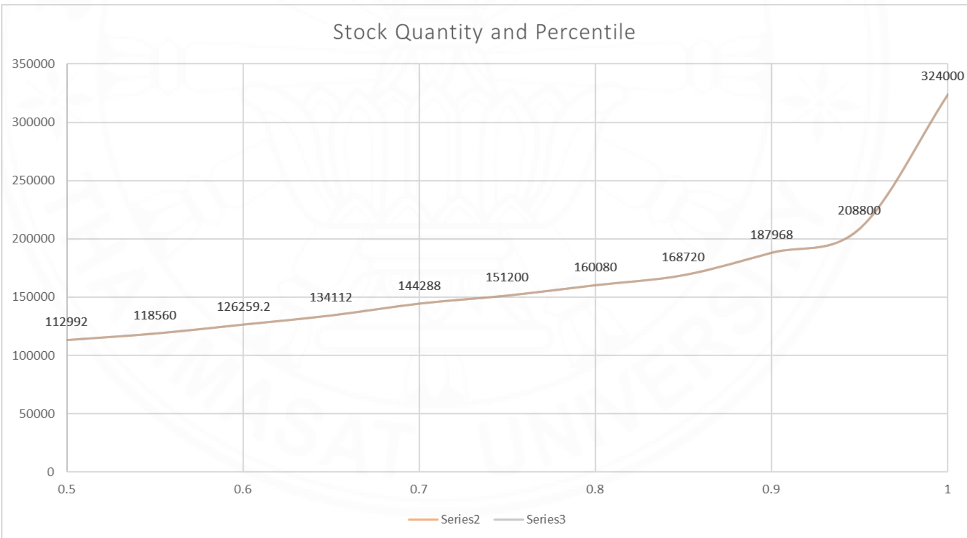


Figure 3.7 Stock Quantity and Percentile

After obtaining the 90th percentile quantity for those 10 SKUs, the result will be compared with the quantity derived from the "Average Stock for 12 Days" column to determine the percentage difference for each SKU as shown in Figure 3.8. By calculating the percentage difference between these two quantities, adjustments can be made to ensure optimal stock levels. This adjustment involves multiplying the average inventory to cover 12 days by the percentage difference for each SKU. This process ensures that the stock quantity for each SKU aligns more closely with the actual demand and minimizes excess or insufficient inventory levels.

Compone	CUT comp	Comp Cat	Brand	Quantity	Average INV to cover 12 days	Quantity by percentile (90%)	%diff
1LSRB4171	LS	LENSES	Raybans	453,420.00	90684.00	186264	2.05
2AM5086A	AM	TEMPLES	Raybans	367,260.00	73452.00	161280	2.20
1TE2130A(	TE	TEMPLES	Raybans	289,804.00	57960.80	156576	2.70
2VT010000	VT	DECORATI	Raybans	185,193.00	37038.60	86688	2.34
1AM5086(	AM	TEMPLES	Raybans	176,114.00	35222.80	79920	2.27
1FR1882A(	FR	FRONTS	Raybans	162,286.00	32457.20	66960	2.06
1ZP1330B(	ZP	DECORATI	Raybans	160,024.00	32004.80	87600	2.74
1AL1354A(	AL	DECORATI	Oakley	154,640.00	30928.00	77760	2.51
1TE2130C(	TE	TEMPLES	Raybans	144,462.00	28892.40	73680	2.55
2RB4171A	RB	FRONTS	Raybans	129,900.00	25980.00	69720.00	2.68
						Average Different	2.41

Figure 3.8 Table showing the top 10 SKUs and their quantity with percentage of different

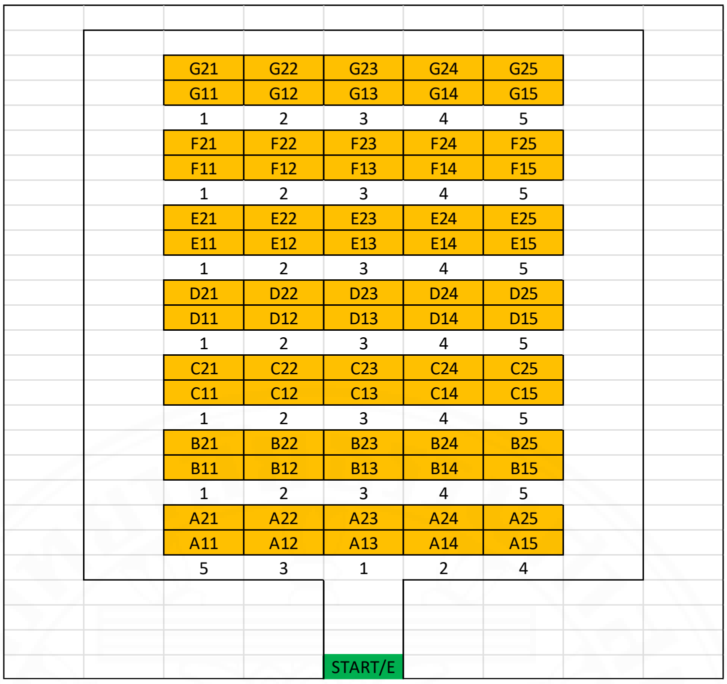
After obtaining the optimal stock quantity, the next step is to calculate the number of master boxes needed and the bins required for each SKU. Referring back to the standard quantity mentioned in the first chapter for each component category, the "Quantity by percentile (90%)" column will be divided by the VLOOKUP of the standard quantity of each item category. The lookup value is column 2, which is "CUTcomp". Once the number of master boxes is calculated, the next step is to determine the number of bins needed. This can be done by dividing the number of master boxes column by 50, as each bin can accommodate 50 master boxes. The example result is shown in Figure 3.9

From the calculation result, the number of bins required to keep the SKU to meet the optimal stock is approximately 411 bins which is 65% of the total bins in the warehouse.

Component	CUT comp	Comp Cat	Brand	Quantity by percentile (90%)	NO of masterbox	No of Bin
1LSRB4171	LS	LENSES	Raybans	186264	932.00	19.00
2AM5086A01	AM	TEMPLES	Raybans	161280	807.00	17.00
1TE2130A00	TE	TEMPLES	Raybans	156576	392.00	8.00
2VT0100001	VT	DECORATION	Raybans	86688	18.00	1.00
1AM5086G0T	AM	TEMPLES	Raybans	79920	400.00	8.00
1FR1882A00	FR	FRONTS	Raybans	66960	1,340.00	27.00
1ZP1330B0T	ZP	DECORATION	Raybans	87600	219.00	5.00
1AL1354A0T	AL	DECORATION	Oakley	77760	32.00	1.00
1TE2130C00	TE	TEMPLES	Raybans	73680	185.00	4.00
2RB4171A01	RB	FRONTS	Raybans	69720.00	1,395.00	28.00
1TE3993A0T	TE	TEMPLES	Vouge	60945.77	153.00	4.00
1TE0215000	TE	TEMPLES	Raybans	55162.58	138.00	3.00
1TE3908B0T	TE	TEMPLES	Raybans	54918.60	138.00	3.00
2GL2886C01	GL	DECORATION	Raybans	54302.39	136.00	3.00
1AM8370B0T	AM	TEMPLES	Vouge	45237.52	227.00	5.00
1FM4086A0T	FM	DECORATION	Raybans	44504.62	223.00	5.00
1AJA0UUA1T	AJ	TEMPLES	Oakley	42431.27	425.00	9.00
1LSVO5276	LS	LENSES	Vouge	40049.34	201.00	5.00
1LSOX8046	LS	LENSES	Oakley	38930.69	195.00	4.00
1AM7837B0T	AM	TEMPLES	Raybans	37368.45	187.00	4.00

Figure 3.9 Example table showing the number of master-boxes and bins needed for store each SKU

The final step before assigning the storage location is to create the layout strategies. In this independent study, there are two layout strategies: storage by brand and by component. However, to optimize the picking route and make it more efficient, it's necessary to design the storage location nearest to the exit. This study will focus on two picking route designs: from left to right and from the nearest to the furthest, which can be represented in Figures 3.10 and 3.11 below



. **Figure 3.10** The design for the order of the storage location from left to right order

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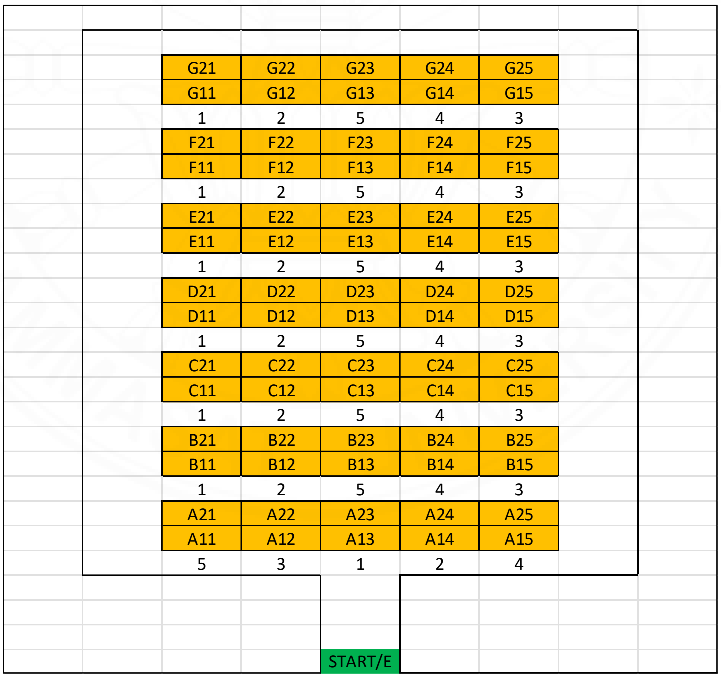


Figure 3.11 The design for the order of the storage location by the nearest to the furthest

In the layout design depicted in Figure 3.10, subsequent to the assignment of locations to the first row, the second row will commence with positions A21 to A25, followed by positions B11 to B15, respectively. Conversely, in the layout represented in Figure 3.1, the sequencing for the second row will initiate with positions A21, B11, A22, B12, A25, B15, A24, B14, and subsequently A23, B3. Consequently, a table format has been devised for recording the outcomes, as illustrated in Figure 3.12.

Production Order	Storage Scenario	Brand	Distance	Sequence
Production order xx	By brand (1st design)			
	By component (1st design)			
	By brand (2nd design)			
	By comp new (2nd design)			
Production order xx	By brand (1st design)			
	By component (1st design)			
	By brand (2nd design)			
	By comp new (2nd design)			

Figure 3.12 Example of the table that will be used to record the result

Based on the provided information, storage locations can be assigned to every SKU based on four scenarios. However, a constraint to consider is that the maximum number of bins in each bay is limited to 9 bins. An example of SKUs already assigned storage locations can be observed in figure 3.13 below

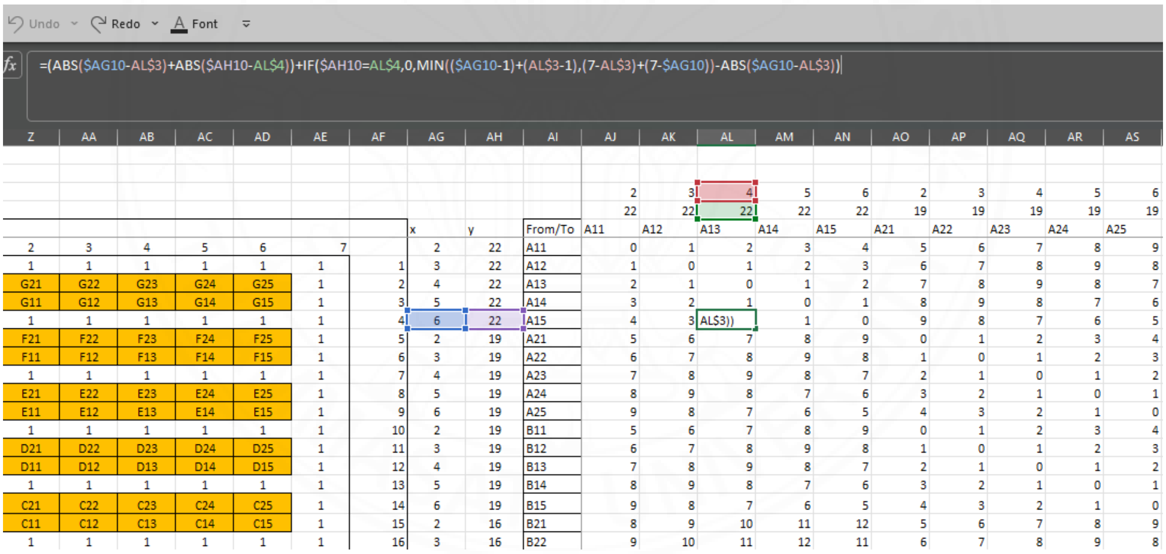
By component (1st design)		By comp new (2nd design)		By brand (1st design)		By brand (2nd design)	
Location	SKU	Location	SKU	Locatio	SKU	Location	SKU
A13	2AM5086A01	A13	2AM5086A01	A13	2AM5086A01	A13	2AM5086A01
A12	2AM5086A01	A12	2AM5086A01	A12	2AM5086A01	A12	2AM5086A01
A12	1TE2130A00	A12	1TE2130A00	A12	1TE2130A00	A12	1TE2130A00
A14	1TE2130A00	A11	1TE2130A00	A11	1TE2130A00	A11	1TE2130A00
A14	1AM5086G0T	A11	1TE4482B0T	A11	1AM5086G0T	A11	1TE4482B0T
A11	1AM5086G0T	A14	1AM5086G0T	A14	1TE2130C00	A14	1AM5086G0T
A11	1TE2130C00	A14	1TE2130C00	A14	1TE4183B0T	A14	1TE2130C00
A15	1TE2130C00	A15	1TE2130C00	A14	1TE0215000	A15	1TE2130C00
A15	1TE0215000	A15	1TE0215000	A14	1TE3908B0T	A15	1TE0215000
A15	1TE3908B0T	A15	1TE3908B0T	A15	1TE3908B0T	A15	1TE3908B0T
A15	1AM7837B0T	A21	1AM7837B0T	A15	1AM5619A00	A21	1AM7837B0T
A25	1AM7837B0T	A21	1AM8464G0T	A15	1AM7837B0T	A21	1AM8464G0T
A25	1AM8464G0T	A21	1AM6879D0T	A21	1AM5086G0T	A21	1TE2569C0T
A25	1TE4482B0T	B11	1AM6879D0T	A21	1AM8464G0T	B11	1AM6879D0T
A25	1AM6879D0T	B11	1AJ6972A0T	A22	1AM8464G0T	B11	1AJ6972A0T
A21	1AJ6972A0T	A22	1TE0215B00	A22	1TE4482B0T	A22	1TE0215B00
A21	1TE0215B00	A22	1AM5619A00	A22	1AM6879D0T	A22	1AM5619A00
A21	1AM5619A00	A22	1TE2569C0T	A22	1TE0215B00	A22	2TE0215B0T

Figure 3.13 The example of the storage location on each SKU

3.4 Mathematical Model

3.4.1 Creating Distance Matrix

In implementing the Vehicle Routing Problem (VRP), the foundational step entails the establishment of a distance matrix delineating the distances between individual nodes. In this particular instance, each storage location constitutes a distinct node within the network, with the designated starting point or depot being denoted as A13. Given the presence of 70 nodes within this problem domain, the resultant distance matrix encompasses 70 x 70 entries, encapsulating the pairwise distances between each node. Each of the distances is already minimal by using the logic and Microsoft Excel formula as represented in figure 3.14. To read this distance matrix, The column in the right side (AI) is “From” node. The Row beside cell “From/To” is the “To” node.
For example, The distance from A15 to A11 is 4 unit of blocks.



Undo Redo Font

fx =(ABS($AG10-AL$3)+ABS($AH10-AL$4))+IF($AH10=AL$4,0,MIN(($AG10-1)+(AL$3-1),(7-AL$3)+(7-$AG10))-ABS($AG10-AL$3))

Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
										2	3	4	5	6	2	3	4	5	6
										22	22	22	22	22	19	19	19	19	19
							x	y	From/To	A11	A12	A13	A14	A15	A21	A22	A23	A24	A25
2	3	4	5	6	7		2	22	A11	0	1	2	3	4	5	6	7	8	9
1	1	1	1	1	1	1	3	22	A12	1	0	1	2	3	6	7	8	9	8
G21	G22	G23	G24	G25	1	2	4	22	A13	2	1	0	1	2	7	8	9	8	7
G11	G12	G13	G14	G15	1	3	5	22	A14	3	2	1	0	1	8	9	8	7	6
1	1	1	1	1	1	4	6	22	A15	4	3	AL$3))	1	0	9	8	7	6	5
F21	F22	F23	F24	F25	1	5	2	19	A21	5	6	7	8	9	0	1	2	3	4
F11	F12	F13	F14	F15	1	6	3	19	A22	6	7	8	9	8	1	0	1	2	3
1	1	1	1	1	1	7	4	19	A23	7	8	9	8	7	2	1	0	1	2
E21	E22	E23	E24	E25	1	8	5	19	A24	8	9	8	7	6	3	2	1	0	1
E11	E12	E13	E14	E15	1	9	6	19	A25	9	8	7	6	5	4	3	2	1	0
1	1	1	1	1	1	10	2	19	B11	5	6	7	8	9	0	1	2	3	4
D21	D22	D23	D24	D25	1	11	3	19	B12	6	7	8	9	8	1	0	1	2	3
D11	D12	D13	D14	D15	1	12	4	19	B13	7	8	9	8	7	2	1	0	1	2
1	1	1	1	1	1	13	5	19	B14	8	9	8	7	6	3	2	1	0	1
C21	C22	C23	C24	C25	1	14	6	19	B15	9	8	7	6	5	4	3	2	1	0
C11	C12	C13	C14	C15	1	15	2	16	B21	8	9	10	11	12	5	6	7	8	9
1	1	1	1	1	1	16	3	16	B22	9	10	11	12	11	6	7	8	9	8

Figure 3.14 The example of the storage location on each SKU

3.4.2 Mathematical Model

After creating a distance matrix, the next step is to define the function's mathematical model, which needs to have both constraint and objective functions for running an optimization using Microsoft Excel Open Solver

Sets:

C = Set of Storage Location node

N = Set of all nodes, including starting point.

Parameter (Input Data):

c_{ij} = Distance from node i to j

Q = Maximum Capacity of the cart

D_i = Demand at each node

Variables:

x_{ij}= Binary variable

y_{ij} = Load Capacity from i (The number of SKUs that need to be picked)

Objective Function

Minimize Total distance:

$$Total\ distance = \ 4 + \sum\sum x_{ij} * c_{ij} \qquad (3.1)$$

Constraint

1. All of the customer nodes must be visited once (if needed)

$$\sum_{j\in N, j\neq i} x_{ij} = 1; \quad \forall i \in C \qquad (3.2)$$

2. Path flow constraint, if a picker arrives at node i, it must leave from that node

$$\sum_{j\in N, j\neq i} x_{ji} - \sum_{j\in N, j\neq i} x_{ij} = 0; \quad \forall i \in N \qquad (3.3)$$

3. Demand constraint, To identify the picker to go to pick the goods at the right node

$$\sum_{j\in N, j\neq i} y_{ji} - \sum_{j\in N, j\neq i} y_{ij} = D_i; \quad \forall i \in C \qquad (3.4)$$

4. Cart capacity, The maximum capacity that cart can carry.

$$y_{ij} \leq Qx_{ij}; \quad \forall i \in N, \forall j \in N \qquad (3.5)$$

5. Only available pickers can be dispatched from the depot.

$$\sum_{j\in C} x_{0j} \leq m \qquad (3.6)$$

6. The binary and non-negativity conditions.

$$x_{ij} \in \{0,\ 1\}; \quad \forall i \in N, \forall j \in N \tag{3.7}$$

$$y_{ij} \geq 0; \quad \forall i \in N, \forall j \in N \tag{3.8}$$

CHAPTER 4
RESULT AND DISCUSSION

After the successful development and implementation of the Optimization model, a series of tests were conducted to evaluate the system's performance across ten production orders for each brand. The objective of these tests was to assess the accuracy, reliability and minimized total distance. The results are summarized in Tables 4.1, 4.2, and 4.3 below.

Table 4.1 Table shows the summary of the total distance for Raybans

Production Order	Storage Scenario	Brand	Distance	Sequence
1830459694	By brand 1st layout	RB	44	A13,C24,C11,B12,A23,B13,B14,A13
1830459694	By component 1st layout	RB	56	A13,A21,C11,B21,C12,F11,D24,A13
1830459694	By brand 2nd layout	RB	44	A13,B14,A24,A23,B11,D12,C15,A13
1830459694	By component 2nd layout	RB	52	A13,B25,B24,C15,E14,D13,B11,A13
1833219326	By brand 1st layout	RB	32	A13,C15,B14,B13,A23,A15,A13
1833219326	By component 1st layout	RB	56	A13,E21,C21,C12,A22,A15,A13
1833219326	By brand 2nd layout	RB	36	A13,C13,B22,A21,A22,A23,B14,A13
1833219326	By component 2nd layout	RB	54	A13,B24,C24,D23,A21,A22,A13
1832686547	By brand 1st layout	RB	40	A13,A14,A25,B21,C21,A11,A13
1832686547	By component 1st layout	RB	48	A13,A14,E14,D11,B22,A11,A13
1832686547	By brand 2nd layout	RB	40	A13,A14,A25,C21,B21,A13
1832686547	By component 2nd layout	RB	54	A13,A14,C25,E21,C12,A13
1833217777	By brand 1st layout	RB	42	A13,B12,A23,B14,D14,B25,A15,A13
1833217777	By component 1st layout	RB	54	A13,B21,C13,D15,A21,A23,A13
1833217777	By brand 2nd layout	RB	42	A13,C23,A21,A22,A23,A24,B15,A13
1833217777	By component 2nd layout	RB	60	A13,C14,B25,C23,F12,A22,A13
1833634194	By brand 1st layout	RB	32	A13,B11,B13,C14,B24,A14,A13
1833634194	By component 1st layout	RB	54	A13,A15,D14,F12,C12,B22,C11,A13
1833634194	By brand 2nd layout	RB	32	A13,A15,A25,B15,B14,B23,B22,A13
1833634194	By component 2nd layout	RB	50	A13,A15,C15,C24,E13,C12,A13
1830459562	By brand 1st layout	RB	42	A13,C24,C11,B12,A23,B13,B14,A13
1830459562	By component 1st layout	RB	54	A13,A21,C11,B21,C12,F11,D24,A13
1830459562	By brand 2nd layout	RB	42	A13,B14,A24,A23,B11,D12,C15,A13
1830459562	By component 2nd layout	RB	50	A13,B25,B24,C15,E14,D13,B11,A13
1833634352	By brand 1st layout	RB	32	A13,B11,B13,C14,B24,A14,A13
1833634352	By component 1st layout	RB	54	A13,A15,D14,F12,C12,B22,C11,A13
1833634352	By brand 2nd layout	RB	32	A13,A15,A25,B15,B14,B23,B22,A13
1833634352	By component 2nd layout	RB	50	A13,A15,C15,C24,E13,C12,A13
1833634077	By brand 1st layout	RB	32	A13,B11,B13,C14,B24,A14,A13
1833634077	By component 1st layout	RB	54	A13,A15,D14,F12,C12,B22,C11,A13
1833634077	By brand 2nd layout	RB	32	A13,A15,A25,B15,B14,B23,B22,A13
1833634077	By component 2nd layout	RB	50	A13,A15,C15,C24,E13,C12,A13
1834054430	By brand 1st layout	RB	44	A13,D21,C11,B11,B13,A14,A13
1834054430	By component 1st layout	RB	54	A13,A22,C11,F13,D15,A13
1834054430	By brand 2nd layout	RB	48	A13,B12,B14,A24,C15,D21,A13
1834054430	By component 2nd layout	RB	58	A13,B12,E23,D13,C15,A13
1834054955	By brand 1st layout	RB	38	A13,A12,C21,B21,A25,A13
1834054955	By component 1st layout	RB	46	A13,A12,B22,D11,E14,A13
1834054955	By brand 2nd layout	RB	38	A13,A12,C21,B21,A25,A13
1834054955	By component 2nd layout	RB	52	A13,A12,C12,E21,C25,A13

Table 4.2 Table shows the summary of the total distance for Oakley

Production Order	Storage Scenario	Brand	Distance	Sequence
1834252676	By brand 1st layout	OAK	54	A13,E14,D24,D23,E12,F13,E24,A13
1834252676	By component 1st layout	OAK	66	A13,C14,C15,F24,D22,B11,B12,A13
1834252676	By brand 2nd layout	OAK	54	A13,D22,E12,D23,E24,F12,A13
1834252676	By component 2nd layout	OAK	64	A13,B15,A24,B23,E12,G11,A13
1833473124	By brand 1st layout	OAK	52	A13,F14,E15,D23,D24,A13
1833473124	By component 1st layout	OAK	60	A13,B12,F23,C15,A13
1833473124	By brand 2nd layout	OAK	52	A13,F14,E13,D22,E12,A13
1833473124	By component 2nd layout	OAK	62	A13,B14,C13,F22,A13
1833796202	By brand 1st layout	OAK	64	A13,F11,E23,F22,D23,D24,E15,D25,A13
1833796202	By component 1st layout	OAK	64	A13,E11,G11,C25,C15,B25,C14,B15,A13
1833796202	By brand 2nd layout	OAK	62	A13,D25,E12,D22,F21,E21,E22,F15,A13
1833796202	By component 2nd layout	OAK	68	A13,E15,G15,C21,B21,C13,B23,B14,A13
1834252037	By brand 1st layout	OAK	52	A13,D25,D24,E14,F15,E25,E21,A13
1834252037	By component 1st layout	OAK	68	A13,C15,C25,F22,D22,B11,B13,A13
1834252037	By brand 2nd layout	OAK	54	A13,E21,F13,E25,D25,E12,A13
1834252037	By component 2nd layout	OAK	68	A13,C13,C21,F21,E12,A23,A24,A13
1834446485	By brand 1st layout	OAK	52	A13,F12,E25,D24,E13,A13
1834446485	By component 1st layout	OAK	60	A13,A24,C15,F22,D21,A13
1834446485	By brand 2nd layout	OAK	52	A13,E25,E23,E12,E14,A13
1834446485	By component 2nd layout	OAK	62	A13,E12,G12,C13,A25,A13
1834252070	By brand 1st layout	OAK	60	A13,F11,E22,F22,D23,D24,E15,D25,A13
1834252070	By component 1st layout	OAK	66	A13,C14,C15,C25,E11,G11,B12,B15,A13
1834252070	By brand 2nd layout	OAK	60	A13,D25,F15,F11,E21,F21,D22,E12,A13
1834252070	By component 2nd layout	OAK	68	A13,C21,E15,G15,C13,B23,B13,B14,A13
1834252787	By brand 1st layout	OAK	58	A13,D25,D24,D23,E11,F11,E22,F21,A13
1834252787	By component 1st layout	OAK	68	A13,B13,C15,C14,C25,C24,E11,G12,A13
1834252787	By brand 2nd layout	OAK	60	A13,D22,E12,D23,E24,F12,A13
1834252787	By component 2nd layout	OAK	68	A13,C21,E15,G15,C13,B23,B13,B14,A13
1834394083	By brand 1st layout	OAK	52	A13,E14,D24,D23,E12,F13,E24,A13
1834394083	By component 1st layout	OAK	64	A13,C14,C15,F24,D22,B11,B12,A13
1834394083	By brand 2nd layout	OAK	52	A13,D22,E12,D23,E24,F12,A13
1834394083	By component 2nd layout	OAK	62	A13,B15,A24,B23,E12,G11,A13
1831764889	By brand 1st layout	OAK	52	A13,E22,E24,F14,D23,D24,A13
1831764889	By component 1st layout	OAK	58	A13,B25,C15,F23,D22,A13
1831764889	By brand 2nd layout	OAK	50	A13,E12,D22,F11,F12,F14,A13
1831764889	By component 2nd layout	OAK	60	A13,F22,D22,B23,C13,A13
1834252153	By brand 1st layout	OAK	54	A13,F21,E13,D24,A13
1834252153	By component 1st layout	OAK	58	A13,G11,C15,A24,A13
1834252153	By brand 2nd layout	OAK	54	A13,E14,E12,F21,A13
1834252153	By component 2nd layout	OAK	56	A13,A25,C13,F25,A13

Table 4.3 Table shows the summary of the total distance for Vouge

Production Order	Storage Scenario	Brand	Distance	Sequence
1834410013	By brand 1st layout	VO	54	A13,G11,G12,F23,F24,A13
1834410013	By component 1st layout	VO	66	A13,G12,E12,C22,B22,B24,A13
1834410013	By brand 2nd layout	VO	54	A13,G15,G14,F22,G12,A13
1834410013	By component 2nd layout	VO	64	A13,C11,D12,F24,D24,A13
1833846910	By brand 1st layout	VO	54	A13,F25,G13,F23,G11,A13
1833846910	By component 1st layout	VO	74	A13,C22,C23,G22,E12,B23,B24,A13
1833846910	By brand 2nd layout	VO	54	A13,G15,F25,F24,F22,A13
1833846910	By component 2nd layout	VO	64	A13,C11,B22,C22,E15,G14,A13
1834655557	By brand 1st layout	VO	54	A13,F25,G13,F23,G11,A13
1834655557	By component 1st layout	VO	74	A13,C22,C23,G22,E12,B23,B24,A13
1834655557	By brand 2nd layout	VO	54	A13,G15,F25,F24,F22,A13
1834655557	By component 2nd layout	VO	64	A13,B22,C11,C22,D12,G14,E15,A13
1834844821	By brand 1st layout	VO	54	A13,F25,G13,F23,G11,A13
1834844821	By component 1st layout	VO	74	A13,C22,C23,G22,E12,B23,B24,A13
1834844821	By brand 2nd layout	VO	54	A13,G15,F25,F24,F22,A13
1834844821	By component 2nd layout	VO	64	A13,B22,C11,C22,D12,G14,E15,A13
1833846122	By brand 1st layout	VO	52	A13,F25,G13,F23,G11,A13
1833846122	By component 1st layout	VO	72	A13,C22,C23,G22,E12,B23,B24,A13
1833846122	By brand 2nd layout	VO	52	A13,G15,F25,F24,F22,A13
1833846122	By component 2nd layout	VO	62	A13,B22,C11,C22,D12,G14,E15,A13
1833846911	By brand 1st layout	VO	52	A13,F25,G13,F23,G11,A13
1833846911	By component 1st layout	VO	72	A13,C22,C23,G22,E12,B23,B24,A13
1833846911	By brand 2nd layout	VO	52	A13,G15,F25,F24,F22,A13
1833846911	By component 2nd layout	VO	62	A13,B22,C11,C22,D12,G14,E15,A13
1834360343	By brand 1st layout	VO	52	A13,G12,F23,F24,G14,F25,A13
1834360343	By component 1st layout	VO	76	A13,E13,G23,C22,B24,B23,A13
1834360343	By brand 2nd layout	VO	52	A13,G12,F23,F24,F25,A13
1834360343	By component 2nd layout	VO	64	A13,B22,C11,D12,F23,E14,A13
1834055120	By brand 1st layout	VO	52	A13,G11,G12,F23,F24,A13
1834055120	By component 1st layout	VO	70	A13,B24,C22,G22,E12,A13
1834055120	By brand 2nd layout	VO	52	A13,G15,G14,F22,G12,A13
1834055120	By component 2nd layout	VO	62	A13,F24,D24,D12,C22,C11,A13
1834204863	By brand 1st layout	VO	52	A13,F25,G13,F23,G11,A13
1834204863	By component 1st layout	VO	72	A13,C22,C23,G22,E12,B23,B24,A13
1834204863	By brand 2nd layout	VO	52	A13,G15,F25,F24,F22,A13
1834204863	By component 2nd layout	VO	62	A13,C11,B22,C22,E15,G14,A13
1834252839	By brand 1st layout	VO	52	A13,F25,G13,F23,G11,A13
1834252839	By component 1st layout	VO	72	A13,C22,C23,G22,E12,B23,B24,A13
1834252839	By brand 2nd layout	VO	52	A13,G15,F25,F24,F22,A13
1834252839	By component 2nd layout	VO	62	A13,C11,B22,C22,E15,G14,A13

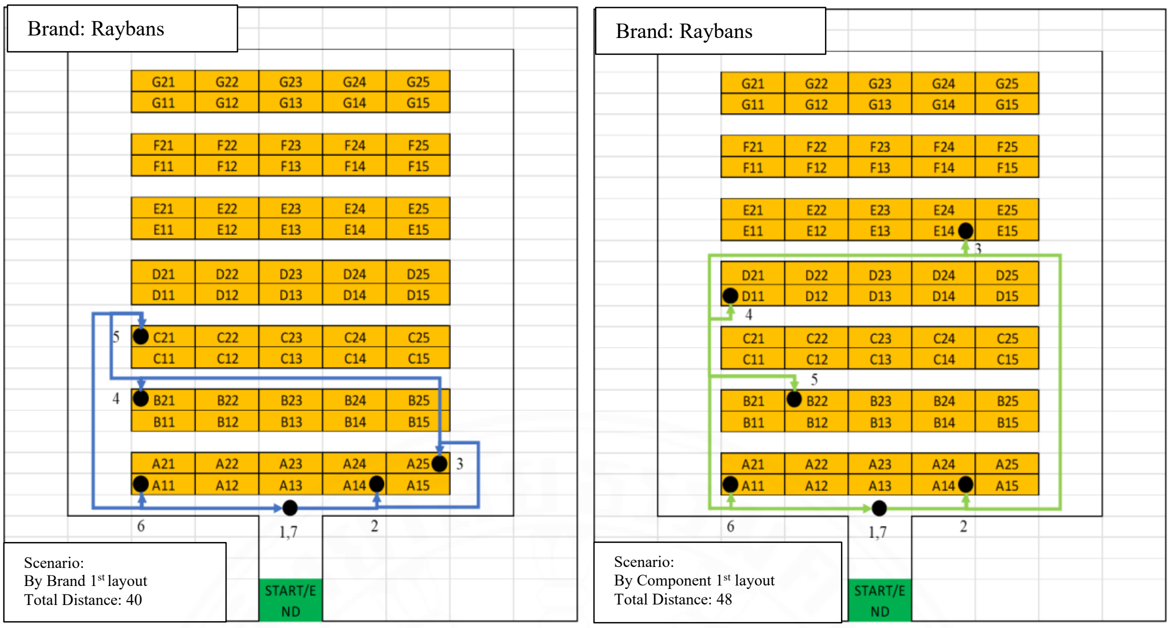


Figure 4.1 Path of picker for Production Order 1832686547, By Brand and By Component 1st layout

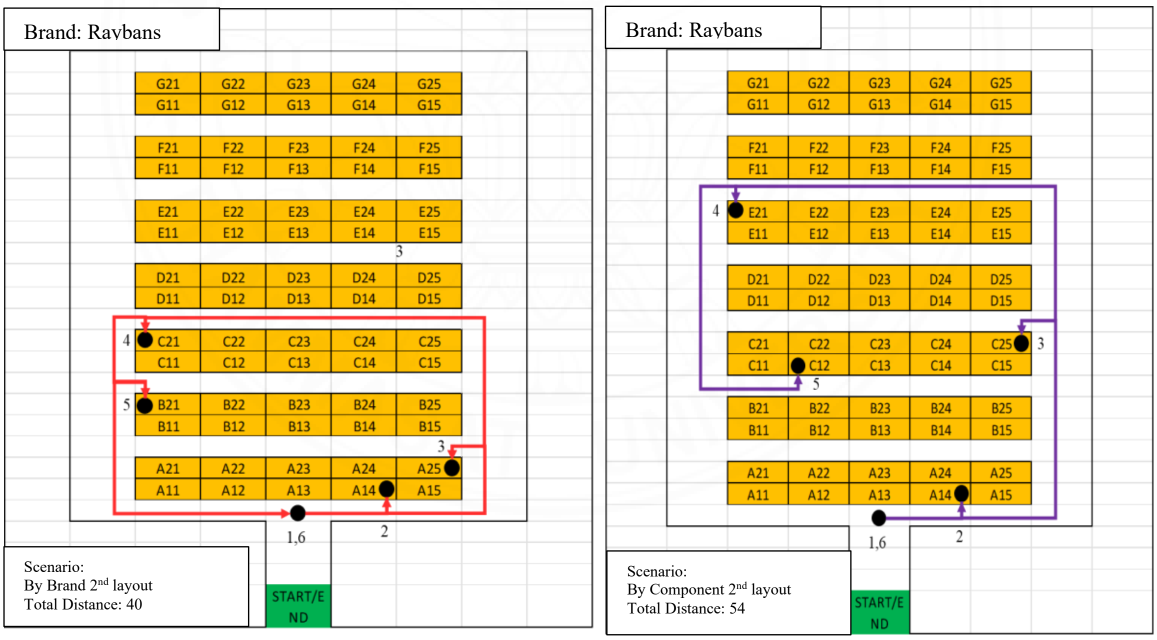


Figure 4.2 Path of picker for Production Order 1832686547, By Brand and By Component2nd layout

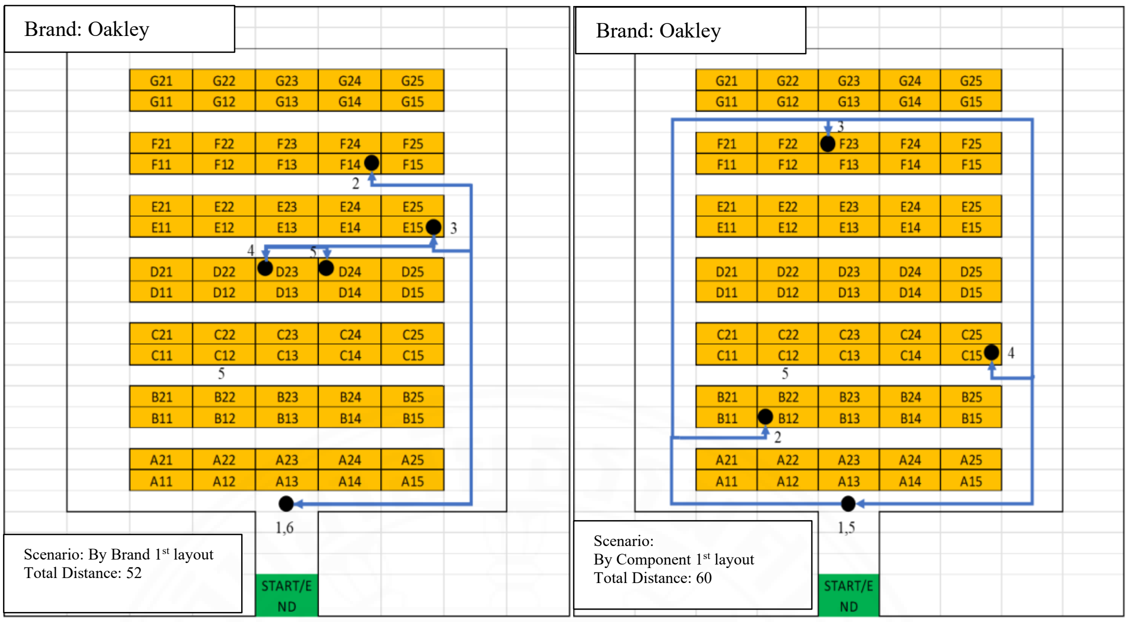


Figure 4.3 Path of picker for Production Order 1833473124, By Brand and By Component 1st layout

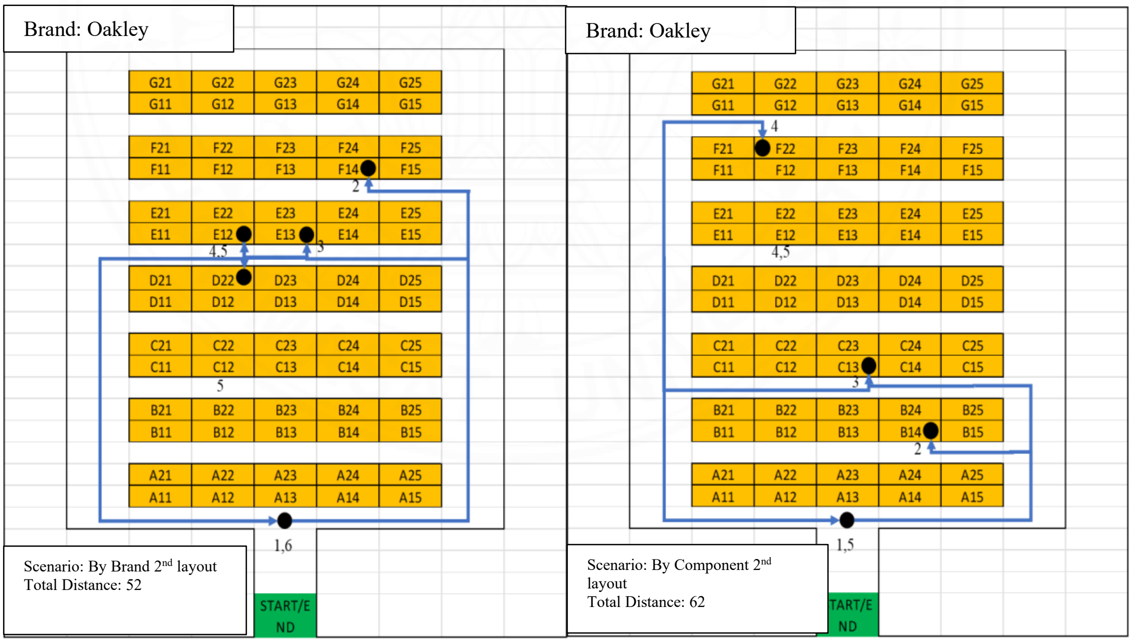


Figure 4.4 Path flow of picker for Production Order 1833473124, By Brand and By Component 2nd layout

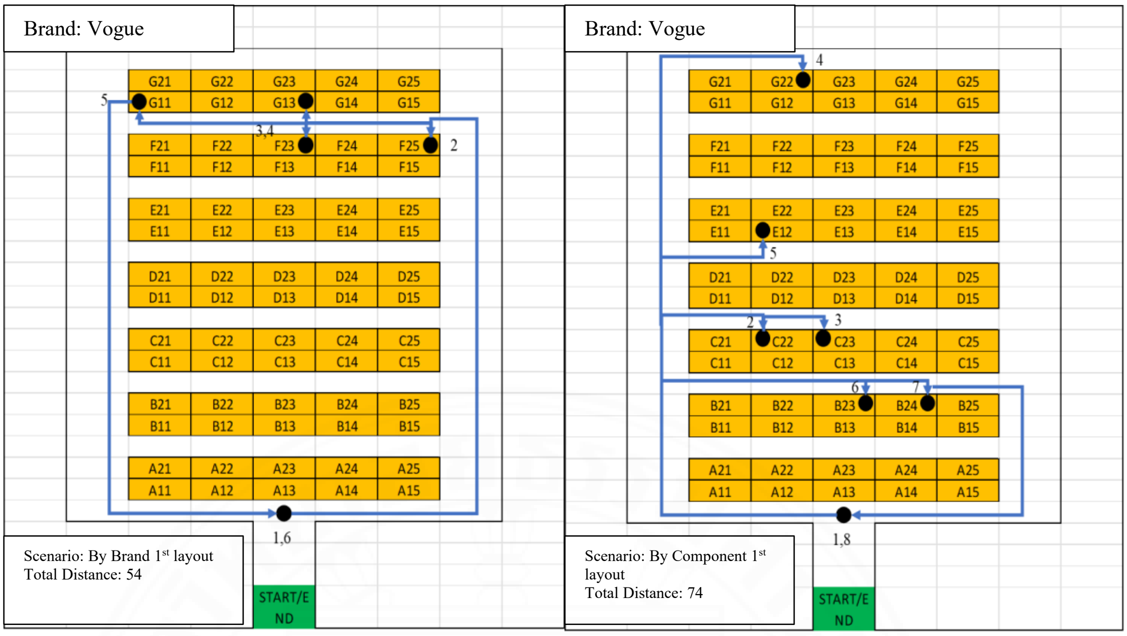


Figure 4.5 Path flow of picker for Production Order 1834844821, By Brand and By Component 1st layout

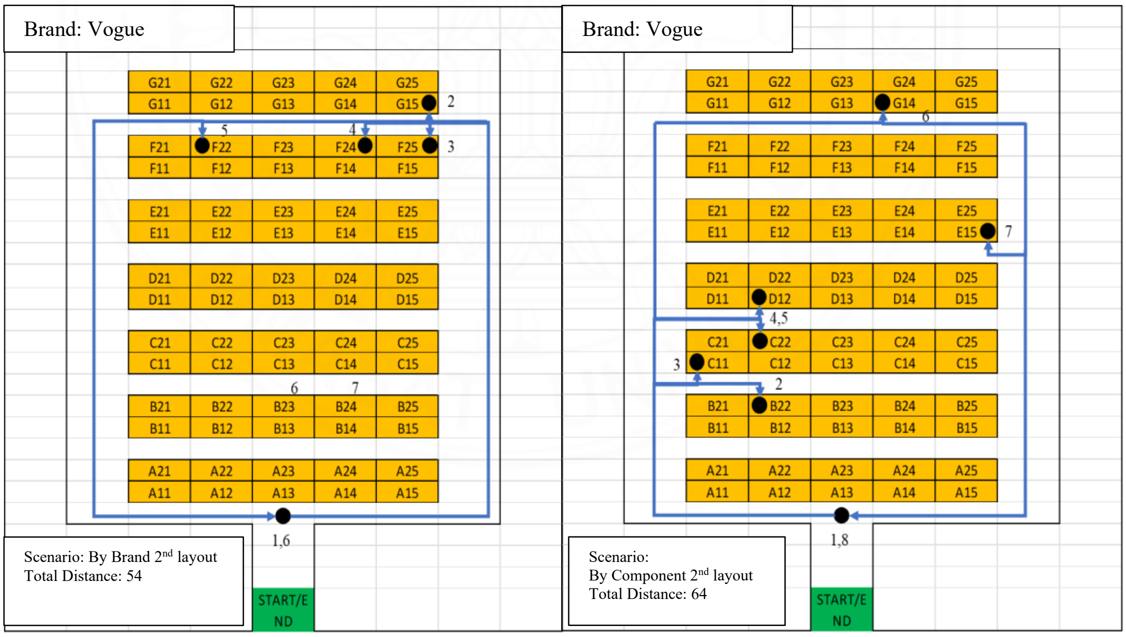


Figure 4.6 Path flow of picker for Production Order 1834844821, By Brand and By Component 2nd layout

After conducting the test, the program can be utilized to calculate the total distance while optimizing for minimization objectives, with a focus on prioritizing bin locations to achieve these goals.

Based on the results from the table 4.1 to 4.3 and figure 4.1 to 4.6 it is evident that the "storage by brand" scenario yields a shorter overall distance compared to the "storage by component" scenario across all brands. However, the total distance for both picking routes in the "by brand" scenario does not show a significant difference. This finding presents an opportunity for further research into these independent study topics. Figure 4.7 shows the result of the average distance of each scenario and brand based on their picking route design.

The limitation of this program is the time to calculate the total distance which requires around 4 to 5 minutes and also some parts may use the humans to put the information into it.

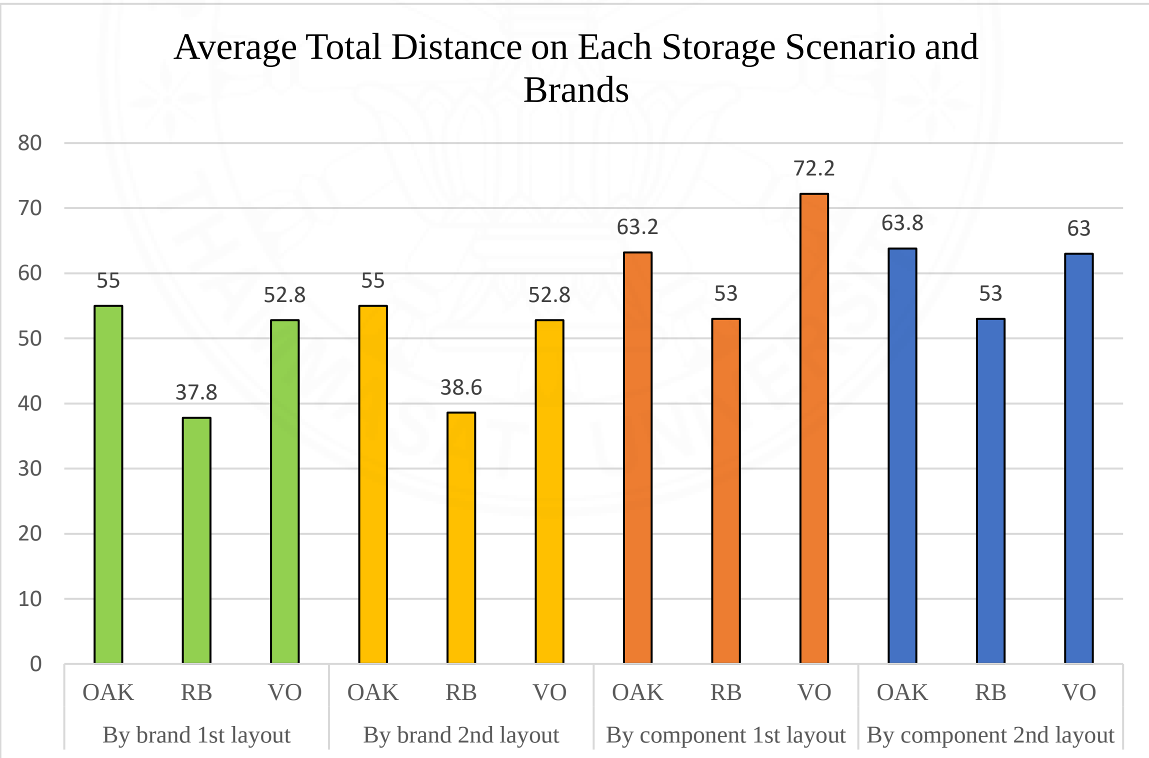


Figure 4.7 The graph shows the average distance of the three brands.

CHAPTER 5
CONCLUSION

This study showed that using OpenSolver to optimize storage location assignments in a warehouse can effectively reduce the distance traveled during the picking process. Comparing two storage strategies: organizing by brand versus organizing by component. The results were clear storing items by brand consistently led to shorter picking distances compared to grouping them by component. This suggests that a brand-based approach to storage could be a smart way to boost efficiency.

However, the difference in total travel distance between the various picking routes, even within the brand-based scenario, wasn't very significant. This means that while organizing by brand helps, the layout and the route planning may be just as important, if not more so, for reducing overall picking time.

One limitation that encountered was the time it took for OpenSolver to compute the optimal routes, which could be a few minutes, and some of the data entry was still done manually, leaving room for human error.

For future studies, it would be interesting to look into automating this process further, perhaps using machine learning or more advanced simulation tools to make it faster and more reliable. There's also room to explore different warehouse layouts and other ways to categorize products, which could reveal even better strategies for improving warehouse efficiency.

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