ORDER PICKING PERFORMANCE IMPROVEMENT IN FAST MOVING GOODS DISTRIBUTION WAREHOUSE:

A CASE OF ALLE BEJIMLA HAWASSA BRANCH

M.Sc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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This is to certify that the thesis entitled "Order Picking Performance Improvement in Fast Moving Goods Distribution Warehouse" submitted in partial fulfilment of the requirements for the degree of Master's with specialization in Industrial Engineering and Logistics Management the Graduate Program of Industrial Engineering and has been carried out by Sahle Mekta ID. No. GPIELMR0012/12 under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defence by Sahle Mekta Zenebe have read and evaluated his/her thesis entitled "Order Picking Performance Improvement in Fast Moving Goods Distribution Warehouse for the case of ALLE Bejimla Hawassa Branch" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfilment of the requirements for the degree.

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Abstract

Warehouses are the areas where goods are stocked in the supply chain. All material handling activities, such as receiving, storage, order picking, accumulation, sorting and consolidation, and shipment of goods, are addressed by warehousing. Order-picking is the most resource-intensive activity in warehousing and it defines the level of service provided to consumers. So, it must be flawless and quick.

Shorter order picking travel distance is one of the key performance measures for order picking. The goal of this study was to improve order picking performance through minimization of order picking travel distance in the ALLE Bejimla Hawassa branch. The current assignment of each good was known through direct recording. Following that, consumers' movements were tracked to know how items were picked from their storage. Using measuring tape, the dimensions of each bay and aisle were known, and the data was utilized to calculate order picking travel distance. Based on the multiplicative value of order frequency and minimum ordering weight, items are classified as high value, medium value and low value. Fourteen items have higher value of ordering frequency times weight.

For first-class items, order picking travel distance was calculated for a single order and multiplied by order frequency. The Hungarian method and item popularity heuristics were then used to determine the best bay assignment for each item. According to the existing assignment 995.4 meters walking is required to pick most popular items per single order scheme. This distance is minimized to 617.2 meters, 788.7 meters, 805.7 meters and 766 meters using assignment model approach, optimal storage strategy approach, equal time storage strategy and equal space storage strategy respectively. Using monthly flow of items, the fractional volume was calculated. The number of restocks was also calculated for various storage strategies, and the optimal allocation strategy led to fewer restocks.

Key Words: Warehousing, Order picking, Items assignment, Order picking travel distance.

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List of Abbreviations

BMILP	Binary Mixed Integer Linear Programming
COI	Cubic Per Index
CSAS	Correlated Storage Assignment Strategy
EQS	Equal Space
EQT	Equal Time
FIFO	First In First Out
FMCG	Fast-Moving Consumer Goods
FRP	Forward Reserve Problem
I/O	Input - Output
LIFO	Last In First Out
OOS	Order Oriented Slotting
OPT	Optimal
POM	Production Operations Management
QAP	Quadratic Assignment Problem
SKU	Stock Keeping Units

CHAPTER ONE

INTRODUCTION

1.1. Background

Warehouses are the places in the supply chain where products come to a halt and are handled. This necessitates both physical space and time (person hours), both of which are costly. Warehouse management is all about making efficient use of space and time (effort or person hours), both of which are costly and should be used as little as possible while delivering products to clients. Warehouses provide valuable services in the current economic environment. These include better matching supply to customer demand, consolidating product, completing processes such as packaging and sorting, and ensuring product safety. Companies are paying greater attention to warehouse management these days, aiming to optimize the location of their items in the facilities based on the amount of time they have before being forwarded (Bartholdi, 2016).

All material handling activities that take place within the warehouse, such as receiving items, storage, order picking, accumulation, sorting and consolidation, and shipment, are referred to as warehousing. Distribution warehouses and production warehouses are the two main types of warehouses. A distribution warehouse, according to Van den Berg (2017), is a warehouse where products from various sellers are collected for delivery to multiple customers, whereas a production warehouse is that a warehouse where raw materials, semifinished products, and finished products are stored in a manufacturing facility.

The process of handling items in storage to fulfil a specific client order is known as order picking. It is a more resource intensive and vital operation in warehousing that impacts how customers perceive service. Order picking accounts for about 55 percent of the total operational costs associated with warehouse activities. As a result, it must be faultless and quick. Order pickers can operate with reduced pick up, searching, and moving time when there is a common quick pick area. This procedure usually takes into account operations like finding, handling, and product transfer, which account for 20%, 50%, and 30% of the overall time spent on order preparation, respectively (Frazelle, 2016).

Bartholdi III and Hackman (2014) handle the problem of reducing travel with the pick-path optimization. Accordingly, transportation of the goods and items in warehouses has been known as a cost-intensive process, and particular emphasis should be placed on this operation as well as the design policies. Therefore, order picking operation which requires a substantial effort among warehouse operations.

The concept of fast pick area / convenient area has been investigated and analysed in order to overcome the challenges identified in the order picking process. The fast-pick area (forward reserve area) is a section of the forward picking area where only a small number of the most popular goods or SKUs (the smallest physical unit of a product that the organization stacks) can be kept. This allows order pickers to fill a large percentage of orders while only traveling a short distance. When there isn't a fast pick area for order pickers, the path an order picker should take through the warehouse to acquire the items of an order must be determined. Modern distribution centres set up their warehouses in fast picking zones in order to fill orders faster and at a cheaper cost while ensuring customer satisfaction (Bartholdi III, 2008).

A forward-pick area is one that is particularly convenient for picking, yet it must be refilled from another location in the warehouse because to space constraints. Popular SKUs can be selected from the ground and supplied by dropping overstock pallets from the above (Bartholdi, 2016). The goal of designing convenient area is to handle order picking by looking for an intelligent product storage within the warehouse. It is, without a doubt, the precise assignment of goods to available storage sites, the establishment of the storage mode, and the determination of the volume of space to be provided for the fast pick area (Manzini, 2012).

For the forward-reserve allocation problem, Hackman (1990) provided a mathematical model. The model comprises a set of integer variables that indicate whether an SKU is assigned to the forward area and a set of continuous variables that indicate how much space is given in the forward area for each item assigned to the forward area. To maximize the benefits of the forward area, it is critical to carefully select which items should be assigned to the forward area and in what quantities, balancing the trade-offs between order picking and replenishment.

As a result, the focus of this study was on properly assigning products by selecting the most popular items by considering order frequency and weight, with the aim of minimizing order picking travel distance for the case warehouse.

1.2. Statement of Problem

Alle Bejimla is a government-owned company that primarily operates in the wholesale and distribution sectors under the Ethiopian Trading Business Corporation umbrella. ALLE Bejimla, Ethiopia's first modernized cash and carry distributor of food and Fast-Moving Consumer Goods (FMCG). https://www.ethiojobs.net/company/36533/ALLE

The company has inaugurated a branch in Hawassa city since 2015 located around "Arogiew Gebeya". This branch has one store for Fast Moving Consumer Goods stored on palletized rack. In ALLE Bejimla Hawassa branch store, goods are stored on the indexed and numbered rack without identifying the items which are picked and transported most frequently and no identification of the most accessible area (convenient area) in the warehouse that is close to the shipping area for the most popular items. So, items are stored without considering items' order frequency and popularity. Due to these issues, order picking process requires to travel long distance along the warehouse.

As a result, the goal of this study is to improve order picking performance in warehouse through proper items assignment approach which minimizes order picking travel distance.

1.3. Research Questions

- What is the total distance travelled to pick an item from a particular bay location?
- Which are the most popular items in terms of ordering frequency?
- How to identify the convenient area?
- How items should be assigned in the convenient area?

1.4. Objectives of the Research

1.4.1. General Objective

The ultimate objective of the research is to improve order picking performance through proper items assignment in fast-moving goods distribution warehouse taking ALLE Bejimla Hawassa branch as a case company.

1.4.2. Specific Objectives

- To measure order picking distance to pick a particular order.
- To identify most fast-moving items using ABC analysis.
- To calculate the fractional volume and identify the convenient area.
- To assign items at the convenient area to minimize order picking travel distance.

1.5. Significances of Research

For the ALLE Bejimla; by applying the concept of fast picking area in warehousing the company will minimize distance for order picking. The company can also know the most popular items which helps in planning and managing the available space.
For other researchers; the research will be used as a reference who planned to conduct a study related to the concepts addressed in this research.

1.6. Scope and Limitation

The study's purpose is to determine which items are the most popular based on order frequency and then arrange them in the most accessible location to make order picking distance shorter. This was done by deciding which products should be placed in the fast-picking section. Due to customer information confidentiality and data intensiveness, only savings related to order picking travel distance per single order and single item basis were investigated. The cost of order processing and seasonal products were not considered into.

1.7. Organization of Thesis

The first chapter of this study provides background information on essential warehousing ideas and terminologies. The second section of Chapter One examines the problem that motivates the researcher to perform the study, while the third section focuses on the research questions that precede the research objectives. The second chapter reviews the research on warehousing layout design, order picking slotting approaches, and assignment models for enhancing order picking performance.

The third chapter describes the numerous research approaches and methodologies employed to achieve the thesis's goals. The study area, data gathering methods, data analysis methodologies, and research framework are all described in this chapter. The fourth chapter focuses on data presentation and results analysis based on data acquired using various methodologies. In this chapter, the frequency of orders during a two-month period was examined in order to categorize items as fast, medium, or slow mover. Under this chapter, the monthly flow and volume of each item's package were examined in order to calculate the amount of space required for each of the items. In the fourth chapter, there is also a comparison of results in terms of order picking travel distance and number of restocks required under different storage strategies.

The fifth and final chapter offers the analysis' conclusion and recommendations. This chapter summarizes the findings of the thesis's analysis section and suggestions to the organization on reducing warehouse order picking travel distances.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

In the past, warehouses were frequently referred to as cost centres that did not offer value. Warehouse operations have changed dramatically as a result of the shift of production to the Far East, the rapid rise of e-commerce, and rising customer demands. Warehouses are widely recognized as an important part of today's supply chain. Managers, on the other hand, must increase efficiency and accuracy while lowering costs and inventories while enhancing customer service. The warehouse, in particular, plays a critical function in the supply chain by ensuring that the exact product is delivered in the right quantity, and it relies on warehouse picking and shipping (Richards, 2014). Warehouses are primarily used to:

1) Protect products from the environment;

2) Consolidate products to save transportation costs;

3) Quickly respond to changes in demand; and

4) Provide value-added processes such as light assembly for special orders.

2.2. Warehousing

The importance of warehousing in distribution and logistics cannot be emphasised. It is the act of storing actual goods in order to sell or distribute it. All types of organizations utilize warehouses to temporarily store things in bulk before moving them to other locations or selling them individually to end customers (Ackerman, 2012). Warehousing systems are costly, requiring significant labour, capital, and information systems. They basically account for 20-25 percent of total distribution and logistics operational expenses (Frazelle, 2016).

According to Goldratt (2004) throughput, inventory, and operational expense are the three bottom line performance parameters that any organization should measure. As a result, advances in warehousing systems design and control are critical to a firm's supply chain's performance. Operating technology planning, equipment selection, layout design, space allocation, and product assignment techniques all require warehouse systems planning.

Order-picking efficiency is influenced by aspects such as storage systems, location, and control methods. In general, there are four techniques to enhancing the efficiency of the order-picking process in order to reduce order picking time and reduce order picker distance in the warehouse. The first step in reducing travel time is to map out an order-picking route. The second method is separating the facility into zones. As a result, order pickers will only work in the zone to which they have been allocated. The third strategy is to place products in locations determined by the most efficient use of shelf space. The connection between the storage assignment rule and the routing technique is crucial in this case. The fourth option is to batch the orders, which reduces travel distance by combining orders from the same batch into a single shipment. The most significant of these strategies are storage assignment, order batching, and routing (Ene, 2012).

Companies have spent approximately 10% to 30% more per year in recent years to minimize travel times through the adoption of technology such as enhanced storage management software, flow racks, voice picking, and radio frequency identification, among others. This is in accordance with data from the literature, which suggests that only about 15% of SKUs (Stock-Keeping Units) are correctly located. A deeper investigation of the right placement of products within a warehouse based on demand for each product might lead to better solutions (Frazelle E. , 2020).

The concept of slotting has lately been investigated and evaluated in industry and expert literature in order to overcome the challenges outlined in the order picking process. In this way, the slotting process tries to solve order picking problems by looking for an intelligent product arrangement within the warehouse. It is the proper assignment of SKUs to available storage sites, as well as the establishment of the storage mode, the volume of space to be assigned, and the precise location for product storage. The goal of slotting is to increase order preparation efficiency while lowering operating costs (Manzini, 2012). The slotting method is required to answer two basic issues, as discussed in Viveros (2021). (1) How should SKUs be classified? (2) How do you allocate classified SKUs to different locations?

2.3. Warehouse Structure

Receiving, stock storage, replenishment, order picking, quality control, sortation and consolidation, and loading are the primary functional areas in a warehouse as depicted in figure below.

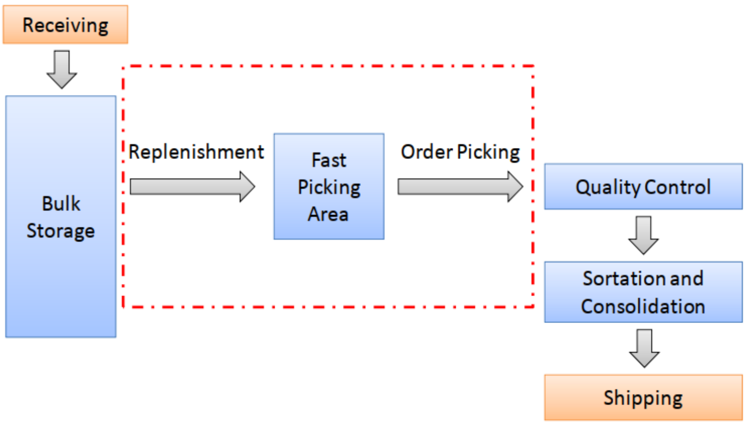


Figure 2-1. Warehouse structure ((Martinez, 2008)

Receiving area: unloading products from the supplier's transport carrier, properly identifying and verifying the product's quality, updating the inventory level, and preparing the product to be transferred to a storage place in the warehouse are all parts of this area's responsibilities.

Replenishment is the process of transferring and storing a product. Replenish is frequently divided into two parts, depending on the warehouse configuration: reserve replenishment and fast picking area replenishment. The first supplies the fast-picking area from the bulk warehouse, while the second puts away any receiving items in the bulk warehouse.

Quality control ensures that the orders collected by order-pickers are in accordance with the customer's instructions. Orders are sorted and consolidated if they are acceptable; otherwise, they are returned to the order pickers.

Sorting and Consolidation involves moving the completed order to the shipping door. The picked orders are bundled and stacked to be palletized prior to shipment. After that, the pallets are labelled and staged near the departure door, ready to be loaded into the shipping carrier (Martinez, 2008).

Order-picking is the most important aspect of a warehouse's functioning. Its job is to complete a series of customer orders by going to the relevant item location, getting the right amount, and placing it in the order box with proper labelling. In contrast to a pallet-picking operation, which involves moving pallet loads in and out, an item picking operation involves collecting single items from storage positions (less-than-case picking). The set of equipment and operating principles utilized in an item picking or storage/retrieval environment is known as a warehousing system (Van den Berg, 2017).

There are three types of warehouse systems based on their amount of automation as manual warehousing systems (picker-to-product systems), automated warehousing systems (product-to-picker systems), and automatic warehousing systems are the three types of warehousing systems available (Raghuram, 2020).

2.4. Dedicated Versus Shared Storage

There are two major ways for storing a product in warehousing. The most basic is dedicated storage, in which each place is assigned to a specific product and only that product is allowed to be stored there. Because product positions do not vary, more popular items can be stored in more convenient areas, and employees can learn the layout, making order-picking more efficient (Gu, 2007).

To serve consumers, a warehouse may have hundreds or tens of thousands of storage places. It could be a shared or dedicated storage system. Each storage location will have an assigned product while using dedicated storage. The replenishing and picking cycles for each product/item may differ. On average, only around half of the storage capacity is used. To improve this, a shared storage technique might be used. The notion is that a product can be assigned to multiple storage locations. When a site becomes vacant, it becomes open for reassignment to another product. Rather than waiting for the original product to be supplied, this area can be filled immediately (Makhmudov, 2012).

There are some dedicated storage approaches that used in warehousing.

- Order Orienting Slotting (OOS); with this system, order pickers can pick multiple products from an order in nearby areas without having to walk for prolonged durations to get to the next sequence (Mantel, 2007).

- Cubic per index (COI); This is accomplished by first calculating the popularity of each item and ranking them in decreasing order, then determining the shortest distance to the depot and assigning products with higher frequency to the closest depot or I/O point (Martinez, 2008).
- Correlated assignment; Frazelle and Sharp (1989) suggested correlated assignment, which is based on a heuristic approach to clustering objects into zones based on the joint possibilities that pairs of items appear in the same order (Chiang, 2011).
- Quadratic Assignment Problem (QAP); Koopmans and Beckmann (1957) developed the Quadratic Assignment Problem (QAP) for assigning plant locations to a set of indivisible facilities that considers facilities to be of equal shape and the distance between them is measured from centroid to centroid based on flow with the goal of minimizing travel distance (Cela, 2013).

2.5. Warehouse Operations

Products are repackaged and reorganized at a warehouse. The product is usually packaged on a greater scale when it arrives and on a smaller scale when it leaves. In other words, breaking down vast volumes of product and redistributing it in smaller quantities is a critical role of this warehouse. Some SKUs, for example, may come in pallet quantities from the vendor or manufacturer but be shipped out to customers in case quantities, while others may arrive in cases but be shipped out individually. Some SKUs with high demand may come on pallets and be shipped as a single item (Bartholdi, 2016).

The reorganization of product takes place through the following physical processes.

A. Inbound processes

- Receiving
- Put-away

B. Outbound processes

- Order-picking
- Checking, packing, shipping

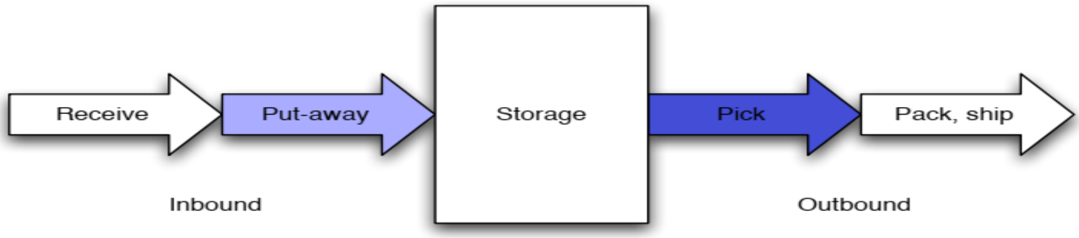


Figure 2-2.Warehouse operations *(Bartholdi, 2016)*

Bartholdi (2016) explain these warehouse operations in the following manner.

Receiving

Receiving may begin with notification of the products' arrival in advance. This enables the warehouse to schedule receiving and unloading in order to better integrate with other warehouse activities. Warehouses frequently arrange trucks to arrive within 30-minute time periods. The item is being unloaded and perhaps staged for storage after it arrives.

Put-away

A suitable storage location must be established before the product can be put away. This is critical since the location in which we store the product has a significant impact on how fast and efficiently you can retrieve it for a customer later. We need to know what storage options are accessible at all times, how big they are, how much weight they can hold, and so on.

Checking and packing

Because each element of a customer order must be handled individually, packing can be time-consuming; however, there is little walking involved. Because each piece will be handled individually, this is a good moment to double check that the customer order is correct and complete.

Order accuracy is a critical indicator of customer service, and it is on this metric that most firms compete. One complexity of packing is that customers desire to get all elements of their order in as few containers as possible to save money on shipping and handling. This means that every effort should be made to ensure that all pieces of an order arrive at packaging together.

Shipping

Because packing has consolidated the materials into fewer containers, shipping often handles larger units than picking (cases, pallets). If product is staged before being put into freight trucks, there may be some walking. If the product must be loaded in reverse order of delivery or if transporting large distances, where each trailer must be completely filled, it is likely to be staged. Because staged freight must be handled twice, it adds to the workload.

2.6. Order Picking

Order picking is the process of removing goods from storage to fulfil customer orders. Because order picking is a labour-intensive task in traditional manual warehouses, it accounts for about 55 percent of total warehousing costs. Many factors in the warehouse can influence the order picking process. The most important is an underestimating of order picking by the organization (Gudehus, 2012; Frazelle, 2016).

Neglect at the warehouse can result in lost income as well as dissatisfaction among warehouse workers. In a warehouse, order picking encompasses selecting and gathering a specific quantity of correct SKUs in accordance with the order, as well as lifting, moving, picking, putting, packaging, and other associated actions (Lee, 2015).

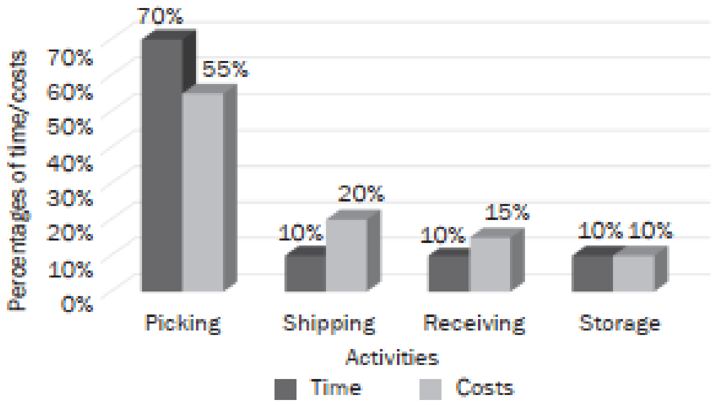


Figure 2-3. Percentage of annual operating costs in a warehouse *(Habazin, 2017)*

The other aspects affecting on picking efficiency is inefficient warehouse processes. Storing of items and picking of items is too often based on the feeling, not on demand or popularity of the items. Inefficient storing strategy or lack of it can cause picking routing to increasing the travel distances and travel times (Frazelle, 2016).

A fast-pick area is one approach for increasing the efficiency of the order picking activity (also referred to as a fast-pick line). The fast-pick area is a section of the forward picking area where only a small number of popular items are kept. This permits the pickers to fill a big number of the orders while only taking up a small amount of space (Masel, 2008).

According to Martinez (2008), there are a variety of order picking systems available during this time to improve warehousing productivity. The order picking approach defines three major systems as picker-to-item, item-to-picker, and automated picking.

Order pickers walk along the rack shelves to retrieve the products on their order lists in a picker-to-item system. There are three main retrieval methods that are useful,

1) One in which the orders are picked one at a time: when orders are small or the picking area is divided into zones, this method is widely utilized.

2) Items are sorted during the picking route*:* involves batch picking of goods, which is particularly practical in warehouses; as a result, it allows a large number of pickers to operate on very big orders, maximizing order picker throughput.

3) Items are picked in a single container and later at the end of the route sorted into their respective orders: This is especially clear when the goods in all of the orders are identical, making it easier for pickers to moving from one point to the next.

In an item-to-picker arrangement, the picker enters the needed set of orders and waits for the item to be recovered and delivered to him. Cranes, Automated Storage and Retrieval Systems, and Vertical Lift Modules are used to pick the objects as a unit load and deliver them to the input/output point (Azadeh, 2019).

In a single block warehouse, Zhang (2016) created Correlated Storage Assignment Strategy (CSAS) to reduce the picker to items order picking system's travel distance. For the storage location assignment, the correlation among Stock Keeping Units (SKUs) was taken into account. The author employs a methodology that involves a pre-process as well as two branching phases, the first of which is the development of a Correlated Storage Assignment Strategy algorithm. The sum-seed and static-seed clustering algorithms are described for the clustering-based Correlated Storage Assignment Strategy, and four algorithms for sequencing item sets and single SKUs were developed. The average trip distance per picking is utilized in the experiment to measure the Correlated Storage Assignment Strategy's performance. The Correlated Storage Assignment Strategy minimizes the average travel distance of each picking up to 2.08 percent when compared to full-turnover storage.

2.6.1. Items Management

Item management entails taking care of all aspects of the item. These factors include item description, dimensions, weight, material type, typical costs per item, storage environment, and so on (Frazelle, 2016). Item management is the process of ensuring that items are available to internal and external customers. Warehouse management can influence warehouse efficiency by using efficient item management. The efficiency of the system can be increased by making judgements about item availability, classification, and storage depending on popularity (Slater, 2010).

Viveros (2021) tackles the problem of assigning multi-level storage sites for SKU pallets, taking into account divisible locations in the first level to improve picking operations and reduce crane trip times. A mathematical programming model was created with the goal of lowering overall order picking travel distance while also increasing storage capacity use in the background.

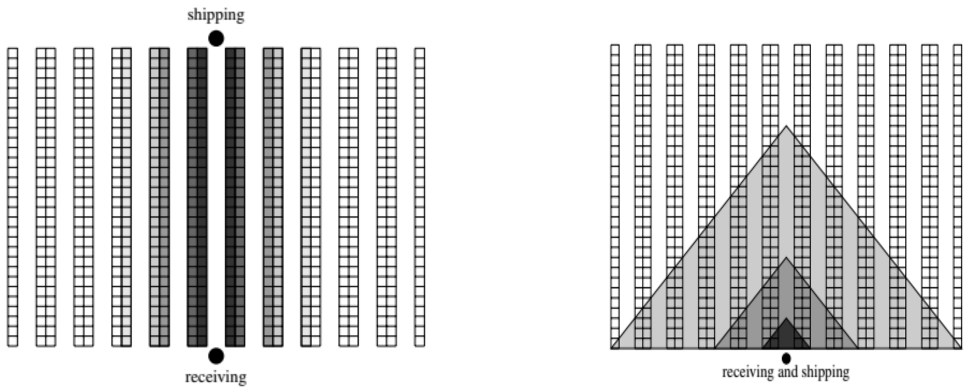
2.6.2. Convenient Storage Locations

The most convenient storage location, according to Bartholdi (2016), is the one with the shortest travel distance (d_i) to the receiving and shipping point. A pallet will be stored at a specific location after traveling from the receiving dock to the location and then from the location to the shipping dock. As a result, each site i is connected with a labour cost incurred as a result of its use. The cost of labour is related to the distance travelled from receiving to location and finally to shipping. As a result, we can speak of convenience in terms of distance. If location “i” is visited “n_i” times during the year, the annual labour cost will be proportional to:

$$\sum_i d_i n_i$$

Distances “d_i” are determined by the layout of the warehouse and are not easily changed. But what to keep is determined by the frequency of customer order visits n_i, and our personal preferences. We may ensure that the most frequently visited sites are those with the greatest convenience (smallest total travel length) by carefully storing the pallets, reducing the order pickup travel distance. The cost associated with each storage location is determined by the warehouse plan.

The layout is called a flow-through design when the average receiving and shipping positions are in the middle of opposite sides of the warehouse (a). This is because all product flows from one side of the facility to the other. As a result, any storage place on one side of an aisle is equally beneficial (darker locations are more convenient) and when receiving and shipping are performed on the same dock (b), there are a few very convenient locations and a few very inconvenient locations illustrated in the figure below.



a. b.

Figure 2-4. Convenient area of warehouse *(Bartholdi, 2016)*

2.7. Items Classification

ABC analysis is a method for prioritizing inventory management. A, B, and C inventories are the three types of inventories. The majority of management work and oversight goes towards controlling A items. C items receive the least attention, whereas B items fall somewhere in the middle. Modern enterprises may store a wide range of commodities, including finished goods, spare components, and raw materials. Thousands of dollars are sometimes involved. Answering at least two questions - how much to order and when to order - is part of managing these stockpiles. The answers to these issues must be based on a demand and lead time analysis (Ravinder, 2016). It is neither efficient nor cost-effective to do this for each item one at a time, but stocks must be controlled. They are frequently the most controllable production costs and account for a large amount of a company's assets. Items will be categorised using numerous criteria in ABC analysis.

A - High: Demand, Price, Obsolescence, Spoilage, Criticality, Scarcity, Replenishment Cost, weight Lead time, Variability (of Demand, Price, Lead time, etc.) Low: Serviceability, Number of Suppliers, Substitutability.

B - Moderate: Demand, Price, Criticality, Scarcity, Replenishment Cost, weight Lead time, Variability (of Demand, Price, Lead time, etc.), Serviceability, Number of Suppliers, Substitutability.

C - High: Serviceability, Number of Suppliers, Substitutability and low Demand, Price, Obsolescence, Spoilage, Criticality, Scarcity, weight Replenishment Cost, Lead time, Variability.

2.8. Assignment Model

The task of assigning objects to storage locations within the storage space is known as storage assignment. Different policies – i.e., general principles – for storage assignment are discussed in the literature. Random storage, dedicated storage, and class-based storage are the most popular. When using a random storage strategy, objects are assigned to (empty) storage locations in the warehouse at random, without regard for their attributes such as pick frequencies, weight, or pick correlations with other items (Wang, 2020).

When items are replenished, locations are sensitive to changes. Random storage strategies, on average, result in longer average trip times and distances. Closely linked to random assignment is the policy of closest open location assignment, in which things are assigned to an empty location closest to the depot rather than to a random spot (Chan, 2011). Diefenbach (2019) uses mixed-integer program to create efficient layouts and storage assignments that cut walking distance by 33% to 50%.

Assignment is a type of transportation problem that is solved by utilizing a transportation model to determine the lowest cost, time, or distance (Taylor, 2013) . It can be solved by the following four methods:

a) Complete enumeration method
b) Simplex Method
c) Transportation method
d) Hungarian method

a. Complete enumeration method

This technique generates a list of all feasible assignments from the available resources and activities. Then a task with the lowest cost, the shortest time or distance, or the highest profit margin is chosen. The problem has numerous optimal solutions if two or more assignments have the same minimum cost, duration, or distance. Only if the number of assignments is small enough to apply this method. When the number of assignments is high, manual calculations become inadequate.

b. Transportation method

The assignment is a type of transportation problem that can be solved with the help of a transportation model. The solution obtained by applying this method would be degenerate. This is because the optimality test in the transportation method requires that there must be m+n-1= (2n-1) basic variables. Because there are n assignments to be performed in an assignment problem of order n x n, the solution will only have n basic variables. The transportation technique is computationally inefficient for solving the assignment problem because of this degeneracy problem of solution.

c. Hungarian assignment method

The Hungarian method of assignment allows us to identify the best solution in a short amount of time. The principles that govern the Hungarian technique are as follows:

(i) If a constant is added to every element of a row and/or column of the cost matrix of an assignment problem the resulting assignment problem has the same optimum solution as the original problem or vice versa.

(ii) The solution having zero total cost is considered as optimum solution.

Based on the Hungarian methods, the followings steps are utilized to implement the assignment method.

1. Subtract the least number in each row from the rest of the row's numbers. This is referred to as a row reduction. Create a new table with the results.
2. Subtract the least number in each column from each number in the column in the new table. This is referred to as a "column reduction." Place the results in a new table.
3. Check to see if an optimal assignment can be generated. We do this by figuring out how many lines (horizontal or vertical) are required to cross out (cover) all of the zeros. An optimal

assignment is possible if the number of lines equals the number of rows. If that's the case, move on to step 6. If not, proceed to step 4.

4. If the number of lines is less than the number of rows, modify the table in this way:
   a) Subtract the smallest uncovered number from every uncovered number in the table.
   b) Add the smallest uncovered number to the numbers at intersections of cross-out lines
   c) Carry over numbers crossed out but not at intersections of cross-out lines carry over to the next table
5. Repeat steps 3 and 4 until an optimal table is obtained.
6. Make the assignments. Begin with simply one zero in each row or column. Match items with zeros in each row and column, using only one match per row and column.

2.9. Fast Picking Area

A warehouse's fast-pick area is used to fill orders for the facility's most popular goods. Several authors have addressed the issue of designing a fast-pick area. Hackman's fluid models (1990) were the first to address the problem of determining the amount of space that should be dedicated to each SKU in order to minimize replenishment expenses. Reserved (dedicated) storage is utilised in the forward pick area to facilitate rapid order-picking.

The Forward/Reserve Problem (FRP) was first established by Hackman (1990) and involves deciding which goods to place in the fast-picking area and determining the best space allocation for each of them in order to reduce order picking, replenishment, and equipment expenses.

Modern distribution centres design their warehouses with fast picking zones to fulfil orders more quickly at a reduced cost and to boost order responsiveness to customer variations in demand as a result of a rise in order customisation with changing demands. The warehouse is divided into a reserve area and a forward area, also known as a fast-picking area. The fast-picking section may only contain single case quantities of some or all SKUs, resulting in a considerable increase in SKU pick density and a significant reduction in order picking time. The reserve space is then used to store vendor bulk pallets and restock the fast-picking area. It's possible that the fast-picking area isn't always distinct from the reserve. The fast-picking area and the reserve area may share space in some cases, with the fast-picking area at the bottom of the racks and the reserve area at the top (De Koster, 2007).

How much space is required for each item?

An item may be selected for storage in the fast pick section based on its viscosity or popularity. Let "v_i" represent the fraction of space allocated to item and "f_i" is the flow of item per a particular duration (Bartholdi, 2016).

$f_i = [(units/month)/(units/case)]*[m^3/case]$ and expressed with m^3/month

$v_i = \frac{\sqrt{f_i}}{\sum_{i=1}^{n}\sqrt{f_i}} * V$ *and number of restocks are* = $\frac{\sqrt{f_i}}{V} * \sum_{j\in\mathcal{F}}\sqrt{f_j}$

Where, v_i = fractional volume for item $_i$

V = available volume in cubic meter

f_i = monthly flows of each item in m^3/month

In general, there are two types of storage strategies:

a. Give each item the equal amount of space. This is referred to as the Equal Space (EQS) method and model it by v_i =V/n and number of restocks per month is equals to $\frac{nf_i}{V}$

b. Each item should be kept in an equal amount of time. This is referred to as the Equal Time strategy (EQT) and $v_i = \left(\frac{f_i}{\sum_j f_i}\right) * V$ and number of restocks per month is equals to $\frac{1}{V} * \sum_{j\in\mathcal{F}} f_j$

The random and dedicated storage policies are combined in the class-based storage policy. The concept is to categorize the items in the inventory. Each class would have its own designated area, with the products belonging to that class occupying any available space inside. Shared storage policies include randomized and class-based storage, which allow multiple goods to occupy the same space at the same time (Tsige, 2013).

In two stages, Ene (2012) uses a developed mathematical model and a stochastic evolutionary optimization approach to develop storage assignment and order picking systems in the automotive industry. The first stage involved using integer programming to solve the storage location assignment problem using a class-based storage policy with the goal of minimizing warehouse transmissions. In the second step, batching and routing issues are considered jointly in order to reduce warehouse travel costs. An integer programming approach was used to find the best answer after analysis.

Perishable items could be grouped together or non-perishable things could be grouped together in inventory management, or by their incoming sequence, i.e., first-in first-out (FIFO) and last-in first-out (LIFO) (LIFO). The most widely utilized class-based strategy is Pareto's popularity method, which is based on the concept that 20% of goods account for 80% of sales or pick volume. The widely utilized ABC layout policy would result from class arrangement based on product popularity (Le-Duc*, 2005). The A-items are the most common class of fast movers, and they would take over the most convenient locations in the warehouse, usually near the I/O points or outgoing shipment door. The B-items are the next quickest moving class, and they take the next most favourable zone places after the A-items. C-movers would be the next class, and so on. Despite the fact that the class-based storage policy places fast-moving objects closer to I/O locations to reduce picking distances.

For a fast-pick area, Masel (2008) uses heuristics to assign storage locations and schedule workloads. The fast-pick system was evaluated both with and without heuristics, and the heuristics-enabled system was compared to a traditional system. According to the findings, heuristics help the proposed system in achieving better efficiency, and allows the system to complete orders at a cheaper labor cost than a traditional system, but they do not determine which individual storage locations an SKU should be placed in.

By incorporating the sequencing variables of the order picking process, Martinez (2008) established an SKU assignment model that can reduce the travel distance of order pickers and re-stockers in a fast-picking area. The integrated SKU assignment problem was formulated as a mathematical Binary Mixed Integer Linear Programming (BMILP) model for the S-shaped routing strategy, which was solved using the LINGO solver in his research.

Velez-Gallego (2018) developed a mixed integer linear formulation for solving the product assignment and space allocation problem within the fast-pick area to help a cosmetics distribution center's picking operation, with the goal of minimizing the sum of the pickers' and replenishing the fast-pick area's distances. Their computational expertise revealed that, while they were able to find numerous viable solutions in all circumstances, finding the best option for realistically sized instances was difficult. The number of storage bins assigned to a given SKU is limited to those in a single storage location in this model.

According to Bahrami (2019) investigation of home locations-free seats in the picking area, initially implemented by a large shoes and footwear wholesaler, to enhance the performance of the order picking process. This was done via simulation by considering equal space storage strategy and results a remarkable potential to shorten total picking travel distances and time.

2.10. Summary and Literature Gaps

Table 2-1. Summary of revised literatures

Authors Name	Approaches Applied
Masel (2008),	Applies heuristics for storage location assignment and workload scheduling for a fast-pick area.
Hackman (1990),	Applies heuristics to Decide which items to place in the fast-picking area and finding the optimal space allocation for each of them such that it minimizes the order picking, replenishment and equipment costs.
Velez-Gallego (2018),	Optimization of a fast-pick area in a cosmetics distribution centre using mixed integer linear programming.
Martinez (2008),	Developed a SKU assignment model that can minimize the walking distances using Binary Mixed Integer Linear Programming (BMILP) model for the S- shaped routing
Bahrami (2019),	Enhancing the order picking process through a new storage assignment strategy in forward reserve area by reducing picking time and distance using simulation approach.
Seval Ene & Nursel Öztürk (2012),	Mathematical model and stochastic evolutionary optimization approach.
Zhang (2016),	Correlated Storage Assignment Strategy (CSAS) to reduce the travel distance in picker to item strategy
Viveros (2021),	Addresses the multi-level storage locations assignment problem using mathematical programming model with the objective of minimizing the total travel distance.

In the above table different order picking performance improvement approaches used by different scholars. But those scholars did not analyse the application of assignment model using Hungarian method in order to assign items at the nearest bay location to the gate of the particular warehouse for the minimization of order picking travel distance and also the weight of an item was not considered while selecting a SKU to be placed at fast pick area. Martinez and Velez-Gallego focused on a single storage single item approach but this research addresses multiple storage bay for a particular item based on the volume requirement of the item.

CHAPTER THREE

MATERIALS AND METHODS

This section presents the methodology used to achieve the objectives of the study. It is also, covered descriptions of the study area, research design, types of data, data collection techniques, methods of data processing and analysis approach employed to this study. In general, this part describes the systematic and appropriate scientific methodological aspects in conducting this research.

3.1. Description of the Study Area

This study was conducted at ALLE Bejimla Hawassa branch that distributes fast moving consumer goods for the society. It is government owned organization in order to supply fast moving consumer goods to the community with reasonable price. The branch has well organized warehouse with sixteen racks each with four bays for each illustrated in the next figure.

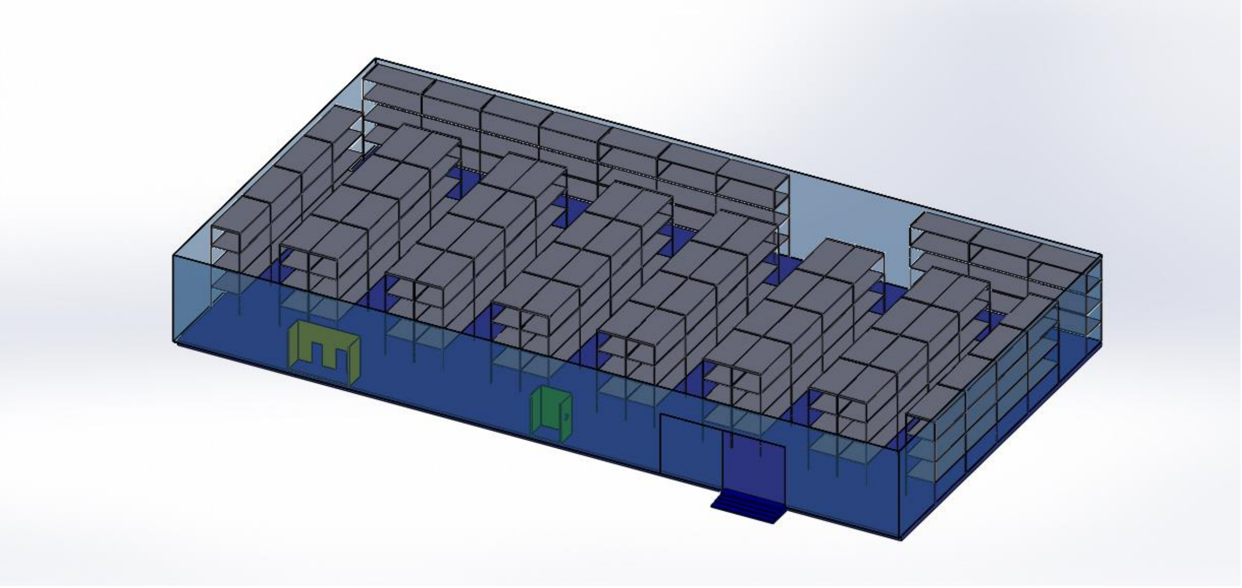


Figure 3-1. Three-dimensional view of ALLE Bejimla Hawassa branch warehouse

3.2. Study Design and Methodology

In order to properly complete the research, appropriate literature reviews, data collection, and analysis were carried out. Concepts and depth of understanding about warehouses, warehousing, warehousing operations, and methodologies used to improve warehousing performance are considered to begin the research. Reviewing warehouse-related literatures, such as books, journal articles published by various scholars on the subject, and reading software instructions are all part of this process.

These were primarily undertaken to gain a better understanding of existing concepts, methods, and advancements linked to improving order picking performance, assigning storage to a specific item, and allocating space for the forward pick area.

After that, the problem was identified in the case warehouse and in relation to the literatures. The next step was to determine what research data was required and how data would be collected. To obtain adequate data, data collection focuses on primary data and secondary data collecting.

The relevant data were acquired directly from the warehouse using the primary data collection methods. These were:

- The current assignment of items on the bay of the storage rack was recorded on the format.
- With the aid of a measuring tape, aisle width, length and width of each rack and bay was directly measured.
- Products packaging system, pieces in the package and packaging material size based on length, width, and height measurements.
- By interviewing sales supervisors about the retailing process, the minimum weight that could be transported in a single order were known.

Secondary data gathering methods from the warehouse's sales report were used to determine the order frequency and quantity of things sold over the course of two months. Following that, based on the frequency of orders and the item's weight, the item's popularity was determined. Using ABC analysis, the items were divided into three categories: fast mover and heavyweight, medium mover and medium weight, and slow mover and low weight.

For the existing system, the order picking travel distance was calculated by tracking and adding each distance of order fulfilment movement for a single pick. The total order picking travel distance was computed by multiplying single order picking travel distance by the order frequency, which gave us the total order picking travel distance, that should be minimized.

The assignment model and items popularity heuristic approaches were identified after knowing each order picking travel distance, with the goal of minimizing total order picking travel distance. In order to determine the optimal assignment of storage bays to products that minimizes overall traveling distance, an assignment model was formulated and analysed using the Hungarian method with the help of POM software. This assignment model is one of several operations research topics which focuses on minimizing assignment costs, time, and distance while also maximizing profit, production, and other factors. It involves assigning a specific (person, labour, or machine) to a specific (task or job), and this study aims to expand its application for optimal storage bay assignment to items in order to minimize order picking travel distance.

3.3. Rationale of Selected Approaches

A. Hungarian method

Hungarian method is a combinatorial optimization algorithm that solves the assignment problem in polynomial time and which anticipated later primal–dual methods. It was developed and published in 1955 by Harold Kuhn, who gave the name "Hungarian method" because the algorithm was largely based on the earlier works of two Hungarian mathematicians: Dénes Kőnig and Jenő Egerváry. An assignment problem can be easily solved by applying Hungarian method which consists of two phases. In the first phase, row reductions and column reductions are carried out. In the second phase, the solution is optimized on iterative basis (Taylor, 2013).

Model is represented as: Minimize D = $\sum_{i=1}^{m} * \sum_{j=1}^{n} fd_{ij} * X_{ij}$

Phase 1

Consider the given matrix (items and available number of storage bays).

Step 1: In a given problem, if the number of rows is not equal to the number of columns and vice versa, then add a dummy row or a dummy column. The assignment costs for dummy cells are always assigned as zero.

Step 2: Reduce the matrix by selecting the smallest element in each row and subtract with other elements in that row.

Phase 2

Step 3: Reduce the new matrix column-wise using the same method as given in step 2.
Step 4: Draw minimum number of lines to cover all zeros.
Step 5: If Number of lines drawn = order of matrix, then optimally is reached, so proceed to step 7. If optimally is not reached, then go to step 6.
Step 6: Choose the smallest element in the entire matrix that isn't "covered" by lines. Subtract this smallest element from all other elements "not covered" by lines, then add the element at the line junction. Leave the single line covering the elements alone. Go to step 4 now.
Step 7: Take any row or column which has a single zero and assign by squaring it. Strike off the remaining zeros, if any, in that row and column (X). Repeat the process until all the assignments have been made.
Step 8: Write down the assignment results and find the minimum cost/time.

This iterative solution method is used when we perform assignment using Hungarian method, but in this research software package (POM) was used.

B. Items popularity heuristics

It is the most popular tool in reduction of order picking travel distance by computing the popularity of each item and then assign the most popular (frequently ordered) item to the bay location with shorter distance to the depot. It provides good result if the retrieval of items occurred in a single item command. The following steps are followed in order to use this approach.
Steps in items popularity heuristics:
Step 1. Count the number of orders (frequency) for each item.
Step 2. Sorting each item in decreasing order based on order frequency.
Step 3. Allocate the item with higher order frequency at the bay location with shorter travel distance.

Using a mathematical formula, the space for storing frequently ordered and heavy items was determined. This was calculated using the monthly flow of each item as well as the package volume of items stored on the storage rack. The monthly flows of each item are calculated by summing daily sales quantity sold per month.

By multiplying the length, width, and height of the packaging material placed on the storage bay, the packaging volume was determined.

The periodic flow of items and fractional volume required for the items was calculated using the following equations (Bartholdi, 2016).

The fractional volume from available space with different storage strategy is:

- Under Optimal allocation (OPT) strategy:

$$v_i = \frac{\sqrt{f_i}}{\sum_{i=1}^{n} \sqrt{f_i}} * V$$

Where, v_i = fractional volume for item i

V = available volume in cubic meter

f_i = monthly flows of each item in m^3/month

$$f_i = [(units / month) / (units / case)] * [m^3 / case]$$

Number of restocks per month under optimal allocation is givens as:

$$= \frac{\sqrt{f_i}}{V} * \sum_{j \in \mathcal{F}} \sqrt{f_j}$$

- Under Equal Space (EQS) strategy:

Space required for each item is $v_i = \frac{V}{n}$

Where, n = number of items

and number of restocks per month is equals to $\frac{nf_i}{V}$

- Under Equal Time strategy (EQT)

$$v_i = \left(\frac{f_i}{\sum_j f_i}\right) * V$$

and number of restocks per month is equals to $\frac{1}{V} * \sum_{j \in \mathcal{F}} f_j$

3.4. Tools Used While Doing the Research

a. SketchUp 2018; this software was used in representing two-dimensional view of the warehouse.

b. Solid Work; this software was used to show three-dimensional view of the warehouse and storage racks.

c. Microsoft paint; this tool was deployed when assigning bay numbers to a particular item.

After all, the research has now been finished according to the methodology indicated, compared to the existing system, and the overall conclusion and recommendations have been mapped out in accordance with the research findings. The research approach is depicted in the schematic diagram below. Literature review was conducted during observation, problem formulation, model selection.

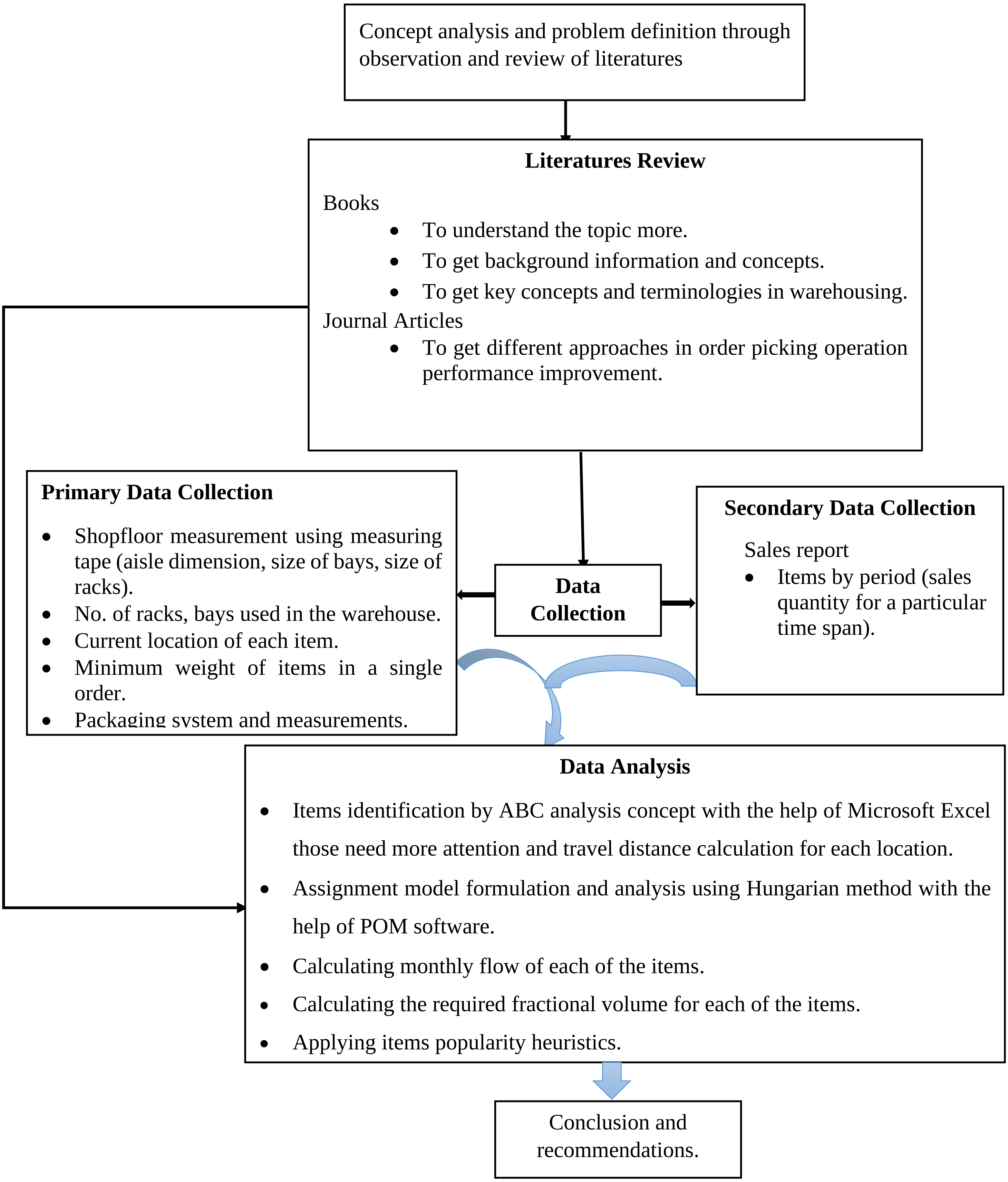


Figure 3-2. Research methodology framework

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Data Presentation

The warehouse is designed to store and sell fast moving consumer goods. It has sixteen racks with four bays and three vertical levels for each rack. The dimension of each rack and bay is presented in the following figure.

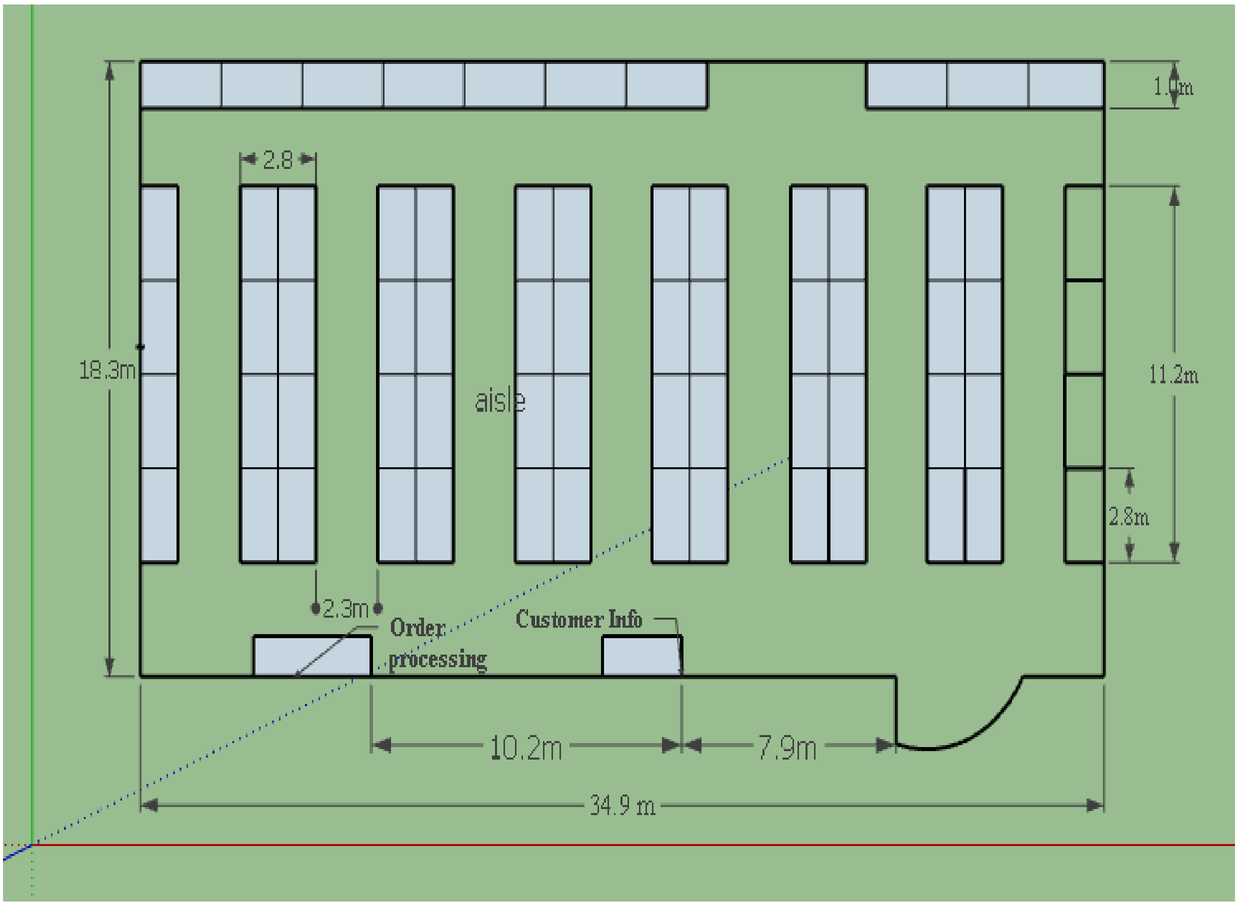


Figure 4-1. Layout of ALLE Bejimla warehouse (all dimensions are in meter)

Currently, only one door is used for receiving and shipping operations. There is also an area for processing orders. The tables below indicate the current assignment of each rack.

Table 4-1. Existing assignment of items on storage bays

Rack # 1				
	Bay #1	Bay #2	Bay #3	Bay #4
Level #3	Conditioner Rotana 750ml	Rotana liquid hand soap 500ml		KOJJ macaroni
Level #2	Conditioner Rotana 750ml	Conditioner Rotana 750ml		KOJJ macaroni
Level #1	Bar soap Sky premium 250gm	Bar soap Sky premium 250gm	KOJJ macaroni	KOJJ macaroni
Rack #2				
	Bay #5	Bay #6	Bay #7	Bay #8
Level #3				
Level #2	Bar soap Sky premium 250gm		Rotana liquid hand soap 500ml	Rotana liquid hand soap 500ml
Level #1	Bar soap Sky premium 250gm	Largo all-purpose 5kg	Largo all-purpose 5kg	Largo all-purpose 5kg
Rack #3				
	Bay #9	Bay #10	Bay #11	Bay #12
Level #3	Hand Sanitizer 500ml	Hand Sanitizer 500ml	Hand Sanitizer 500ml	Rotana liquid hand soap 500ml
Level #2	Beauty soap Aura (milk & honey) 80gm, Rotana shampoo	Rotana liquid hand soap 500ml	Rotana liquid hand soap 500ml	
Level #1	Beauty soap Aura (rose and olive) 80gm	Beauty soap Aura (olive, milk & honey) 80gm	Rotana liquid hand soap 500ml (blue &berry), lifebuoy 70gm	Beauty soap lifebuoy 70gm

Rack#4				
	Bay #13	Bay #14	Bay #15	Bay #16
Level #3	Beauty soap Aura 80gm	Lux beauty soap 170gm	Beauty soap Lux 170gm	
Level #2	Beauty soap Aura 80gm	Lifebuoy lemon, lifebuoy 70gm	Lifebuoy 70gm	Rotana liquid hand soap 500ml
Level #1	Beauty soap Aura 80gm	Lifebuoy 70gm	Lifebuoy	Hand Sanitizer 500ml
Rack#5				
	Bay #17	Bay #18	Bay #19	Bay #20
Level #3	Hand Sanitizer 500ml			Hand Sanitizer 500ml
Level #2	Ajax dish wash 750ml	Hand sanitizer, Gion Bleach Ghion 800cc, Ajax dish wash 750ml	Ajax dish wash 750ml, Sky soap 250gm	Bar soap Sky premium 250gm
Level #1	Vitol 500ml, Liquid detergent Act	Bleach Ghion 800cc	Bleach Ghion 800cc, sky liquid soap	Bleach Ghion 5L
Rack#6				
	Bay #21	Bay #22	Bay #23	Bay #24
Level #3				
Level #2	Bar soap Sky premium 250gm	Liquid detergent Act	Liquid detergent Act	Liquid detergent Act, 555 liquid detergent 1L
Level #1	Multipurpose cleaner Kuzey 5L, Bleach Ghion 5L	Multipurpose cleaner Kuzey 5L, Bleach Ghion 5L	Multipurpose cleaner Kuzey 5L, Bleach Ghion 5L	Bleach Ghion 5L

Rack#7				
	Bay #25	Bay#26	Bay #27	Bay #28
Level #3	Bleach Ghion 800cc	Bleach Ghion 800cc	Bar soap Sky 250gm	
Level #2	Bleach Ghion 300cc	Bleach Ghion 300cc	Bar soap Sky 250gm	Roll Omo 5kg and 30gm
Level #1	Multipurpose cleaner Kuzey 5L, Bleach Ghion 5L	Multipurpose cleaner Kuzey 5L, Bleach Ghion 5L	Bar soap Sky 250gm	555 powders (450,900,180) gm
Rack#8				
	Bay #29	Bay#30	Bay #31	Bay #32
Level #3	Bleach Ghion 800cc	Bleach Ghion 800cc	Bleach Ghion 300cc	Bleach Ghion 300cc
Level #2	Bar soap Sky 250gm	Rotana Dish wash, sky soap 250gm	Bleach Ghion 5L	Bleach Ghion 800cc
Level #1	Bleach Ghion 800cc	Repi liquid soap, Ajax bar, Act ajax	Bleach Ghion 5L	Bleach Ghion 5L
Rack #9				
	Bay #33	Bay#34	Bay#35	Bay#36
Level #3	Snack Teddy chips	Macaroni 25kg	Macaroni 25kg	Macaroni 25kg
Level #2	Safe instant 500gm&1kg	Macaroni 25kg	Macaroni 25kg	Macaroni 25kg
Level #1	Rice 5kg double star	Macaroni 25kg	Macaroni 25kg	Macaroni 25kg

Rack #10				
	Bay#37	Bay #38	Bay #39	Bay#40
Level #3	Macaroni 25kg	Macaroni 25kg	Macaroni 25kg	Macaroni 25kg
Level #2	Macaroni 25kg	Macaroni 25kg	Macaroni 25kg	Macaroni 25kg
Level #1	Macaroni 25kg	Macaroni 25kg	Macaroni 25kg	Macaroni 25kg
Rack#11				
	Bay#41	Bay #42	Bay #43	Bay#44
Level #3	Knorr hard cube 8gm, Loose tea Addis	Knorr hard cube 8gm	Knorr hard cube 8gm	Knorr hard cube 8gm
Level #2	Mini nib chocolate, nib chocolate, Adiss tea	Loose tea Ahadu 80gm	KOJJ Spaghetti	M – amole iodized salt 450gm
Level #1	KOJJ Spaghetti	KOJJ Spaghetti	KOJJ p Spaghetti	KOJJ Spaghetti
Rack#12				
	Bay#45	Bay #46	Bay #47	Bay#48
Level #3	Backing powder	Backing powder	Backing powder	Backing powder
Level #2	Blue backing powder, baking powder	Zat -Acheto	Iodized salt 700gm	Iodized salt 450gm
Level #1	KOJJ Spaghetti	KOJJ Spaghetti	KOJJ Spaghetti	Backing powder
Rack#13				
	Bay#49	Bay #50	Bay #51	Bay#52
Level #3	Loose tea Ahadu 80gm	Loose tea Ahadu 80gm	Loose tea Ahadu 80gm	
Level #2	The day marmalata	The day marmalata	Knorr,	Danalac baby milk
Level #1	Oche Spaghetti	Rice 5kg	Oche Spaghetti	Danalac baby milk

Rack#14				
	Bay#53	Bay #54	Bay #55	Bay#56
Level #3	Macaroni	Macaroni	Macaroni	Macaroni
Level #2	Iodized salt 700gm	Mini nib chocolate, nib chocolate and candy	Danalac baby milk	Danalac baby milk
Level #1	Oche Spaghetti	Oche Spaghetti, nib candy	Danalac baby milk	Macaroni
Rack #15				
	Bay#57	Bay #58		
Level #3				
Level #2	Oche Spaghetti			
Level #1	Danalac baby milk	Sunflower oil Tena		

Rack #16							
	Bay#60	Bay #61	Bay #62	Bay#63	Bay #64	Bay #65	Bay#66
Level #3	Snack Teddy chips		Dish wash Rotana 750ml	Dish wash Rotana 750ml	Dish wash Rotana 750ml		
Level #2	Bar soap Sky 250gm	Dish wash Rotana 750ml		Roll powder 5kg	Roll powder 5kg		
Level #1	Bar soap Sky 250gm	Bar soap Sky 250 gm	Multipurpose cleaner Kuzey 5L	Multipurpose cleaner Kuzey 5L	Multipurpose cleaner Kuzey 5L	Multipurpose cleaner Kuzey 5L	Macaroni

4.1.1. Analysis of Order Frequency

The structure of multi-aisle routes enables us to view the distances travelled by order picking sequences from a linear perspective. Some orders have some idle travel, meaning that they are crossing bays where no picking is needed. In an ideal warehousing world, we would want every order to only travel bays where picks are required, but because it is not physically possible to overlap one bay over another there will always be some idle walk involved.

The amount of distance D travelled by each order picking is given by the product of its length L (to reach item location) times its frequency F (the number of orders containing the same product mix). We can easily understand that to minimize the total distance D it is necessary to reduce the length L of order picking. The achievement of such a minimization is the ultimate aim of this research work. The following figure illustrates that how customers order is processed and picked in ALLE Bejimla warehouse. Here, customers enter into the warehouse and contact the customer relation personnel to know whether an item they plan to purchase available or not. After confirming the availability of the item, customers take shopping cart & goes to the respective rack that the item is stored and pick the required item. After picking the item, customers go to the casher area with the items in order to make payment. After completing the payment process customers leave the warehouse.

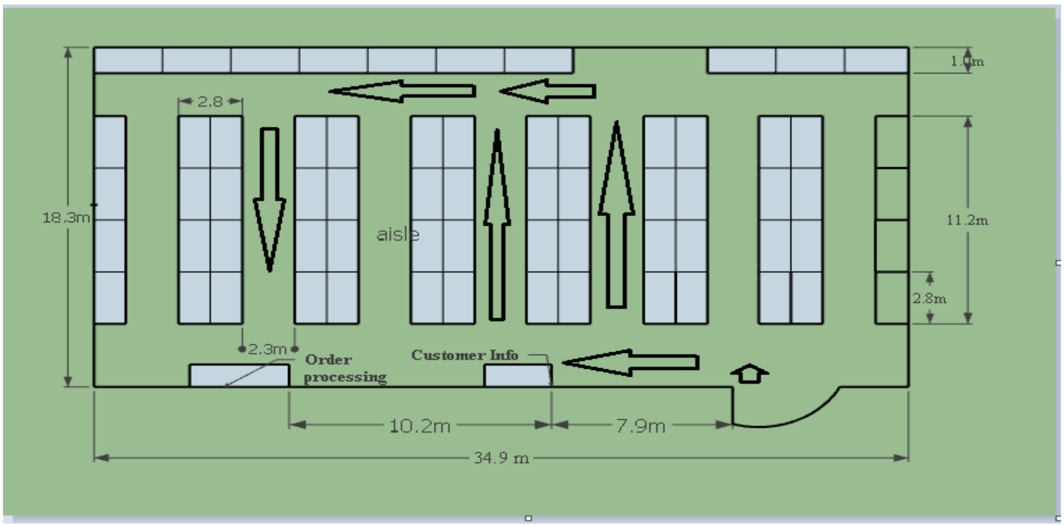


Figure 4-2. Picking process

Items are prioritized as follows based on the number of daily orders sold over the course of two months and the weight of the item.

Table 4-2. Order frequency and weight of each item

S.No.	Item Name	Numbers of Orders (May - July 2021)	Minimum Weight can be picked (kg)
1	Bar soap Sky premium 250gm	64	0.25
2	Snack Teddy chips 25gm	9	1.25
3	Dish wash liquid Rotana 750ml	25	0.75
4	Multipurpose cleaner Kuzey 5L	206	5
5	Detergent powder Roll Bio 5kg	31	5
6	Macaroni	340	25
7	Infant formula milk powder Danalac 400 gm	26	0.4
8	Spaghetti 500gm	397	10
9	Sunflower oil Tena 1L	233	0.88
10	Iodized salt	139	0.7
11	Nib chocolate	76	0.03
12	Marmelade The Day	53	0.45
13	Loose tea 80gm	114	0.96
14	Knorr hard cube 8gm	165	0.96
15	Baking powder baked 100gm	54	0.1
16	Vinegar Zat white PET 500ml	36	0.5
17	Yeast Safe-Instant 11gm	73	0.264
18	Rice 5kg	271	5
19	Bleach Ghion 800cc &300cc	104	1.1
20	Detergent bar Ajax Repi 100gm	87	0.1
21	Bleach Ghion 5L	169	5
22	Detergent bar soap Act 100gm	13	0.1
23	Detergent powder Roll Sachet 30gm	8	0.36
24	Detergent powder 555 Gulele	57	0.9
25	555 Liquid detergent 1L	7	1
26	Liquid detergent Act 1kg	148	1
27	Ajax dish wash 750ml	46	0.75
28	Disinfectant liquid Vitol 500ml	27	0.5
29	Hand sanitizer Safi 250ml	2	0.25
30	Beauty soap Lux 170gm	55	0.7
31	Beauty soap lifebuoy	247	0.28
32	Rotana liquid hand soap 500 ml	101	0.5
33	Beauty soap Aura 80gm	242	0.48
34	Beauty soap Aura 175gm	49	0.7
35	Conditioner Rotana 750ml	71	0.75
36	Liquid detergent Largo All-purpose 5kg	203	5
	Total orders	3,948	

Based on order frequency and minimum picking weight, items are classified into class A (higher value of order frequency times weight), class B (medium value of order frequency times weight) and class C (low value of order frequency times weight).

Table 4-3. ABC classification of items

No.	Item Name	Minimum Weight can be picked (kg)	Numbers of orders (19 May - 19July 2021)	Total weight	Class
1	Macaroni	25	340	8500	A High value of order frequency × weight
2	Spaghetti 500gm	10	397	3970	
3	Rice	5	271	1355	
4	Multipurpose cleaner Kuzey 5L	5	206	1030	
5	Liquid Largo All-purpose 5kg	5	203	1015	
6	Bleach Ghion 5L	5	169	845	
7	Sunflower oil Tena 1L	0.88	233	205.04	
8	Knorr hard cube 8gm	0.96	165	158.4	
9	Detergent powder Rol Bio 5kg	5	31	155	
10	Liquid detergent Act 1kg	1	148	148	
11	Beauty soap lifebuoy	0.56	247	138.32	
12	Beauty soap Aura 80gm	0.48	242	116.16	
13	Bleach Ghion 800cc &300cc	1.1	104	114.4	
14	Iodized salt	0.7	139	97.3	
15	Loose tea 80gm	0.48	114	54.72	B Medium value of order frequency × weight
16	Conditioner Rotana 750ml	0.75	71	53.25	
17	Detergent powder 555 Gulele	0.9	57	51.3	
18	Rotana liquid hand soap 500 ml	0.5	101	50.5	
19	Beauty soap Lux 170gm	0.68	55	37.4	
20	Ajax dish wash 750ml	0.75	46	34.5	
21	Beauty soap Aura 175gm	0.7	49	34.3	
22	MarmeladeTHeDaY	0.45	53	23.85	
23	Yeast Safe-Instant 11gm	0.264	73	19.272	
24	Dish wash liquid Rotana 750ml	0.75	25	18.75	
25	Vinegar Zat white PET 500ml	0.5	36	18	
26	Bar soap Sky premium 250gm	0.25	64	16	
27	Disinfectant liquid Vitol 500ml	0.5	27	13.5	
28	Snack Teddy chips 25gm	1.25	9	11.25	C Low value of order frequency × weight
29	Infant formula milk powder	0.4	26	10.4	
30	Detergent bar ajax Repi 100gm	0.1	87	8.7	
31	555 Liquid detergent 1L	1	7	7	
32	Baking powder baked 100gm	0.1	54	5.4	
33	Detergent powder Rol 30gm	0.36	8	2.88	
34	Nib chocolate	0.03	76	2.28	
35	Detergent bar soap Act 100gm	0.1	13	1.3	
36	Hand sanitizer Safi 250ml	0.25	2	0.5	
		Total	3,948		

As shown on the above table, the first fourteen items (Spaghetti, Macaroni, Rice, Beauty soap lifebuoy, Beauty soap Aura 80gm, Sunflower oil Tena, Multipurpose cleaner Kuzey 5L, Liquid detergent Largo 5kg, Bleach Ghion 5L, Knorr hard cube 8gm, Liquid detergent Act, Detergent powder Rol Bio 5kg, Bleach Ghion 800cc &300cc and Iodized salt) are first class items since they have higher multiplicative value of order frequency and weight. Therefore, these items should be stored in more convenient area in order to improve the order picking process through minimizing the distance travelled to pick these items. Let's analyse where these items were slotted and the order picking distance in order to pick these items. The order picking travel distance can be known by following the movement of customers to reach the bay number where the required item stored.

Travel distance to reach customer service, travel distance to reach bay location where an item is stored, travel distance to order processing, and travel distance from order processing to the exit are all elements that considered while calculating total order picking distance for a specific order. The following layout shows the dimension of the warehouse including the area of aisle and dimensions of each rack bay.

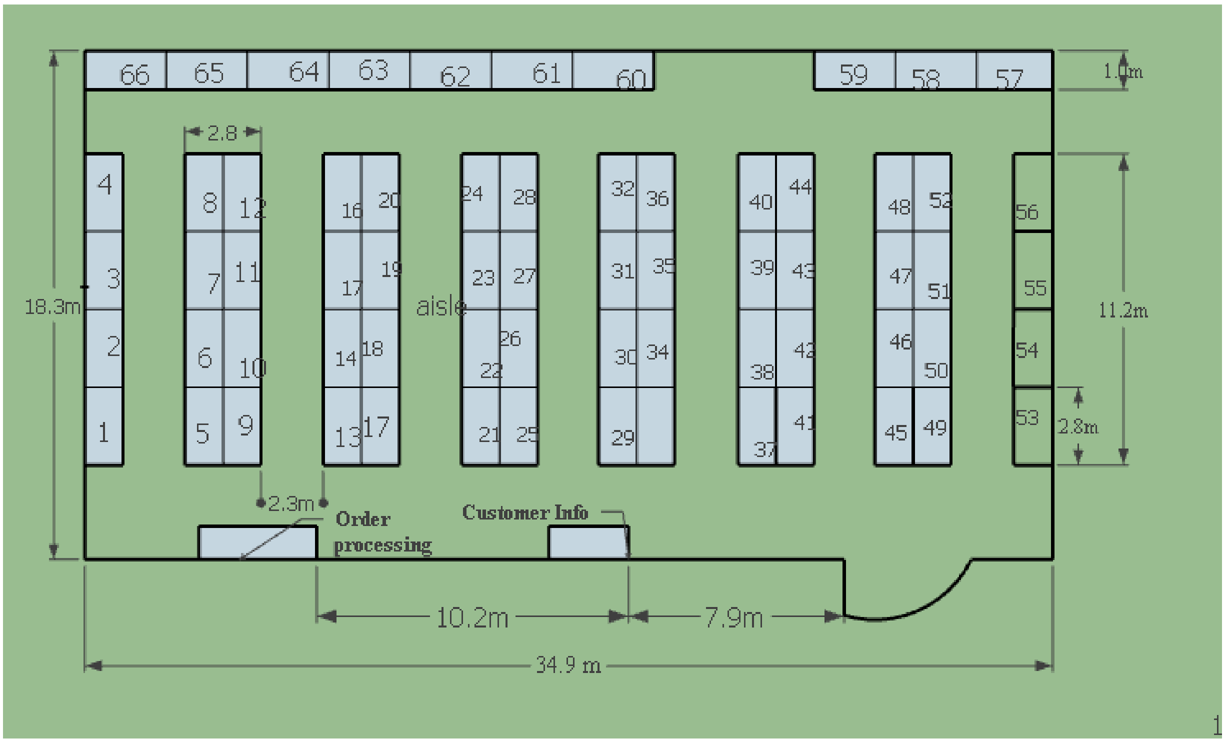


Figure 4-3. Size of ALLE's warehouse

By referring the above figure, we can calculate the total order picking distance in order to pick fast mover and heavy items.

The total order picking travel distance “Rice 5kg” can be found as:

Rice was stored at bay number 33 and 50. The total distance to fulfil an order of rice from these bays is:

Picking an order of rice from bay number 33:

7.9m + 2.3 m = 10.2m (distance from gate to customer service plus aisle distance to reach bay #33)
2.8m + 10.2m + 2.3m = 15.3 m (distance from bay #33 to order processing area for payment)
And 18.1m (travel distance from order processing area to exit point).
The total travel distance to fulfil an order by picking from bay number 33 is:
10.2m + 15.3m +18.1m = 43.6m and

Picking an order of rice from bay number 50:
7.9m + 7.9m + 2.3m + 2.8m + 2.8m = 23.7m (distance from gate to customer service plus distance to reach bay #50).
2.8m + 2.8m + 2.3m + 7.9m + 10.2m +2.3m = 28.3m (distance from bay #50 to order processing area for payment) plus 18.1m travel distance from order processing area to exit point.
The total distance is 23.7m + 28.3m + 18.1m = 70.1m

The longest distance was taken for the analysis since the objective is minimization of order picking distance. And using the same procedure order picking distance was calculated for other class A (items with higher multiplicative value of order frequency and weight) items and summarized in the following table.

Table 4-4. Order picking travel distance (bolded numbers represent the farthest bay)

Item name	Assigned bay number (existing)	Travel length (L) per single visit	Order Frequency	Distance
Spaghetti 500gm	41,42,43,44,45,46, 47,49,51,53,54,**57**	93.8	397	37,238.6
Macaroni	3,4,34,35,36,37,38,39, 40,53,54,55,**56**,66	87.2	340	29,648
Rice 5kg	33,**50**	70.1	271	18,997.1
Beauty soap lifebuoy	11,**12**,14,15	60	247	14,820
Beauty soap Aura 80gm	9,10,**13**	47.1	242	11,398.2
Sunflower oil Tena	**58**	99.6	233	23,206.8
Multipurpose cleaner Kuzey 5L	21,22,23,25,26,62,63, 64,**65**	72.9	206	15,017.4
Liquid detergent Largo 5kg	6,7,**8**	63.2	203	12,829.6
Bleach Ghion 5L	**12**,21,22,23,24,25,26, 31,32	59.9	169	10,123.1
Knorr hard cube 8gm	41,42,43,44 (Lv-3),**51**	78	165	12,870
Liquid detergent Act	22,23,**24** (Lv-3)	57.8	148	8,554.4
Bleach Ghion 800cc &300cc	18,19, 29, (30,31,**32** 25,26,27,**28**(Lv-3))	57.6	104	5,990.4
Detergent powder Rol Bio 5kg	**63**,64	70.6	31	2,188.6
Iodised salt	44,47,**48**,53(Lv-2)	77.7	139	10,800.3
	Total distance	995.4 m		213,682.3

As depicted on the table above, the total order picking travel distance 995.4 meter in order to pick class A items in a single order. This is due to the unproper storing arrangement of items in the warehouse and it should be minimized. To minimize the total order picking travel distance, let’s see the following discussions.

➢ ***Approach I: Using assignment model to minimize order picking distance***

4.2. Assignment Model Formulation

Assignment model is special case of transportation model that aims in minimization of costs, time, and distance relate to transportation. Where, dij represents the distance travelled to pick the i^{th} item. Let xij denote the j^{th} bay assigned to the i^{th} item and f is the frequency. Mathematically assignment model can be stated as:

Minimize D = $\sum_{i=1}^{m} * \sum_{j=1}^{n} fd_{ij} * X_{ij}$ ………………. Equation 4-1

Subjected to;

$$X_{ij} = \begin{cases} 1, \ if \ the \ j^{th} \ bay \ is \ assigned \ to \ the \ i^{th} \ item \\ 0, \ if \ the \ j^{th} \ bay \ is \ not \ assigned \ the \ i^{th} \ item \end{cases}$$

The constant fdij in the above problem represents distance. It may be cost or some other parameter which is to be minimised in the assignment problem under consideration. Note that an assignment problem is a special type of transportation problem. And we can use a method known as the Hungarian method for solving it. This method is used to get the optimal solution of a transportation problem. Let us explain Hungarian method of finding the optimal solution of an assignment problem.

The assignment method involves adding and subtracting appropriate numbers in the table to find the lowest opportunity for each assignment. While we are doing an assignment using Hungarian methods, the followings steps are utilized.

1. Subtract the smallest number in each row from every number in the row. This is called a row reduction. Enter the results in a new table.
2. Subtract the smallest number in each column of the new table from every number in the column. This is called a column reduction. Enter the results in another table
3. Test whether an optimum assignment can be made. We do this by determining the minimum number of lines (horizontal or vertical) needed to cross out (cover) all zeros.

If the number of lines equals the number of rows, an optimum assignment is possible. In that case, go to step 6. Otherwise go on to step 4.

4. If the number of lines is less than the number of rows, modify the table in this way:

   a) Subtract the smallest uncovered number from every uncovered number in the table.

   b) Add the smallest uncovered number to the numbers at intersections of cross-out lines

   c) Carry over numbers crossed out but not at intersections of cross-out lines carry over to the next table

5. Repeat steps 3 and 4 until an optimal table is obtained.
6. Make the assignments. Begin with rows or columns with only one zero. Match items that have zeros, using only one match for each row and each column. Eliminate both the row and the column after the match.

This will be used when the rows and columns are small in number. For large number of rows and columns software packages are more appropriate. Since we have fourteen class A items and sixty-six bays to be assigned. So, it is better to use POM software in order to get the optimum assignment that minimizes the total order picking travel distance. The distance to reach each bay is illustrated in the table below.

$$
\begin{aligned}
\text{Minimize } D = \quad & fd_{1,1}X_{1,1} + fd_{1,2}X_{1,2} + fd_{1,3}X_{1,3} + \ldots + fd_{1,66}X_{1,66} \\
& fd_{2,1}X_{2,1} + fd_{2,2}X_{2,2} + fd_{2,3}X_{2,3} + \ldots + fd_{2,66}X_{2,66} \\
& fd_{3,1}X_{3,1} + fd_{3,2}X_{3,2} + fd_{3,3}X_{3,3} + \ldots + fd_{3,66}X_{3,66} \\
& \vdots \quad + \quad \vdots \quad + \quad \vdots \quad + \ \ldots \ + \quad \vdots \\
& fd_{14,1}X_{14,1} + fd_{14,2}X_{13,2} + fd_{14,3}X_{14,3} + \ldots + fd_{14,66}X_{14,66}
\end{aligned}
$$

Subjected to,

$$\sum_{i=1}^{66} xij = 1, j = 1,2,3, \ldots ,66$$

$$\sum_{j=1}^{14} xij = 1, i = 1,2,3, \ldots ,14$$

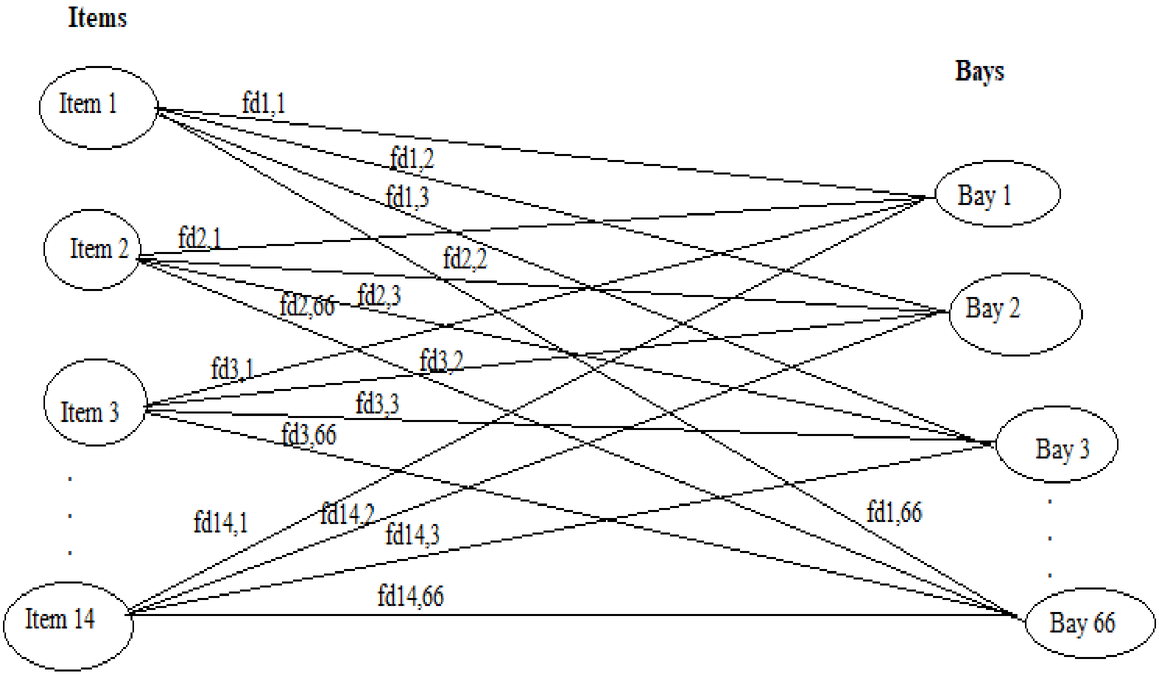


Figure 4-4. Network of order picking distance

Table 4-5. Available bay numbers with respective distance to pick an order

Bay No.	Distance (m)	Bay No.	Distance (m)	Bay No.	Distance (m)
1	51	23	52	45	61.2
2	56.6	24	57.6	46	66.8
3	62.2	25	40.8	47	72.4
4	67.8	26	46.4	48	78
5	46.4	27	52	49	65.8
6	52	28	57.6	50	70.1
7	57.6	29	40.8	51	77
8	63.2	30	46.4	52	82.6
9	40.8	31	52	53	70.4
10	46.4	32	57.6	54	76
11	54.3	33	43.6	55	81.6
12	59.9	34	49.2	56	87.2
13	38.5	35	54.8	57	93.8
14	44.1	36	60.4	58	99.6
15	49.7	37	51	59	105
16	55.5	38	56.6	60	78.4
17	40.8	39	62.2	61	72.8
18	46.4	40	67.8	62	67.2
19	52	41	56.6	63	70.6
20	57.6	42	62.2	64	67.3
21	40.8	43	67.8	65	72.9
22	46.4	44	73.4	66	66.8

Here, we have unbalanced transportation tableau (fourteen items and sixty-six bays) and we should add dummy item with zero distance to balance the transportation tableau. The POM software package inserts this dummy item to solve the problem appropriately. The next table illustrates input information of POM software. Which was done by multiplying single order picking travel distance by its frequency to pick a particular item from each storage bay. The table presents order picking travel distance to pick an item from the first ten bays and the remaining information is presented at appendix.

Table 4-6. Order picking travel distance for two months

		Bay number and distance (meter)									
		1	2	3	4	5	6	7	8	9	10
No.	Items	fd_1	fd_2	fd_3	fd_4	fd_5	fd_6	fd_7	fd_8	fd_9	fd_{10}
1	Macaroni	17,340	19,244	21,148	23,052	15,776	17,680	19,584	21,488	13,872	15,776
2	Spaghetti 500gm	20,247	22,470	24,693	26,917	18,421	20,644	22,867	25,090	16,198	18,421
3	Rice 5kg	13,821	15,339	16,856	18,374	12,574	14,092	15,610	17,127	11,057	12,574
4	Multipurpose cleaner Kuzey 5L	10,506	11,660	12,813	13,967	9,558	10,712	11,866	13,019	8,405	9,558
5	Liquid detergent Largo 5kg	10,353	11,490	12,627	13,763	9,419	10,556	11,693	12,830	8,282	9,419
6	Bleach Ghion 5L	8,619	9,565	10,511	11,458	7,842	8,788	9,734	10,681	6,895	7,842
7	Sunflower oil Tena	11,883	13,188	14,492	15,797	10,811	12,116	13,421	14,726	9,506	10,811
8	Knorr hard cube 8gm	8,415	9,339	10,263	11,187	7,656	8,580	9,504	10,428	6,732	7,656
9	Detergent powder Rol Bio 5kg	1,581	1,755	1,928	2,102	1,438	1,612	1,786	1,959	1,265	1,438
10	Liquid detergent Act	7,548	8,377	9,206	10,034	6,867	7,696	8,525	9,354	6,038	6,867
11	Beauty soap Aura 80gm	12,342	13,697	15,052	16,408	11,229	12,584	13,939	15,294	9,874	11,229
12	Bleach Ghion 800cc &300cc	5,304	5,886	6,468	7,051	4,826	5,408	5,990	6,573	4,243	4,826
13	Beauty soap lifebuoy	12,597	13,980	15,363	16,746	11,461	12,844	14,227	15,610	10,078	11,461
14	Iodized salt	7,089	7,867	8,646	9,424	6,450	7,228	8,006	8,785	5,671	6,450

This information was directly fed into the software to solve using the Hungarian method and the results are presented as follows.

Table 4-7. Bay assignment solution (Hungarian Method)

Objective

- ○ Maximize
- ◉ Minimize

Assignment Results

Bay Assignment Solution

Optimal solution value = 124843	bay1	bay2	bay 3	bay4	bay5	bay 6	bay 7	bay 8	bay 9	bay 10	bay11	bay 12
Macaroni	17340	19244	21148	23052	15776	17680	19584	21488	13872	15776	18462	20366
Spaghetti 500gm	20247	22470	24693	26917	18421	20644	22867	25090	16198	18421	21557	23780
Rice 5kg	13821	15339	16856	18374	12574	14092	15610	17127	11057	12574	14715	16233
Multipurpose cleaner Ku...	10506	11660	12813	13967	9558	10712	11866	13019	8405	9558	11186	12339
Liquid detergent Largo 5...	10353	11490	12627	13763	9419	10556	11693	12830	8282	Assign 9419	11023	12160
Bleach Ghion 5L	8619	9565	10511	11458	7842	8788	9734	10681	6895	7842	9177	10123
Sunflower oil Tena	11883	13188	14492	15797	10811	12116	13421	14726	9506	10811	12652	13957
Knorr hard cube 8gm	8415	9339	10263	11187	7656	8580	9504	10428	6732	7656	8960	9884
Detergent powder Rol Bi...	1581	1755	1928	2102	1438	1612	1786	1959	1265	1438	1683	1857
Liquid detergent Act	7548	8377	9206	10034	6867	7696	8525	9354	6038	6867	8036	8865
Beauty soap Aura 80gm	12342	13697	15052	16408	11229	12584	13939	15294	Assign 9874	11229	13141	14496
Bleach Ghion 800cc &30...	5304	5886	6468	7051	Assign 4826	5408	5990	6573	4243	4826	5647	6230
Beauty soap lifebuoy	12597	13980	15363	16746	11461	12844	14227	15610	10078	11461	13412	14795
Iodized Salt 450g	7089	7867	8646	9424	6450	7228	8006	8785	5671	6450	7548	8326
items 15	Assign 0	0	0	0	0	0	0	0	0	0	0	0
items 16	0	Assign 0	0	0	0	0	0	0	0	0	0	0

As shown in the table, bays are assigned for specific item and the minimum order picking travel distance is found as 124,843 meter for two months and picking distance for single order of those items is 617.2 meter which is less than the existing assignment method. Therefore, Hungarian method gives encouraging result by minimizing the total order picking travel distance.

The assignment list is summarized as follow.

Table 4-8. Items assignment list

Assignment List		
Bay Assignment		
Item name	Assigned bay No.	Distance (m)
Macaroni	Bay17	13,872
Spaghetti 500gm	Bay 21	16,198
Rice 5kg	Bay 25	11,057
Multipurpose cleaner Kuzey 5L	Bay 14	9,085
Liquid detergent Largo 5kg	Bay 10	9,419
Bleach Ghion 5L	Bay 18	7,842
Sunflower oil Tena	Bay 33	10,159
Knorr hard cube 8gm	Bay 22	7,656
Detergent powder Rol Bio 5kg	Bay 13	1,460
Liquid detergent Act	Bay 26	6,867
Beauty soap Aura 80gm	Bay 9	9,874
Bleach Ghion 800cc &300cc	Bay5	4,826
Beauty soap lifebuoy	Bay 29	10,078
Iodize Salt 450g	Bay 30	6,450
Minimized total distance		124,843 meters

The table shows the proper assignment of items on a bay number location that minimizes order picking travel distance. But some questions may be raised about the space required for each of the items, which most convenient area and arrangement of those items. The next section of this research addresses these questions.

4.3. Determining the Amount of Space Required for Each Items

In order to assign items in the convenient area first it is better to know the required space for each item based on the flow of items. The fractional volume and number of restocks required for each of the items under different storage strategy is:

Under Optimal allocation (OPT) strategy:

$$v_i = \frac{\sqrt{f_i}}{\sum_{i=1}^{n}\sqrt{f_i}} * V$$ ……………………………………………….. Equation 4-2

Where, v_i = fractional volume for item $_i$

V = available volume in cubic meter

f_i = monthly flows of each item in m^3/month

$$f_i = [(units / month) / (units / case)] * [m^3 / case]$$ ……… Equation 4-3

Number of restocks per month under optimal allocation is givens as:

$$= \frac{\sqrt{f_i}}{V} * \sum_{j \in \mathcal{F}} \sqrt{f_j}$$ ………………………………………….. Equation 4-4

Under Equal Space (EQS) strategy:

Space required for each item is $v_i = \frac{V}{n}$ ……………………. Equation 4-5

Where, n = number of items

and number of restocks per month is equals to $\frac{nf_i}{V}$ ……. Equation 4-6

Under Equal Time strategy (EQT)

$$v_i = \left(\frac{f_i}{\sum_j f_i}\right) * V$$ ………………………………. Equation 4-7

and number of restocks per month is equals to $\frac{1}{V} * \sum_{j \in \mathcal{F}} f_j$ …… Equation 4-8

Using these equations, we can find the fractional volume required for each of the item. Available volume of ALLE Bejimla warehouse is 66 bays with 11.76 m^3 volume for each and the total effective volume of all storage rack is 776.16 cubic meter.

- Units (quantity) sold for one month.
- Pieces per package.
- Size of each package (length, width and height) and the volume of those packages (L× W ×H)

Table 4-9. Packaging volume of each item

S.No.	Item Name	Units sold per month	Packaging on rack	Items per pack	Size (m)			Volume (m^3)
					Length	Width	Height	
1	Bar soap sky Premium 250gm	14,100 pcs	Cartoon	50 pcs	0.395	0.25	0.245	0.0242
2	Snack Teddy chips 25gm	1,050 pcs	Cartoon	50 pcs	0.6	0.4	0.32	0.0768
3	Dish wash liquid Rotana 750ml	116 pcs	Cartoon	12 pcs	0.46	0.33	0.38	0.0577
4	Multipurpose cleaner Kuzey 5L	456pcs	Pack	4 pcs	0.36	0.26	0.29	0.0271
5	Detergent powder roll bio 5 kg	120kg	Bag	5kg	0.45	0.3	0.08	0.0108
6	Macaroni	18,125kg	Sack	25 kg	0.9	0.59	0.11	0.0584
7	Infant formula milk powder 400gm	380 tins	Cartoon	24 tins	0.46	0.31	0.103	0.0147
8	Spaghetti 500gm	9,350kg	Cartoon	10 kg	0.28	0.14	0.275	0.0108
9	Tena sunflower oil 1 ltr.	1,875 pcs	Cartoon	12 pcs	0.38	0.29	0.35	0.0386
10	Nib chocolate	495 boxes	Cartoon	12 boxes	0.28	0.2	0.15	0.0084
11	MarmeladeThe-Day	183 pcs	Cartoon	24 pcs	0.135	0.344	0.516	0.0240
12	Rice 5kg	2,260kg	Bag	5 kg	0.31	0.11	0.47	0.0160
13	Loose Tea (80 g)	3,030 boxes	Cartoon	100 boxes	0.56	0.375	0.375	0.0788
14	Knorr hard cube 8gm	931boxes	Cartoon	12 boxes	0.6	0.4	0.25	0.0600
15	Backing powder 500g	26 boxes	Cartoon	6 boxes	0.43	0.32	0.11	0.0151
16	Blue backing powder 100 g	1814 pcs	Cartoon	72 pcs	0.55	0.3	0.26	0.0429
17	Vinegar Zat white Pet 500ml	900 pcs	Pack	12 pcs	0.29	0.22	0.23	0.0147
18	Iodized salt 450 gm	6,140 pcs	Cartoon	20 pcs	0.2	0.28	0.25	0.0140
19	Yeast Safe-Instant 11gm	888 packets	Box	20 packets	0.348	0.262	0.198	0.0181
20	Bleach Ghion 800cc	2,675 pcs	Cartoon	12 pcs	0.38	0.29	0.35	0.0386
21	Bleach Ghion 300cc	888 pcs	Cartoon	24 pcs	0.2	0.15	0.2	0.0060
22	Detergent bar Ajax REPI 100gm	5,300 pcs	Cartoon	50 pcs	0.21	0.23	0.18	0.0087
23	Bleach Ghion 5L	352 pcs	Pack	2 pcs	0.184	0.26	0.29	0.0139

24	Detergent bar soap act 100gm	400 pcs	Cartoon	100 pcs	0.62	0.3	0.28	0.0521
25	Detergent powder Rol Sachet 30gm	1,008 sachets	Pack	144 sachets	0.6	0.45	0.3	0.081
26	Detergent powder 555 Gulele 450gm	240 pcs	Cartoon	12 pcs	0.24	0.34	0.17	0.0139
27	Detergent powder 555 Gulele 900 gm	62 pcs	Cartoon	6 pcs	0.24	0.34	0.17	0.0139
28	555 liquid detergent 1 litre	84 pcs	Pack	2 pcs	0.27	0.17	0.12	0.0055
29	Liquid detergent act 1kg	696 pcs	Pack	6 pcs	0.27	0.34	0.18	0.0165
30	Liquid detergent act 2kg	180 pcs	Pack	4 pcs	0.28	0.34	0.2	0.0190
31	Ajax Dish wash 750ml	256 pcs	Cartoon	12 pcs	0.38	0.29	0.35	0.0386
32	Disinfectant liquid Dettol 500ml	429 pcs	Pack	12 pcs	0.35	0.27	0.32	0.0302
33	Hand Sanitizer Safi 250 ml	8 pcs	Cartoon	12 pcs	0.36	0.12	0.25	0.0108
34	Beau soap Aura Rose 80gm	13,464 pcs	Cartoon	72 pcs	0.37	0.3	0.25	0.0278
35	Beauty soap lux 170gm	360 pcs	Cartoon	48 pcs	0.196	0.456	0.136	0.0122
36	Beauty soap lifebuoy 70gm	4,452 pcs	Cartoon	72 pcs	0.6	0.3	0.25	0.0450
37	Rotana liquid hand soap 500 ml	906 pcs	Cartoon	12 pcs	0.35	0.27	0.32	0.0302
38	Conditioner Rotana 750ml	2,516 pcs	Cartoon	12 pcs	0.46	0.33	0.38	0.0577
39	Liquid detergent Largo All-purpose 5kg	427 pcs	Pack	2 pcs	0.184	0.26	0.29	0.0139
40	Beauty soap Aura Milk & Honey 175gm	840 pcs	Cartoon	48pcs	0.196	0.456	0.136	0.0122

Let's calculate the flow per month for each of the items stored.

Monthly flow of Bar soap sky Premium 250gm

$f_i = [(units / month) / (units / case)] * [m^3 / case]$

$f_{\text{bar soap}}$ = [(14,100pcs/month)/(50pcs/carton)] ×[0.0242m^3/carton]

= 6.82m^3/month

and $\sqrt{f_{\text{bar soap}}} = \sqrt{6.82}$ = 2.61 m^3/month

Monthly flow of Snack Teddy chips 25gm

f_{chips} = [(1,050 pcs /month)/(50pcs/carton)] × [0.0768 m^3/carton]

= 1.614 m^3/month

And $\sqrt{f_{\text{chips}}} = \sqrt{1.614}$ = 1.27 m^3/month

Monthly flow of Dish wash liquid Rotana 750ml

f_{dishwash} = [(116 pcs /month)/(12pcs/carton)] × [0.0577m^3/carton]

= 0.56m^3/month

And $\sqrt{f_{\text{Dishwash}}} = \sqrt{0.56}$ = 0.74 m^3/month

Monthly flow of Multipurpose cleaner Kuzey 5L

f_{Kuzey} = [(456 pcs /month)/(4pcs/carton)] × [0.0271m^3/carton]

= 3.089m^3/month

And $\sqrt{f_{\text{Kuzey}}} = \sqrt{3.0889}$ = 1.76 m^3/month

Monthly flow of Detergent powder roll bio 5 kg

$f_{\text{roll bio}}$ = [(120 kg /month)/(5kg/bag)] × [0.0108m^3/bag]

= 0.26m^3/month

And $\sqrt{f_{\text{rollbio}}} = \sqrt{0.26}$ = 0.51 m^3/month

Monthly flow of Macaroni

$f_{Macaroni}$ = [(18,125 kg /month)/(25kg/bag)] × [0.0584m^3/bag]

= 42.34m^3/month

And $\sqrt{f_{Macaroni}} = \sqrt{42.34}$ = 6.5 m^3/month

Monthly flow of Spaghetti 500gm

$f_{Spaghetti}$ = [(9,350kg/month)/(10kg/carton)] × [0.0108m^3/carton]

= 10m^3/month

$\sqrt{f_{Spaghetti}} = \sqrt{10}$ = 3.16 m^3/month

Monthly flow of Tena sunflower oil 1 ltr.

f_{oil} = [(1,875 pcs/month)/(12pcs/carton)] × [0.029m^3/carton]

= 4.53m^3/month

$\sqrt{f_{oil}} = \sqrt{4.53}$ = 2.13m^3/month

Fractional volume for ‘Macaroni’ under optimal allocation is calculated as:

$$v_i = \frac{\sqrt{f_i}}{\sum_{i=1}^{40}\sqrt{f_i}} * V$$

$$v_{macaroni} = \frac{\sqrt{42.34}}{\sum_{i=1}^{40}\sqrt{f_i}} * 776.16\ m^3 = v_{barsoap} = \frac{6.51}{56.2} * 776.16\ m^3 = 89.86m^3$$

Fractional volume for ‘Macaroni’ under Equal time (EQT) allocation is calculated as:

$$v_i = \left(\frac{f_i}{\sum_j f_i}\right) * V = v_{macaroni} = \left(\frac{42.34}{100.622}\right) * 456.04 = 191.89m^3$$

The fractional volume for ‘Macaroni’ under Equal Space (EQS) allocation is calculated as:

$$v_{macaroni} = \frac{V}{n} = \frac{456.04}{14} = 32.57m^3$$

Using the same calculation, monthly flow of each item and fractional volume is calculated and summarized in the table 4-10.

Table 4-10. Monthly flow and fractional volume for each items

S.No.	Item Name	Units sold per month	Items per package	Volume (m^3)	f_i (m^3/month)	$\sqrt{fi}$	Fractional volume (v_i) m^3
1	Bar soap sky Premium 250gm	14,100 pcs	50 pcs	0.0242	6.823	2.612	36.08
2	Snack Teddy chips 25gm	1,050 pcs	50 pcs	0.0768	1.613	1.270	17.54
3	Dish wash liquid Rotana 750ml	116 pcs	12 pcs	0.0577	0.558	0.747	10.31
4	Multipurpose cleaner Kuzey 5L	456pcs	4 pcs	0.0271	3.094	1.759	24.30
5	Detergent powder roll bio 5 kg	120kg	5kg	0.0108	0.259	0.509	7.03
6	Macaroni	18,125kg	25 kg	0.0584	42.347	6.507	89.88
7	Infant formula milk powder 400gm	380 tins	24 tins	0.0147	0.233	0.482	6.66
8	Spaghetti 500gm	9,350kg	10 kg	0.0108	10.079	3.175	43.85
9	Tena sunflower oil 1 ltr.	1,875 pcs	12 pcs	0.0290	4.531	2.13	29.40
10	Nib chocolate	495 boxes	12 boxes	0.0084	0.347	0.589	8.13
11	Marmelade The -Day	183 pcs	24 pcs	0.0240	0.183	0.427	5.90
12	Rice 5kg	2,260kg	5kg	0.0160	7.244	2.692	37.17
13	Loose Tea (80 g)	3,030 boxes	100 boxes	0.0788	2.386	1.545	21.33
14	Knorr hard cube 8gm	931boxes	12 boxes	0.0600	4.655	2.158	29.80
15	Backing powder 500g	26 boxes	6 boxes	0.0151	0.066	0.256	3.54
16	Blue backing powder 100 g	1814 pcs	72 pcs	0.0429	1.081	1.040	14.36
17	Vinegar Zat white Pet 500ml	900 pcs	12 pcs	0.0147	1.101	1.049	14.49
18	Iodized salt 450 gm	6,140 pcs	20 pcs	0.0140	4.298	2.073	28.63
19	Yeast Safe-Instant 11gm	888 packets	20 packets	0.0181	0.804	0.896	12.38
20	Bleach Ghion 800cc	2,675 pcs	12 pcs	0.0386	8.598	2.932	40.50
21	Bleach Ghion 300cc	888 pcs	24 pcs	0.0060	0.222	0.471	6.51
22	Detergent bar Ajax REPI 100gm	5,300 pcs	50 pcs	0.0087	0.922	0.960	13.26
23	Bleach Ghion 5L	352 pcs	2 pcs	0.0139	2.442	1.563	21.58

24	Detergent bar soap act 100gm	400 pcs	100 pcs	0.0521	0.208	0.456	6.30
25	Detergent powder Rol Sachet 30gm	1,008 sachets	144 sachets	0.0810	0.567	0.753	10.40
26	Detergent powder 555 Gulele 450gm	240 pcs	12 pcs	0.0139	0.277	0.527	7.27
27	Detergent powder 555 Gulele 900 gm	62 pcs	6 pcs	0.0139	0.143	0.379	5.23
28	555 liquid detergent 1 litre	84 pcs	2 pcs	0.0055	0.231	0.481	6.64
29	Liquid detergent act 1kg	696 pcs	6 pcs	0.0165	1.917	1.384	19.12
30	Liquid detergent act 2kg	180 pcs	4 pcs	0.0190	0.857	0.926	12.78
31	Ajax Dish wash 750ml	256 pcs	12 pcs	0.0386	0.823	0.907	12.53
32	Disinfectant liquid Dettol 500ml	429 pcs	12 pcs	0.0302	1.081	1.040	14.36
33	Hand Sanitizer Safi 250 ml	8 pcs	12 pcs	0.0108	0.007	0.085	1.17
34	Beau soap Aura Rose 80gm	13,464 pcs	72 pcs	0.0278	5.189	2.278	31.46
35	Beauty soap lux 170gm	360 pcs	48 pcs	0.0122	0.091	0.302	4.17
36	Beauty soap lifebuoy 70gm	4,452 pcs	72 pcs	0.0450	2.783	1.668	23.04
37	Rotana liquid hand soap 500 ml	906 pcs	12 pcs	0.0302	2.283	1.511	20.87
38	Conditioner Rotana 750ml	2,516 pcs	12 pcs	0.0577	12.094	3.478	48.03
39	Liquid detergent Largo All-purpose 5kg	427 pcs	2 pcs	0.0139	2.962	1.721	23.77
40	Beau soap Aura Milk & Honey 175gm	840 pcs	48pcs	0.0122	0.213	0.461	6.37
	Total					56.19	776.16

Now, we can focus on items which have higher multiplicative value of order frequency and weight. Number of restocks and space required for those items were calculated using equations 4-2 to 4-8 and summarized as follows.

Table 4-11. Restocks per month and fractional volume under different storage strategies

			Fractional volume (v_i) m^3			Restocks/month		
Item name	Flow (f_i) (m^3/month)	$\sqrt{fi}$	OPT	EQT	EQS	OPT	EQT	EQS
Macaroni	42.347	6.507	89.88	191.93	32.57	0.45	0.22	1.30
Spaghetti 500gm	10.079	3.175	43.85	45.68	32.57	0.22	0.22	0.31
Rice 5kg	7.244	2.692	37.17	32.83	32.57	0.19	0.22	0.22
Multipurpose cleaner Kuzey 5L	3.094	1.759	24.30	14.02	32.57	0.12	0.22	0.09
Liquid detergent Largo 5kg	2.962	1.721	23.77	13.42	32.57	0.12	0.22	0.09
Bleach Ghion 5L	2.442	1.563	21.58	11.07	32.57	0.11	0.22	0.07
Sunflower oil Tena	4.533	2.455	29.4	20.54	32.57	0.17	0.22	0.14
Knorr hard cube 8gm	4.655	2.158	29.8	21.10	32.57	0.15	0.22	0.14
Detergent powder Rol Bio 5kg	0.259	0.509	7.03	1.17	32.57	0.04	0.22	0.01
Liquid detergent Act	1.917	1.384	19.12	8.69	32.57	0.10	0.22	0.06
Beauty soap Aura 80gm	5.189	2.278	31.46	23.52	32.57	0.16	0.22	0.16
Bleach Ghion 800cc &300cc	8.820	1.431	47.01	39.97	32.57	0.10	0.22	0.27
Beauty soap lifebuoy	2.783	1.668	23.04	12.61	32.57	0.11	0.22	0.09
Iodized salt	4.298	2.073	28.63	19.48	32.57	0.14	0.22	0.13
Total	100.622	31.373	456.04			2	3	3

As shown in the table the optimal storage strategy gives us a smaller number of restocks and that will minimize the restocking cost. Therefore, we can use the optimal allocation for assignment of items to minimize the number of restocks.

- ***Approach II: Using items popularity Heuristic***

<u>Case A</u>: Using Optimal (OPT) allocation strategy

We know that the required number of bays for each of items under the optimal storage strategy (dividing fractional volume by volume of a bay). The upcoming table shows this value.

Table 4-12. Required number of bays for each first-class item under OPT allocation

Item name	Fractional optimal volume (v_i) m^3	Required number of bays
Macaroni	89.88	(89.88m^3÷11.76m^3/bay) = 8
Spaghetti 500gm	43.85	(43.85m^3÷11.76m^3/bay) = 4
Rice 5kg	37.17	(37.17m^3÷11.76m^3/bay) = 3
Multipurpose cleaner Kuzey 5L	24.30	(24.3m^3÷11.76m^3/bay) = 2
Liquid detergent Largo 5kg	23.77	(23.77m^3÷11.76m^3/bay) = 2
Bleach Ghion 5L	21.58	(21.58m^3÷11.76m^3/bay) = 2
Sunflower oil Tena	29.4	(29.4 m^3÷11.76m^3/bay) =3
Knorr hard cube 8gm	29.8	(29.8m^3÷11.76m^3/bay) = 3
Detergent powder Rol Bio 5kg	7.03	(7.03m^3÷11.76m^3/bay) = 1
Liquid detergent Act	19.12	(19.12m^3÷11.76m^3/bay) = 2
Beauty soap Aura 80gm	31.46	(31.46m^3÷11.76m^3/bay) = 3
Bleach Ghion 800cc &300cc	47.01	(47.01m^3÷11.76m^3/bay) = 4
Beauty soap lifebuoy	23.04	(23.04m^3÷11.76m^3/bay) = 2
Iodized salt	28.63	(28.63m^3÷11.76m^3/bay) = 3
Total volume	456.04 cubic meter	Total of 42 bays

Based on their monthly flow, some goods require more than one bay placement. As a result, using the allocation of bays to a specific item found through the Hungarian method may be challenging. Therefore, we need take into account the popularity heuristic approach, which is more adaptable. There are two major groups of items available in the above table: food items and sanitation items.

As a result, using a heuristic approach, we can group goods while assigning locations to them, and we can also assign each item according to its order frequency and needed volume. The allocation of these items to the respective bay number need to follow some basic steps as discussed below.

Steps in items popularity heuristics:

Step 1. Count the number of orders (frequency) for each item. (This was presented at section 4.1.1)

Step 2. Sorting each item in decreasing order based on order frequency.

Step 3. Allocate the item with higher value of order frequency times weight at the bay location with shorter travel distance as follows.

For example; Macaroni has higher multiplicative value of order frequency and weight. So that, it should get the nearest bay locations (9,13, 17, 21,25,29, 14 and 33) with the longest order picking travel distance of 44.1 meter per single walk. And with the same approach, allocations were performed for other items and summarized in the following figure and table.

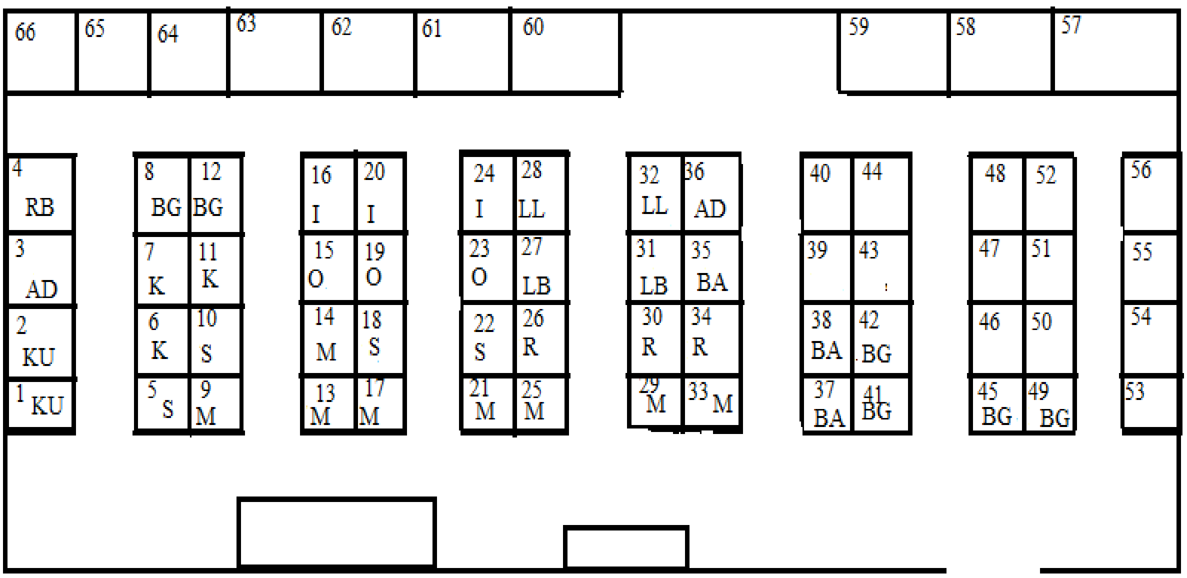


Figure 4-5. Allocated bay numbers for first class items under optimal allocation

KEY: Bold numbers indicate the farthest bay number for each item

Table 4-13. Legend to items and assigned bay number (under optimal assignment)

Symbol	Item name	Assigned bay locations	Distanc (m) Single trip	Total Distance (m)
M	Macaroni	9,13,17,21,25,29,**14**,33	44.1	14,994
S	Spaghetti 500gm	5,10,18,**22**	46.4	18,421
R	Rice 5kg	26,30,**34**	49.2	13,333
KU	Multipurpose cleaner Kuzey 5L	1,**2**	56.6	11,660
LL	Liquid detergent Largo 5kg	28,**32**	57.6	11,693
GB	Bleach Gion 5L	**8**,12	63.2	10,681
O	Tena oil	15,**19**,23	52	12,116
K	Knorr hard cube 8gm	6,**7**,11	57.6	9,504
RB	Detergent powder Rol Bio 5kg	**4**	67.8	2,102
AD	Liquid detergent Act 1kg	**3**,36	62.2	9,206
LB	Beauty soap lifebuoy	27,**31**	52	12,844
BA	Beauty soap Aura 80gm	35,37,**38**	56.6	13,697
GB	Bleach Gion 800cc and 300cc	41,42,45,**49**	65.8	6,843
I	Iodized salt	16,**20,24**	57.6	8,006
		Total	788.7 m	155,099 m

***Case B*: Using Equal time (EQT) allocation strategy**

The required number of bays for each of items under the equal time strategy is found by dividing fractional volume required for each item to volume of a single bay. The upcoming table shows this value.

Table 4-14. Required number of bays for each first-class item under EQT

Item name	Fractional volume (v_i) m^3 under (EQT)	Required number of bays
Macaroni	191.93	($191.93m^3 \div 11.76m^3$/bay) = 16
Spaghetti 500gm	45.68	($45.68m^3 \div 11.76m^3$/bay) = 4
Rice 5kg	32.83	($32.83m^3 \div 11.76m^3$/bay) = 3
Multipurpose cleaner Kuzey 5L	14.02	($14.02m^3 \div 11.76m^3$/bay) = 1
Liquid detergent Largo 5kg	13.42	($13.42m^3 \div 11.76m^3$/bay) = 1
Bleach Ghion 5L	11.07	($11.07m^3 \div 11.76m^3$/bay) = 1
Sunflower oil Tena	20.54	($20.54m^3 \div 11.76m^3$/bay) =2
Knorr hard cube 8gm	21.10	($21.1m^3 \div 11.76m^3$/bay) = 2
Detergent powder Rol Bio 5kg	1.17	($1.17m^3 \div 11.76m^3$/bay) = 1
Liquid detergent Act	8.69	($8.69\ m^3 \div 11.76m^3$/bay) = 1
Beauty soap Aura 80gm	23.52	($23.52m^3 \div 11.76m^3$/bay) =2
Bleach Ghion 800cc &300cc	39.97	($39.97m^3 \div 11.76m^3$/bay) = 3
Beauty soap lifebuoy	12.61	($12.61m^3 \div 11.76m^3$/bay) = 1
Iodized salt	19.48	($19.48m^3 \div 11.76m^3$/bay) = 2
Total volume	456.04 cubic meter	Total of 40 bays

Example; Macaroni has higher multiplicative value of order frequency and weight and it needs sixteen bays if equal time allocation strategy is adopted. So that, it should get the nearest bay locations (5,9,10, 13,14,15,17,18 21,22,25,26,29,30,33 and 34) with the longest order picking travel distance of 49.7meter per single walk. And with the same approach, allocations were performed for other items and summarized in the following figure and table.

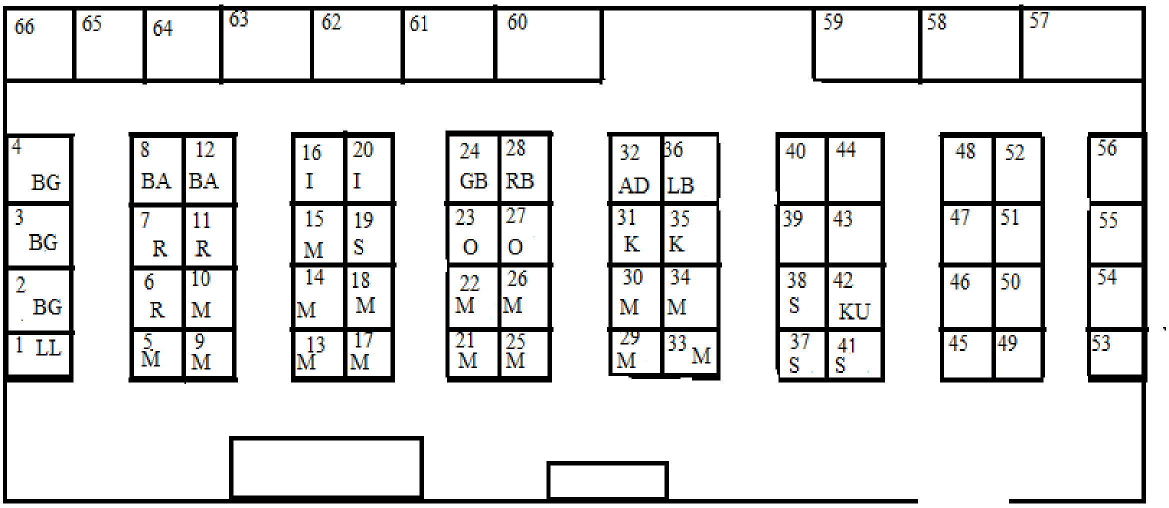


Figure 4-6. Allocated bay numbers for first class items with EQT allocation

Table 4-15. Legend to items and assigned bay number (under EQT allocation)

Symbol	Item name	Assigned bay locations	Distance Single trip	Total Distance (m)
M	Macaroni	5,9,10,13,14,**15**,17,18 21,22,25,26,29,30,33,34	49.7 m	16,898
S	Spaghetti 500gm	19,37,**38**,41	56.6	22,470
R	Rice 5kg	6,**7**,11	57.6	15,610
KU	Multipurpose cleaner Kuzey 5L	**42**	62.2	12,813
LL	Liquid detergent Largo 5kg	1	51	10,353
GB	Bleach Gion 5L	24	57.6	9,734
O	Tena oil	**23,27**	52	12,116
K	Knorr hard cube 8gm	31,**35**	54.8	9,042
RB	Detergent powder Rol Bio 5kg	28	57.6	1,786
AD	Liquid detergent Act 1kg	32	57.6	8,525
LB	Beauty soap lifebuoy	36	60.4	14,919
BA	Beauty soap Aura 80gm	**8**,12	63.2	15,294
GB	Bleach Gion 800cc and 300cc	2,3,**4**	67.8	7,051
I	Iodized salt	16,**20**	57.6	8,006
		Total	805.7 m	164,618 m

<u>Case C</u>: Using Equal space (EQS) allocation strategy

The required number of bays for each of items with equal space strategy is found by dividing fractional volume under equal space strategy to volume of a single bay. The upcoming table shows this value.

Table 4-16. Required number of bays for each first-class item under EQS

Item name	Fractional volume (v_i) m^3 under (EQS)	Required number of bays
Macaroni	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Spaghetti 500gm	32.57	($32.57M^3 \div 11.76m^3$/bay) = 3
Rice 5kg	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Multipurpose cleaner Kuzey 5L	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Liquid detergent Largo 5kg	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Bleach Ghion 5L	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Sunflower oil Tena	32.57	($32.57m^3 \div 11.76m^3$/bay) =3
Knorr hard cube 8gm	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Detergent powder Rol Bio 5kg	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Liquid detergent Act	32.57	($32.57\ m^3 \div 11.76m^3$/bay) = 3
Beauty soap Aura 80gm	32.57	($32.57m^3 \div 11.76m^3$/bay) =3
Bleach Ghion 800cc &300cc	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Beauty soap lifebuoy	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Iodized salt	32.57	($32.57m^3 \div 11.76m^3$/bay) = 3
Total volume	456.04 cubic meter	Total of 42 bays

Under equal space strategy items get 32.57 cubic meter space and which is equal for all items with higher value of order frequency times weight. <u>Example;</u> Macaroni has higher multiplicative value of order frequency and weight and it needs three bays if equal space allocation strategy is adopted. So that, it should get the nearest bay locations (9,13 and 17) with the longest order picking travel distance of 40.8 meter per single walk. The next table shows allocation of the other items.

Table 4-17. Legend to items and assigned bay number (under EQS allocation)

Symbol	Item name	Assigned bay locations	Distanc (m) Single trip	Total Distance (m)
M	Macaroni	9,13,17	40.8	13,872
S	Spaghetti 500gm	21,25,29	40.8	16,198
R	Rice 5kg	10,14,**18**	46.4	12,574
KU	Multipurpose cleaner Kuzey 5L	22,**23**,26	52	10,712
LL	Liquid detergent Largo 5kg	27,31,**35**	54.8	11,124
GB	Bleach Gion 5L	37,**38**,41	56.6	9,565
O	Tena oil	30,33,**34**	49.2	11,464
K	Knorr hard cube 8gm	5,6,**7**	57.6	9,504
RB	Detergent powder Rol Bio 5kg	16,20,**24**	57.6	1,786
AD	Liquid detergent Act 1kg	28,32,**36**	60.4	8,939
LB	Beauty soap lifebuoy	1,2,**3**	62.2	15,363
BA	Beauty soap Aura 80gm	42,45,**49**	65.8	15,924
GB	Bleach Gion 800cc and 300cc	**4**,8,12	67.8	7,051
I	Iodized salt	11,**15**,19	54.3	7,548
		Total	766.3m	151,624 m

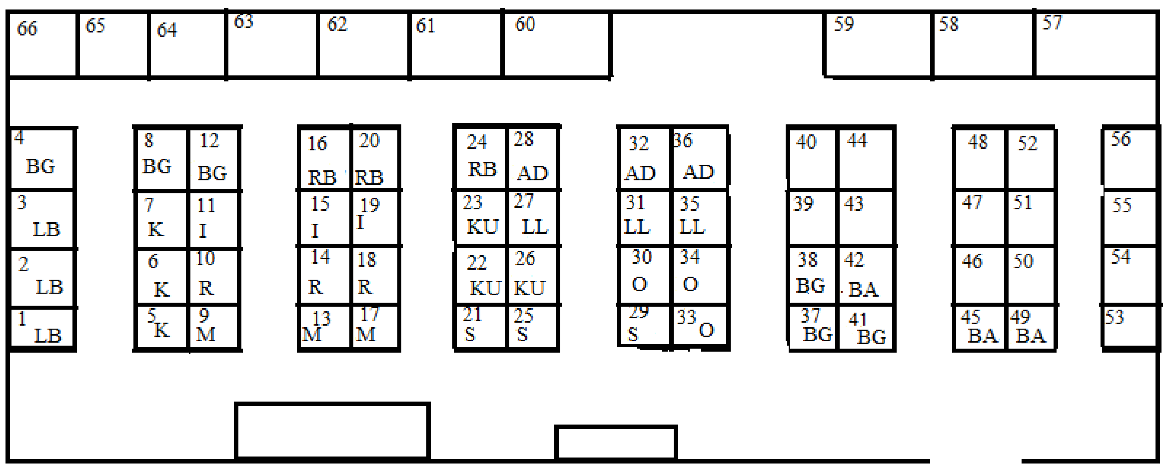


Figure 4-7. Allocated bay numbers for first class items with EQS allocation

4.4. Discussion of Results

According to the existing assignment system, the total order picking distance for a single order of items with higher value of order frequency times weight and based on order frequency was 995.4m and 213,682.3 meter, respectively. Due to an optimal item allocation approach, the total minimized order picking distance in a single order of those become 788.7 meters, and the total order picking distance of those items for two months is 155,099 meters. When we use an equal time allocation technique, we get an order picking travel distance of 805.7 meters per single order and 164,618 meters when we account order frequency. Order picking travel distance under the equal space (EQS) allocation approach is 766.3 meters for a single order and 151,624 meters for a two-month order. The following table depicts these results and improvement indexes.

Table 4-18. Summary of results

Order	Order picking Distance (m)		
	Existing	Improved	Improvement in percentage
		Hungarian Method	
Single order	995.4m	617.2m	[(995.4-617.2)/995.4] *100 = ***37.99%***
For two months (based on the frequency scheme)	213,682.3m	124,843m	[(213,682.3-124,843)/213,682.3] * 100 = ***41.57%***
		Popularity Heuristics	
		Under optimal allocation strategy (OPT)	
Single order	995.4m	788.7m	[(995.4-788.7)/995.4] *100 = ***20.76%***
Based on the frequency scheme	213,682.3m	155,099m	[(213,682.3-155,099)/213,682.3] * 100 = ***27.4%***
		Under Equal time allocation strategy (EQT)	
Single order	995.4m	805.7m	[(995.4-805.7)/995.4] *100 = ***19.06%***
Based on the frequency scheme	213,682.3m	164,618m	[(213,682.3-164,618)/213,682.3] * 100 = ***22.96%***
		Under Equal time allocation strategy (EQS)	
Single order	995.4m	766.3m	[(995.4-766.3)/995.4] *100 = 23***%***
Based on the frequency scheme	213,682.3m	151,624m	[(213,682.3-151,624)/213,682.3] * 100 = ***29.04%***

From Hungarian assignment model, the improvement is 41.57% which is better result and it assigns one bay number for one item. But most of the items need more than one bay location and to overcome this challenge the heuristics approach was analysed. This heuristics approach is tested under optimal, equal space and equal time storage strategies. From these strategies better improvement is achieved under equal space and optimal storage approaches.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Receiving goods, storing them, picking orders, accumulating, sorting and consolidating them, and transporting them are all covered by warehousing. The process of handling things in a warehouse to fulfil a specific client order is referred to as order-picking. It is the warehousing's most resource-intensive and critical function, and it must be flawless and quick.

Shorter order picking travel distance is one of the major performance indicators of order picking activity, and this study attempts to reduce order picking travel distance at the ALLE Bejimla Hawassa branch warehouse located at "Arogiew Gebeya." Different approaches are applied in the most recent warehouse management system. Identifying the most popular/fast moving goods and placing them in the most convenient location is considered a good technique among these approaches. For a period of two months sales, this thesis paper attempts to identify the most popular items. Using ABC analysis, fourteen items have higher multiplicative value of order frequency and weight. The total order picking travel distance was then calculated based on the existing allocation system to pick those items in single item single order approach. For a single order, the total order picking distance to pick items which have higher multiplicative vale of order frequency and weight is 995.4 meters, and for a two-months order, the distance is 213,682.3 meters. This distance is considered as longer order picking travel distance and should be reduced as much as possible.

To reduce the longer distance, an assignment model was constructed and solved with the help of POM software using the Hungarian method. In a single order, the new assignment gives 617.2-meter (37.99 % reduction) order picking travel distance for items which have higher multiplicative value of order frequency and weight. This solution is an optimal solution but it basically works when single item should be assigned to specific single bay location. In ALLE’s warehouse items need more than one bay location and in order to achieve this requirement, items popularity heuristic was applied.

To apply this approach the optimal fractional volume required for items and their order frequency was considered. Then an items with higher value frequency times weight were allocated to the bay number that has shorter distance to input-output point. Under optimal, equal time, and equal space allocation strategies, order picking travel distance decreased from 213,682.3 meters to 155,099 meters, 164,618 meters, and 151,624 meters over a two-month period. Using optimal, equal time, and equal space allocation strategies, the improvement index is 27.4 percent, 22.96 percent, and 29.04 percent, respectively. By considering monthly flow of items, a 456.04 cubic meter of space is required for all first-class items. Number of restocks required are two restocks per month under optimal allocation strategy and three for equal time and space allocation strategy. As a result, we may deduce that order picking distance is influenced by the assignment of each item to a specific bay number location.

5.2. Recommendations

As per the research findings and concept of warehousing, the following recommendations are forwarded to the organization.

- As retailing and distribution warehouse, it is better to know heavyweight and fast mover items to store them at the nearest location to the depot area.
- Customer feedback has positive contribution to improve performance of any organization. So that, it is better to measure customers satisfaction regarding to conveniency and storage strategy.
- Flexibility is one of business philosophy in this century, therefore, ALLE should work on flexible storage mechanism as per the flow of items.
- The available storage volume of ALLE Hawassa branch warehouse is much higher than the utilized volume. So, the organization should focus on efficient utilization of available storage space.
- Consider creating a warehouse in a warehouse. The organization can gain wonderful efficiency by grouping together the 20 - 30 percent of items that complete 80 percent of orders. This cuts down on travel time and distance for order pickers.
- In ALLE's warehouse items are stored on the ground along storage racks. This narrows the aisle space and leads to some difficulties while moving. So, the organization's order should be based on the designed storage capacity.

5.3. Suggestion for Future Work

Although every effort was made to perform this research as extensively as feasible, time and other constraints may have prevented the consideration of all other concerns. In general, the goal of this study is to show how to increase order picking travel distance under different storage assignment strategies. For the future, I suggest considering the effect of longer order picking travel distance relating with ergonomics under different picking paths.

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ANNEX

Annex I. Daily sales report

Description	Qty.	No. of orders
LIQUID DETERGENT Largo All purpose 5kg	7.00	2.00
DETERGENT BAR Ajax REPI 100gm	100.00	4.00
555 Liquid Detergent 1 Litre	12.00	1.00
BLEACH Ghion 5L	28.00	5.00
LAUNDRY SOAP 555 250 gm Wrapped white	100.00	3.00
DETERGENT BAR SOAP ACT 100GM	100.00	5.00
LIQUED DETERGENT ACT 1kg	24.00	1.00
LIQUED DETERGENT ACT 2KG	12.00	
MULTIPURPOSE CLEANER KUZEY 5LIT	21.00	5.00
DETERGENT POWDER 555 GULELE 900 GM	2.00	1.00
BAR SOAP SKY Premium 250gm	150.00	1.00
SHAMPOO Rotana Egg 750ml	1.00	1.00
LIQUID HAND SOAP Rotana Olive 2 500ml	1.00	1.00
LIQUID HAND SOAP Rotana Orange 500ml	3.00	
BEAUTY SOAP LIFEBUOY TOTAL 70gm	60.00	3.00
BEAUTY SOAP LIFEBUOY LEMON 70gm	12.00	
BEAUTY SOAP LUX SOFT CARESS 70gm	24.00	1.00
BEAU SOAP Aura Milk & Honey 80gm	216.00	

5.19.21 | 5.20.21 | 5.21.21 | **5.22.21** | 5.24.21 | 5.25.21 | 5.26.21 | 5.27.21 | 5.29.21 | 5.31.2

Description	Qty.	No. of orders
Mini Nib Chocolate	1.00	1.00
Nib Fruit Cocktail Lollipop	3.00	
SNACK TEDDY CHIPS 25GM	550.00	3.00
LIQUID DETERGENT Largo All purpose 5kg	23.00	4.00
DETERGENT BAR Ajax REPI 100gm	100.00	6.00
BAR SOAP Diva MultiPurpose White 200gm	50.00	1.00
555 Liquid Detergent 1 Litre	6.00	1.00
BLEACH Ghion 800cc	3.00	1.00
BLEACH Ghion 5L	18.00	4.00
Candle Alem 35gram	336.00	
Ajax Dish wash 750ml	4.00	1.00
LIQUID DETEREGENT DISH WASH AJAX 5 LITER	8.00	1.00
LAUNDRY SOAP 555 250 gm Wrapped white	300.00	5.00
DISINFECTANT LIQUID Victol 500ml	76.00	2.00
LIQUED DETERGENT ACT 1kg	120.00	5.00
MULTIPURPOSE CLEANER KUZEY 5LIT	12.00	3.00
BAR SOAP SKY Premium 250gm	3,100.00	6.00
LIQUID HAND SOAP Rotana Olive 2 500ml	6.00	1.00
LIQUID HAND SOAP Rotana Orange 500ml	1.00	
BEAUTY SOAP LIFEBUOY TOTAL 70gm	60.00	

5.19.21 | 5.20.21 | 5.21.21 | 5.22.21 | **5.24.21** | 5.25.21 | 5.26.21 | 5.27.21

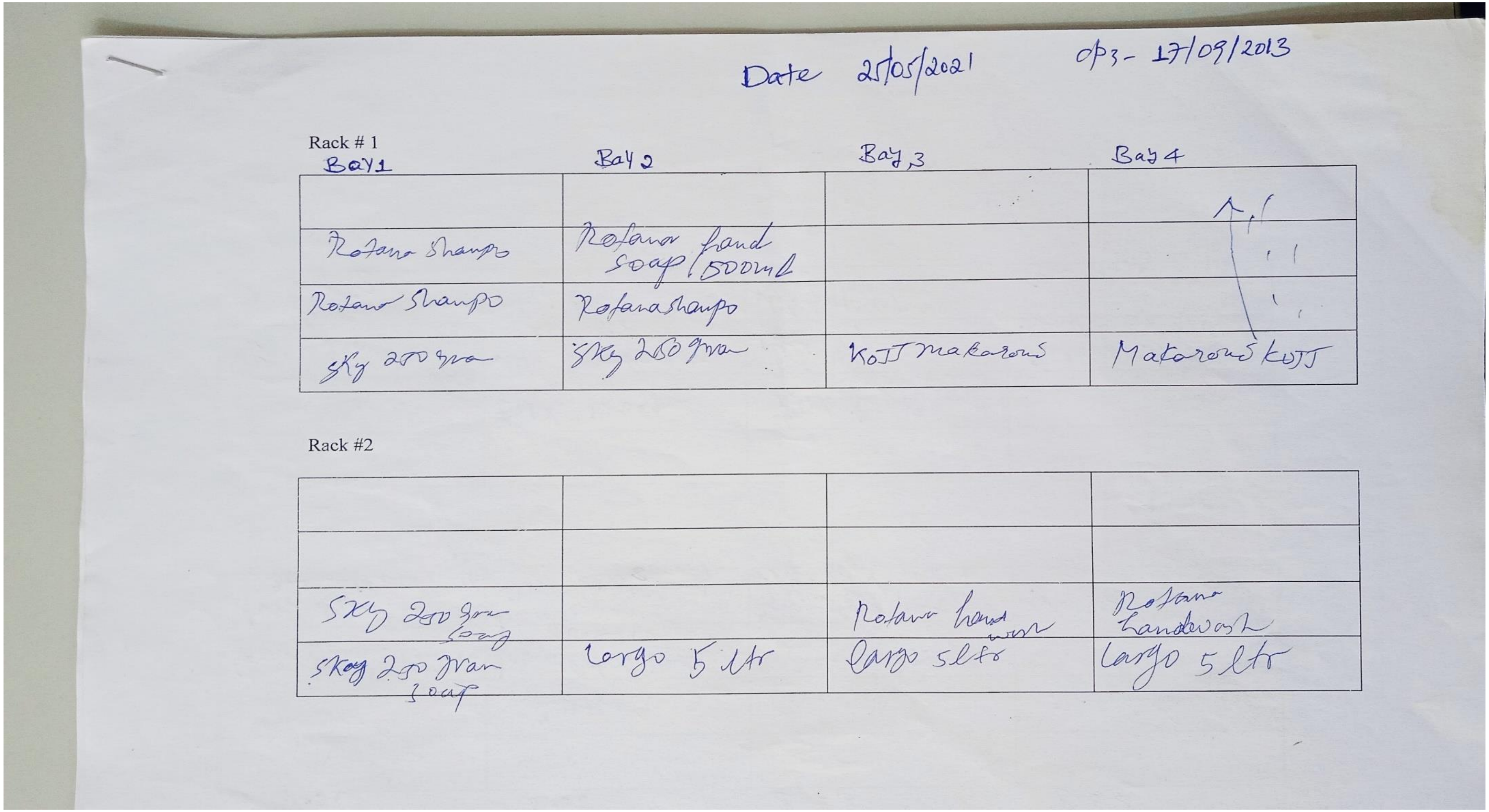
Annex II. Respective bay location distance

		Bay # with distance (meter)																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
No.	Items	fd1	fd2	fd3	fd4	fd5	fd6	fd7	fd8	fd9	fd10	fd11	fd12	fd13	fd14	fd15	fd16	fd17	fd18	fd19	fd20	fd21	fd22
1	Macaroni	17,340	19,244	21,148	23,052	15,776	17,680	19,584	21,488	13,872	15,776	18,462	20,366	16,014	14,994	16,898	18,870	13,872	15,776	17,680	19,584	13,872	15,776
2	Spaghetti 500gm	20,247	22,470	24,693	26,917	18,421	20,644	22,867	25,090	16,198	18,421	21,557	23,780	18,699	17,508	19,731	22,034	16,198	18,421	20,644	22,867	16,198	18,421
3	Rice 5kg	13,821	15,339	16,856	18,374	12,574	14,092	15,610	17,127	11,057	12,574	14,715	16,233	12,764	11,951	13,469	15,041	11,057	12,574	14,092	15,610	11,057	12,574
4	Multipurpose cleaner Kuzey 5L	10,506	11,660	12,813	13,967	9,558	10,712	11,866	13,019	8,405	9,558	11,186	12,339	9,703	9,085	10,238	11,433	8,405	9,558	10,712	11,866	8,405	9,558
5	Liquid detergent Largo 5kg	10,353	11,490	12,627	13,763	9,419	10,556	11,693	12,830	8,282	9,419	11,023	12,160	9,561	8,952	10,089	11,267	8,282	9,419	10,556	11,693	8,282	9,419
6	Bleach Ghion 5L	8,619	9,565	10,511	11,458	7,842	8,788	9,734	10,681	6,895	7,842	9,177	10,123	7,960	7,453	8,399	9,380	6,895	7,842	8,788	9,734	6,895	7,842
7	Sunflower oil Tena	11,883	13,188	14,492	15,797	10,811	12,116	13,421	14,726	9,506	10,811	12,652	13,957	10,974	10,275	11,580	12,932	9,506	10,811	12,116	13,421	9,506	10,811
8	Knorr hard cube 8gm	8,415	9,339	10,263	11,187	7,656	8,580	9,504	10,428	6,732	7,656	8,960	9,884	7,772	7,277	8,201	9,158	6,732	7,656	8,580	9,504	6,732	7,656
9	Detergent powder Rol Bio 5kg	1,581	1,755	1,928	2,102	1,438	1,612	1,786	1,959	1,265	1,438	1,683	1,857	1,460	1,367	1,541	1,721	1,265	1,438	1,612	1,786	1,265	1,438
10	Liquid detergent Act	7,548	8,377	9,206	10,034	6,867	7,696	8,525	9,354	6,038	6,867	8,036	8,865	6,971	6,527	7,356	8,214	6,038	6,867	7,696	8,525	6,038	6,867
11	Beauty soap Aura 80gm	12,342	13,697	15,052	16,408	11,229	12,584	13,939	15,294	9,874	11,229	13,141	14,496	11,398	10,672	12,027	13,431	9,874	11,229	12,584	13,939	9,874	11,229
12	Bleach Ghion 800cc &300cc	5,304	5,886	6,468	7,051	4,826	5,408	5,990	6,573	4,243	4,826	5,647	6,230	4,898	4,586	5,169	5,772	4,243	4,826	5,408	5,990	4,243	4,826
13	Beauty soap lifebuoy	12,597	13,980	15,363	16,746	11,461	12,844	14,227	15,610	10,078	11,461	13,412	14,795	11,634	10,893	12,276	13,709	10,078	11,461	12,844	14,227	10,078	11,461
14	Iodized salt	7,089	7,867	8,646	9,424	6,450	7,228	8,006	8,785	5,671	6,450	7,548	8,326	6,547	6,130	6,908	7,715	5,671	6,450	7,228	8,006	5,671	6,450

23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
fd23	fd24	fd25	fd26	fd27	fd28	fd29	fd30	fd31	fd32	fd33	fd34	fd35	fd36	fd37	fd38	fd39	fd40	fd41	fd42	fd43	fd44
17,680	19,584	13,872	15,776	17,680	19,584	13,872	15,776	17,680	19,584	14,824	16,728	18,632	20,536	17,340	19,244	21,148	23,052	19,244	21,148	23,052	24,956
20,644	22,867	16,198	18,421	20,644	22,867	16,198	18,421	20,644	22,867	17,309	19,532	21,756	23,979	20,247	22,470	24,693	26,917	22,470	24,693	26,917	29,140
14,092	15,610	11,057	12,574	14,092	15,610	11,057	12,574	14,092	15,610	11,816	13,333	14,851	16,368	13,821	15,339	16,856	18,374	15,339	16,856	18,374	19,891
10,712	11,866	8,405	9,558	10,712	11,866	8,405	9,558	10,712	11,866	8,982	10,135	11,289	12,442	10,506	11,660	12,813	13,967	11,660	12,813	13,967	15,120
10,556	11,693	8,282	9,419	10,556	11,693	8,282	9,419	10,556	11,693	8,851	9,988	11,124	12,261	10,353	11,490	12,627	13,763	11,490	12,627	13,763	14,900
8,788	9,734	6,895	7,842	8,788	9,734	6,895	7,842	8,788	9,734	7,368	8,315	9,261	10,208	8,619	9,565	10,512	11,458	9,565	10,512	11,458	12,405
12,116	13,421	9,506	10,811	12,116	13,421	9,506	10,811	12,116	13,421	10,159	11,464	12,768	14,073	11,883	13,188	14,493	15,797	13,188	14,493	15,797	17,102
8,580	9,504	6,732	7,656	8,580	9,504	6,732	7,656	8,580	9,504	7,194	8,118	9,042	9,966	8,415	9,339	10,263	11,187	9,339	10,263	11,187	12,111
1,612	1,786	1,265	1,438	1,612	1,786	1,265	1,438	1,612	1,786	1,352	1,525	1,699	1,872	1,581	1,755	1,928	2,102	1,755	1,928	2,102	2,275
7,696	8,525	6,038	6,867	7,696	8,525	6,038	6,867	7,696	8,525	6,453	7,282	8,110	8,939	7,548	8,377	9,206	10,034	8,377	9,206	10,034	10,863
12,584	13,939	9,874	11,229	12,584	13,939	9,874	11,229	12,584	13,939	10,551	11,906	13,262	14,617	12,342	13,697	15,052	16,408	13,697	15,052	16,408	17,763
5,408	5,990	4,243	4,826	5,408	5,990	4,243	4,826	5,408	5,990	4,534	5,117	5,699	6,282	5,304	5,886	6,469	7,051	5,886	6,469	7,051	7,634
12,844	14,227	10,078	11,461	12,844	14,227	10,078	11,461	12,844	14,227	10,769	12,152	13,536	14,919	12,597	13,980	15,363	16,747	13,980	15,363	16,747	18,130
7,228	8,006	5,671	6,450	7,228	8,006	5,671	6,450	7,228	8,006	6,060	6,839	7,617	8,396	7,089	7,867	8,646	9,424	7,867	8,646	9,424	10,203

45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
fd45	fd46	fd47	fd48	fd49	fd50	fd51	fd52	fd53	fd54	fd55	fd56	fd57	fd58	fd59	fd60	fd61	fd62	fd63	fd64	fd65	fd66
20,808	22,712	24,616	26,520	22,372	23,834	26,180	28,084	23,936	25,840	27,744	29,648	31,892	33,864	35,700	26,656	24,752	22,848	24,004	22,882	24,786	22,712
24,296	26,520	28,743	30,966	26,123	27,830	30,569	32,792	27,949	30,172	32,395	34,618	37,239	39,541	41,685	31,125	28,902	26,678	28,028	26,718	28,941	26,520
16,585	18,103	19,620	21,138	17,832	18,997	20,867	22,385	19,078	20,596	22,114	23,631	25,420	26,992	28,455	21,246	19,729	18,211	19,133	18,238	19,756	18,103
12,607	13,761	14,914	16,068	13,555	14,441	15,862	17,016	14,502	15,656	16,810	17,963	19,323	20,518	21,630	16,150	14,997	13,843	14,544	13,864	15,017	13,761
12,424	13,560	14,697	15,834	13,357	14,230	15,631	16,768	14,291	15,428	16,565	17,702	19,041	20,219	21,315	15,915	14,778	13,642	14,332	13,662	14,799	13,560
10,343	11,289	12,236	13,182	11,120	11,847	13,013	13,959	11,898	12,844	13,790	14,737	15,852	16,832	17,745	13,250	12,303	11,357	11,931	11,374	12,320	11,289
14,260	15,564	16,869	18,174	15,331	16,333	17,941	19,246	16,403	17,708	19,013	20,318	21,855	23,207	24,465	18,267	16,962	15,658	16,450	15,681	16,986	15,564
10,098	11,022	11,946	12,870	10,857	11,567	12,705	13,629	11,616	12,540	13,464	14,388	15,477	16,434	17,325	12,936	12,012	11,088	11,649	11,105	12,029	11,022
1,897	2,071	2,244	2,418	2,040	2,173	2,387	2,561	2,182	2,356	2,530	2,703	2,908	3,088	3,255	2,430	2,257	2,083	2,189	2,086	2,260	2,071
9,058	9,886	10,715	11,544	9,738	10,375	11,396	12,225	10,419	11,248	12,077	12,906	13,882	14,741	15,540	11,603	10,774	9,946	10,449	9,960	10,789	9,886
14,810	16,166	17,521	18,876	15,924	16,964	18,634	19,989	17,037	18,392	19,747	21,102	22,700	24,103	25,410	18,973	17,618	16,262	17,085	16,287	17,642	16,166
6,365	6,947	7,530	8,112	6,843	7,290	8,008	8,590	7,322	7,904	8,486	9,069	9,755	10,358	10,920	8,154	8,154	6,989	7,342	6,999	7,582	6,947
15,116	16,500	17,883	19,266	16,253	17,315	19,019	20,402	17,389	18,772	20,155	21,538	23,169	24,601	25,935	19,365	17,982	16,598	17,438	16,623	18,006	16,500
8,507	9,285	10,064	10,842	9,146	9,744	10,703	11,481	9,786	10,564	11,342	12,121	13,038	13,844	14,595	10,898	10,119	9,341	9,813	9,355	10,133	9,285

Annex III. Existing allocation (Data)



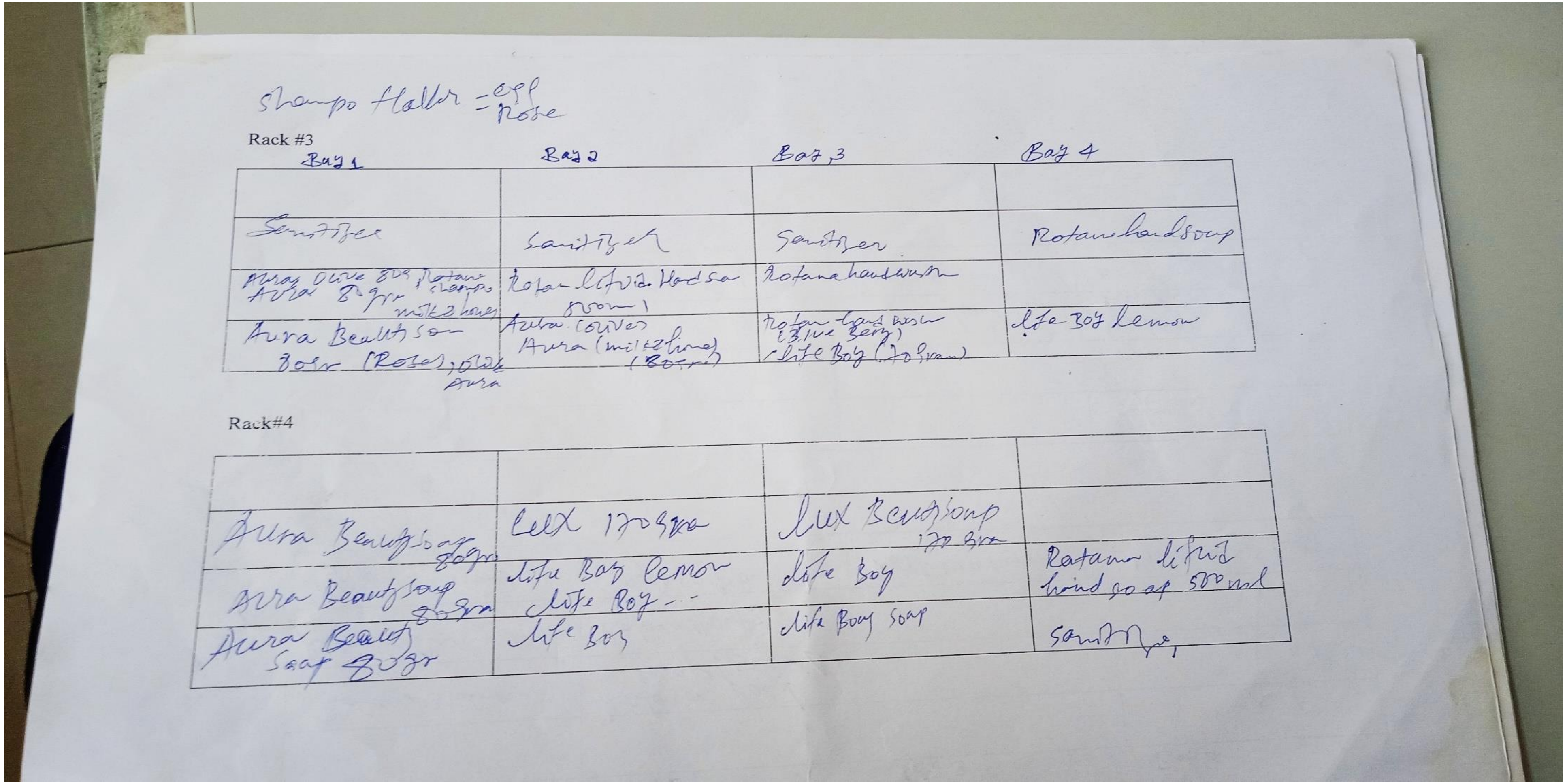
Date 25/05/2021 op3- 17/09/2013

Rack # 1

Bay1	Bay 2	Bay 3	Bay 4
Rotana Shampo	Rotana hand soap 500ml		
Rotana Shampo	Rotanashampo		
sky 200 gram	sky 250 gram	KoJJ makarons	Makarons KoJJ

Rack #2

Sky 200 gram soap		Rotana hand wash	Rotana handwash
sky 200 gram soap	Largo 5 ltr	Largo 5ltr	Largo 5 ltr



shampo Haller = oil / Rose

Rack #3

Bay 1	Bay 2	Bay 3	Bay 4
Sanitizer	Sanitizer	Sanitizer	Rotana hand soap
Aura Olive 80g, Rotana shampo, Aura 80gr milk & honey	Rotana liquid Hand soap 500ml	Rotana hand wash	
Aura Beauty soap 80gr (Roses), olive Aura	Aura (olive) Aura (milk & lime) (80gr)	Rotana hand wash (Blue Berry) Life Boy (70gram)	Life Boy Lemon

Rack#4

Aura Beauty soap 80gr	Lux 170gra	Lux Beauty soap 170gra	
Aura Beauty soap 80gra	Life Boy Lemon Life Boy ...	Life Boy	Rotana liquid hand soap 500ml
Aura Beauty Soap 80gr	Life Boy	Life Boy Soap	Sanitizer