Development of Storage Allocation Models in a Warehouse

by

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Declaration

This is to certify that the thesis work entitled " Development of Storage Allocation Models in a Warehouse" has been carried out by Syed Ariful Islam in the Department of Industrial Engineering and Management, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Abstract

The developments in warehouses have significantly influenced the existing paradigms in inventory research. Unfortunately, the attention paid by researchers in inventory theory to the management of storage systems such as warehouses has been relatively limited. Often, it was considered mainly to be a technical issue and therefore belong to a different area, i.e., material handling research. The warehouse problems can be classified mainly into two groups i.e., the design problem and the operational problem. The design problem deals with the issues such as over all structure, sizing and dimensioning, department layout, equipment selection, and operation strategy of the warehouse. On the other hand, the operational problems deal with receiving and shipping, and storage and retrieval (order picking). Chapter 2 provides a brief description of the literature related to operational problems. Maintenance environment warehouse is very similar to production warehouse where spare parts are stored and retrieved. In such an environment, allocation of space and assignment of spare-parts in a warehouse is a vital problem for sound operation of a warehouse. Miss-allocation of spare-parts takes huge time to find out parts. This problem causes extra time consumption and money expenditure for the involvement of labor for long time and creates risk of unavailability of spare parts that lead to improper maintenance or repair of machines. Generally, allocations of items are done in alphanumerical order without regard to issue frequency, size, weight or volume. As a result, it will be creates problems in issuing/retrieving the spare parts with minimum waste of time & effort.

The objective of this research is to study the developments of operational problems related to production warehouse especially for maintenance environment. Chapter 3 is devoted to develop an efficient methodology to identify the similar parts i.e., spare_part_set (SPS) that can be grouped together and be kept in one place. Doing so, it may increase the efficiency of the storage and retrieval. The weight (popularity index) is used to identify the spare_part_set as slow moving or fast. The weight of a spare_part_set is the summation of all item's frequency of usages in year. By considering weight, higher weight SPS (fast moving) should be kept near to issue counter and less weight (slow moving) SPS is to be placed far from counter.

In chapter 4, the model is simulated for hypothetical warehouses. The objective of the experiment is to investigate the performance of the methodology described in the previous chapter in terms of travel distance to collect all the items of a demand. For this purpose, three hypothetical warehouses are considered. The first one, in which the spare parts are stored in alphanumerical order and the second one, in which the spare parts are stored according to the algorithm described in chapter 3 and in the third one, spare part are stored randomly. The details of the experiment and the results of the experiment are presented in chapter 4. The performance of the algorithm is evaluated in terms of the average travel distance needed to collect an order of SPS. It is found that the average travel distance is minimum (20%) less for our proposed methodology.

Lastly, in chapter 5, conclusions and some recommendations are presented.

Table of Contents

List of Tables

List of Figure

List of Image

CHAPTER- 1

Introduction

1.1 Definition

A warehouse is a large building where goods are stored and where they may be catalogued, shipped, or received, depending upon the type. Though in the past, many warehouses, often located in industrial areas sometimes next to major shipping ports, were teeming with workers, the modern warehouse may be either completely or totally automated depending upon how advanced the company is. Sometimes a manufacturing facility also has an attached warehouse, where their manufactured goods are stored until shipped.

Warehouses have existed for several centuries, and the word itself is not hard to understand. “Wares” were the things possessed by a seller and to house these in a central location meant you were storing your wares. Normally, though, modern warehouses may store not just the possessions of a single seller or manufacturer, but a host of different products. The principal operation of the place is receiving, getting in new products, and shipping out products already stored. Another important part of maintaining a good warehouse is keeping inventory of what products are presently in the warehouse, what has been shipped and what has been received. This process is again largely automated that described by Tricia Ellis-Christensen, 2003-2011in Warehouse Article Details. [1]

Such stores tend to have concrete floors, and high shelves made of metal with products sold in bulk. Instead of spending a lot of money on merchandising and attractive displays these stores are able to stock more merchandise and can offer consumers much lower prices since they order so much more. However, such stores may also have warehouses from which they draw supplies, or they may need to order supplies from other companies that maintain warehouses.

1.2 Types of Warehouse

According to the principles of supply chain management, modern companies attempt to achieve high-volume production and distribution using minimal inventories throughout the logistic chain that are to be delivered within short response times. The changes outlined above have had a dramatic impact on warehouse management. Low volumes have to be delivered more frequently with shorter response times from a significantly wider variety of *Stock Keeping Units* (SKUs). In a further attempt to decrease total inventory, many companies replaced several relatively small *Distribution Centers* (DCs) by a small number of large DCs with an extensive distribution network. Often, an entire continent, like North America or Europe, is serviced by a small number of DCs at strategic positions. Basically, we may distinguish three types of warehouses:

- Distribution warehouses,
- Production warehouses, and
- Contract warehouses,

A *distribution warehouse* is a warehouse in which products from different suppliers are collected (and sometimes assembled) for delivery to a number of customers. A *production warehouse* is used for the storage of raw materials, semi-finished products and finished products in a production facility. A *contract warehouse* is a facility that performs the warehousing operation on behalf of one or more customers. Commercial warehousing has improved their technology for their better business process and even customer service and they keep on getting bigger and bigger.

1.3 Statement of the problems

The developments in warehouses have significantly influenced the existing paradigms in inventory research. Unfortunately, the attention paid by researchers in inventory theory to the management of *storage systems* such as warehouses has been relatively limited. Often, it was considered mainly to be a technical issue and therefore belonging to a different area, i.e., material handling research. The warehouse problems can be classified mainly into two groups i.e., the design problem and the operational problem. The design problem deals with the issues such as over all structure, sizing and dimensioning, department layout, equipment selection, and operation strategy of the warehouse. On the other hand, the operational problems deal with receiving and shipping, and storage and retrieval (order picking). Chapter 2 provides a brief description of the literature related to operational problems. Maintenance environment warehouse is very similar to production warehouse where spare parts are stored and retrieved. In such an environment, allocation of space and assignment of spare-parts in a warehouse is a vital problem for sound operation of a warehouse. Miss-allocation of spare-parts takes huge time to find out parts. This problem causes extra time consumption and money expenditure for the involvement of labor for long time and creates risk of unavailability of spare parts that lead to improper maintenance or repair of machines. Generally, allocations of items are done in alphanumerical order without regard to issue frequency, size, weight or volume. As a result, it will create problems in issuing/retrieving the spare parts with minimum waste of time & effort.

1.4 Objective of the Study

The objective of this research is to study the developments of operational problems related to production warehouse especially for maintenance environment and develop an efficient method to identify the similar parts that can be grouped together and be kept in one place. Doing so, it may increase the efficiency of the storage and retrieval.

1.5 Organization of the project work

This thesis is organized as follows:

Chapter 1 presents introduction on warehouse, type of warehouse, statement of the problem and objective of the study.

Chapter 2 describes the literatures related to operational problems of a warehouse. The schematic diagram of operational problems.

Chapter 3 describes the problem environment; necessary concepts, formulas and algorithm are developed and discussed.

Chapter 4 describes the experiment is conducted by generating the random demand for different types of maintenance works. For each experiment the traveling distance to collect all the items for both the arrangements are calculated and summarized in table 4.14.

Chapter 5 presents the Conclusion and Decision on Simulation Result and graphical chart from table 4.14 and lastly presents future plan and researches.

CHAPTER- 2

LITERATURE REVIEW

This chapter describes the literatures related to operational problems of a warehouse. The schematic diagram of operational problems are shown figure – 2.1

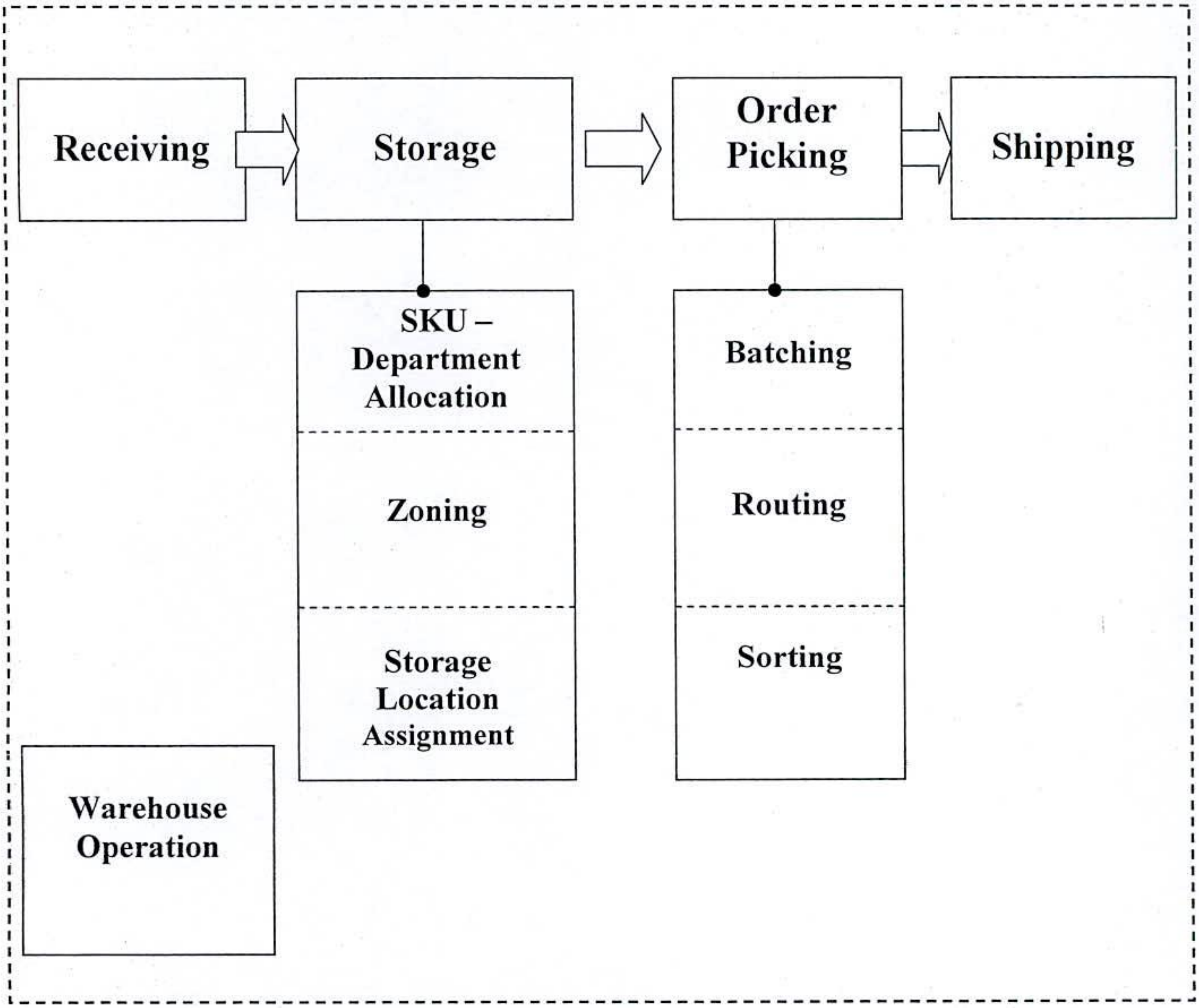


Figure 2.1: Operational problems of a warehouse.

2.1 Receiving and Shipping

Goods arrive to a warehouse in a carrier and are unloaded at the receiving docks. Later they are loaded into a carrier and leave the warehouse through the shipping docks. For cross-docking warehouses, received goods are sent directly from the receiving docks to the shipping docks. For traditional warehouses that hold inventory, received goods are put away into storage and later picked and shipped through shipping docks. In this case, the receiving and shipping operations are more complex to manage since they are coupled with the storage and order picking function. Given the

- Information about incoming shipments, such as their arrival time and contents
- Information about customers demands, such as orders and their expected shipping time.
- Information about warehouse dock layout and available material handling resources.

The basic decisions in receiving/shipping are to determine:

(1) The assignment of inbound and outbound carriers to docks, which determines the aggregate internal material flows.

(2) The schedule of the service of carriers at each dock. Assuming a set of carriers is assigned to a dock, the problem is similar to a machine scheduling problem, where the arriving carriers are the jobs to be scheduled.

(3) The allocation and dispatching of material handling resources, such as labor and material handling equipment.

(4) Resources required completing all shipping/ receiving operations.

(5) Levels of service, such as the total cycle time and the load/unload time for the carriers.

(6) Layout, or the relative location and arrangement of docks and storage departments.

(7) Management policies, e.g., one customer per shipping dock.

(8) Throughput requirements for all docks

2.2 Storage

Storage is a major warehouse function. Three fundamental decisions shape the storage functions. These are:

Storage of a Warehouse

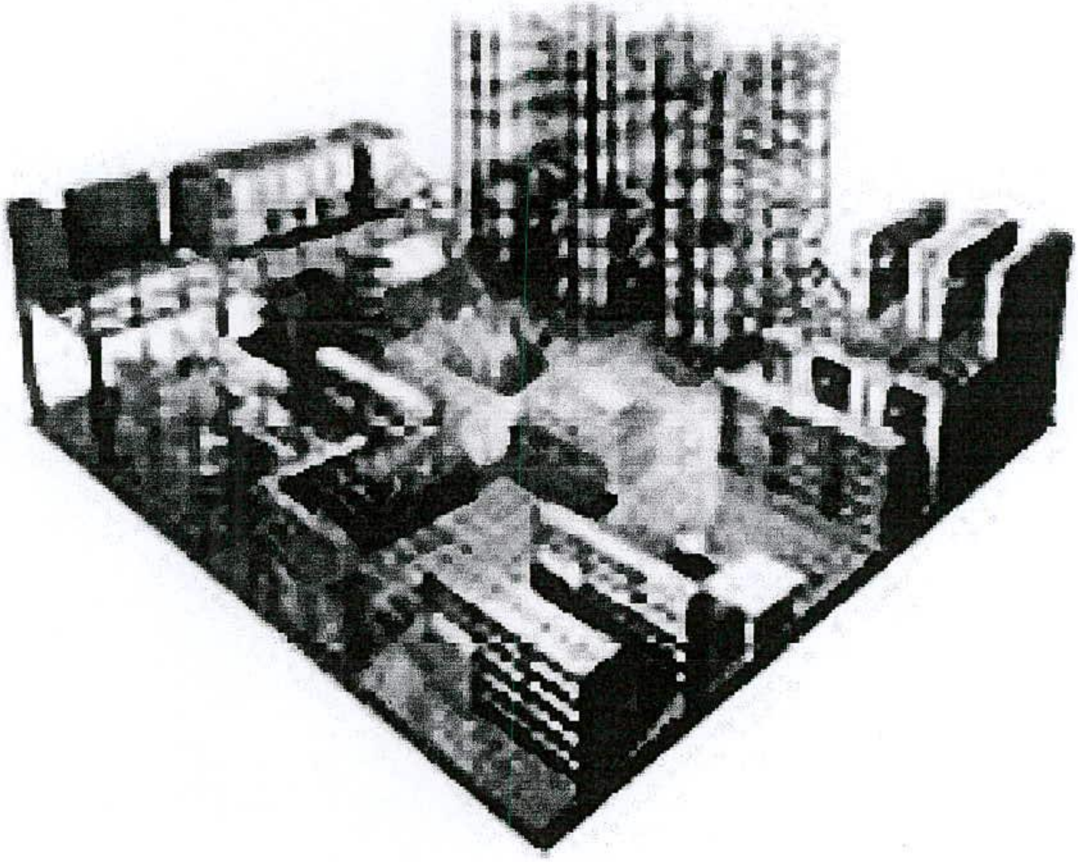


Image -2.1

1. How much inventory should be kept in the warehouse for an SKU
2. How frequently and at what time should the inventory for an SKU be replenished;
3. Where the SKU should be stored in the warehouse and distributed and moved among the different storage areas.

2.2.1 Assigning SKUs across departments

A SKU may be stored in more than one warehouse department. The specification of departments is a design decision. Once the departments are specified, one needs to determine which SKU should be stored in which department, in what quantity, and what are the corresponding inter-departmental moves for that SKU. In some cases, this decision is straightforward. For example, if a department is dedicated to a certain customer, then all SKUs for that customer are assigned to that department; or if a SKU will be stored and picked only in units of pallets, then it will be assigned only to the pallet storage department. In other cases, a SKU could be assigned to multiple departments. These departments are usually different in terms of their storage and material-handling capability. Therefore, a careful decision needs to be made in order to balance the tradeoff between storage and material handling cost and capacities. The forward-reserve problem belongs to this category and is a well-researched problem. [Frazelle et al. (1994), [2] extend the problem and solution method of Hackman and Rosenblatt (1990), [3] by treating the size of the forward area as a decision variable. The costs in their model include the equipment cost of the fast pick area (modeled as a linear function of its size), and the material handling cost for order picking and replenishment.] It is a common practice in warehousing to create a separate physically compact forward (or ''fast pick'') area for picking high-demand, fast-moving products. This reduces order picking costs but at the expense of requiring additional material handling to restock the forward area from a reserve area, and additional space as storage is less efficient in the forward area than in the reserve area. Furthermore, since the size of the forward area usually is limited, one needs to determine which SKUs should be stored in the forward area and in what quantity.

2.2.2 Assigning SKUs across zones (zoning)

The zoning problem is to specify different storage zones within a department and assign SKUs to the specified zones. It can be both a ''hard'' and a ''soft'' decision; it is a hard decision if it leads to zone-specific storage technology selection and physical arrangement, but it is a soft decision if it is simply an organization of similar storage locations. Thus, zoning decisions fall in between warehouse design decisions and warehouse operation decisions. A primary reason for dividing a storage department into zones is to organize order picking activities (i.e., zone picking). The fundamental advantages of zone picking are the limited space the picker has to traverse to pick an order, the increased familiarity of the picker with a subset of the SKUs, and the reduced order picking time span for an order if zones are picked in parallel. On the other hand, additional costs may be incurred in zone picking, caused by sorting in parallel zone picking and by the queuing in sequential zone picking. Storage needs to be planned for zone picking to determine the specification (the number, size, and shape) of the zones and to assign SKUs to zones in such a way that minimizes the total order picking cost and balance the workloads across zones. The literature on the storage planning for zone picking is very limited Petersen (2002), [4] with simulation. It is shown that zone shape has a substantial impact on the operational cost depending on factors such as the zone size and the batch size. Algorithms for assigning SKUs to zones can be found in Jane (2000), [5] and Jewkes, et al. (2004), [6]. Jane (2000), [5] proposes a simple heuristic approach that assigns SKUs to zones to balance the workloads of pickers. Jewkes et al. (2004), [6] consider a specific sequential zone picking method where pickers work at home bases within their zones and are required to return to their home bases after each pick.

2.2.3 Storage Location Assignment

The Storage Location Assignment Problem (SLAP) is to assign incoming products to storage locations in storage departments/zones in order to reduce material handling cost and improve space utilization. Different warehouse departments might use different SLAP policies depending on the department- specific SKU profiles and storage technology. The storage location assignment problem is formally defined as follows: Given the information on:

(1) The storage area, including its physical configuration and storage layout.

(2) The storage locations, including their availability, physical dimensions, and location.

(3) The set of items to be stored, including their physical dimensions, demand, quantity, arrival and departure times.

Determine the physical location where arriving items will be stored. Subject to performance criteria and constraints such as:

(1) Storage capacity and efficiency.

(2) Picker capacity and efficiency based on the picker cycle time.

(3) Response time.

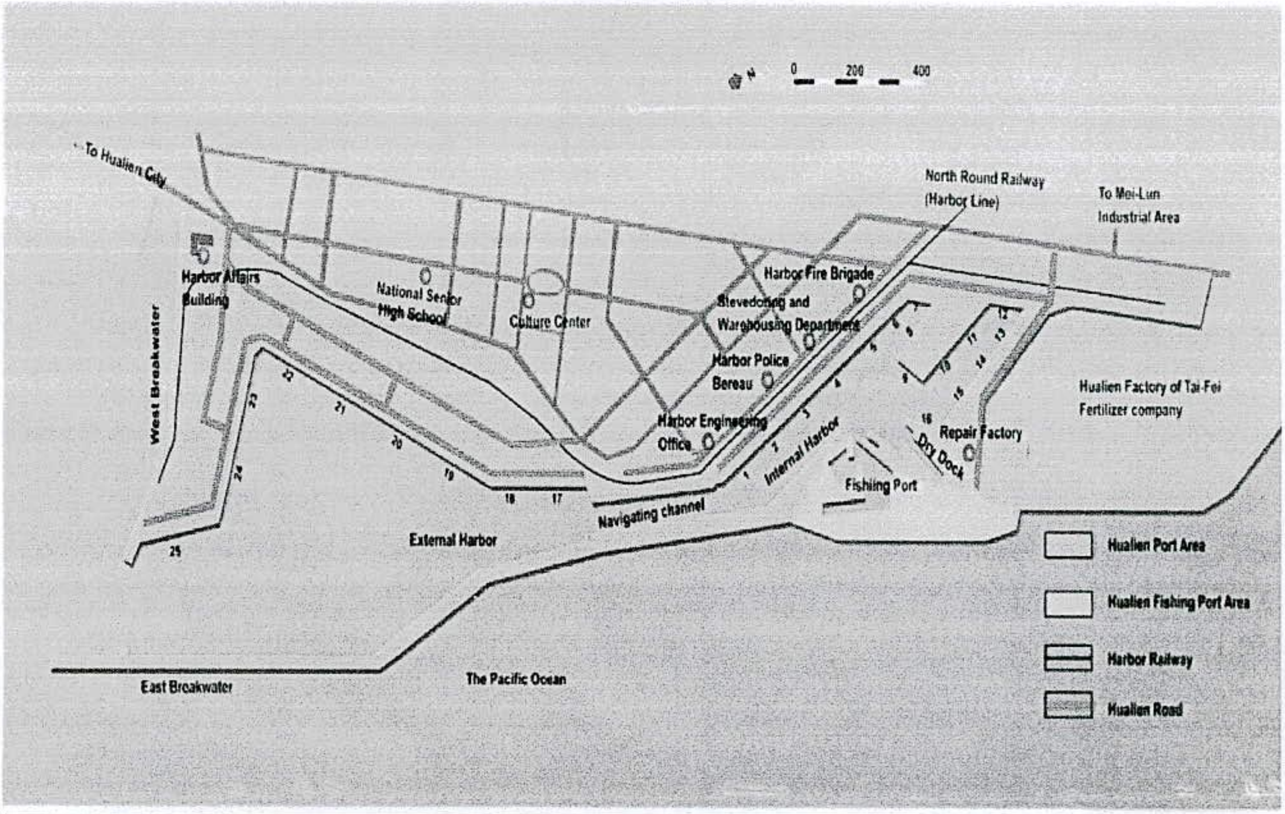
(4) Compatibility between products and storage locations and the compatibility between products.

(5)Item retrieval policy such as FIFO (First-In, First-Out), LIFO (Last-In, First-Out), BFIFO (Batch First-In, First-Out). When using the BFIFO policy, items that arrived in the same replenishment batch are considered to be equivalent.

There is an example in INDIA which authority is Halien Harbour Bureau named HALIEN PORT. Where all support for product release from ship and destination Industries or area is closer to each other. So travel time and cost must be poor for proper distribution.

Warehouse keeping facility

HUALIEN PORT



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2.2.3.1 Storage Location Assignment Problem based on Item Information (SLAP/II)

In the SLAP/II problem, it is assumed that complete information is known about the arrival and departure time of the individual items. The resulting problem is a specially structured Assignment Problem (AP), where items are assigned to storage locations. The special structure derives from the property that two items can occupy the same storage location, provided they do not occupy it at the same time. This problem has been called the Vector Assignment Problem (VAP), since the occupation is no longer expressed as a single binary status variable but as a vector over the different time periods (Goetschalckx, 1998), [7]. The optimal solution of this problem for typical warehousing operations is computationally impractical because of the very large problem instances. The problem is of interest in academic research on warehouse operations because it provides a cost lower bound or performance upper bound. An example of a heuristic SLAP/II policy is the Duration-of-Stay (DOS) policy of Goetschalckx and Ratliff (1990), [8]. In DOS-based policies the expected DOS of the ith unit of a SKU with replenishment lot size Q is i/k for i = 1, 2. . . Q, where k is the demand rate of that SKU. Then the items of all the different products having the shortest DOS are assigned to the closest locations. Hence, the items of a single replenishment batch of a single product may not be stored together in the warehouse.

2.2.3.2 Storage Location Assignment Problem based on Product Information (SLAP/PI)

Often only product information is known about the items to be stored, and items are instances of products. Products may be classified into product classes, e.g. by size or usage rate. The assignment problem now assigns an individual item to a product class based on its product characteristics, and assigns a product class to storage locations. The location of an item in its class is most often done using some simple rule, such as nearest location, or randomly. If the number of classes is equal to the number of products, then this policy is called Dedicated Storage. If the number of classes is equal to one, it is called Random Storage. Otherwise, it is called Class-Based Storage, which may have any number of storage classes ranging from two to the number of products minus one (2–5 storage classes are commonly used in warehouse operations). Different criteria can be used to assign a product (class) to storage locations. The three most frequently used criteria (see also Frazzled, 2002), [9] are

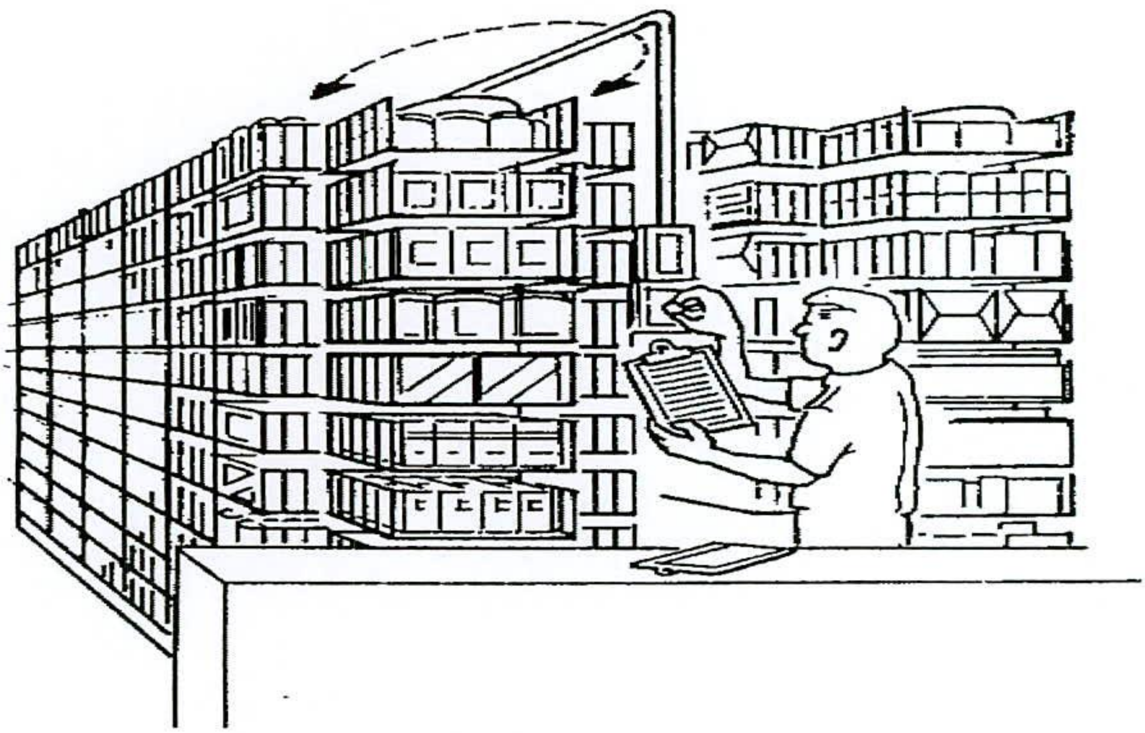
- Popularity (defined as the number of storage/ retrieval operations per unit time period). For the popularity policy, product classes are ranked by decreasing popularity and the classes with the highest popularity are assigned the most desirable locations.
- Maximum inventory (defined as the maximum warehouse space allocated to a product class). For the maximum inventory policy, product classes are ranked by

increasing maximum inventory and the classes with the lowest maximum inventory are assigned the most desirable locations.

- Cube-Per-Order Index (COI, which is defined as the ratio of the maximum allocated storage space to the number of storage/retrieval operations per unit time). The COI policy takes into consideration both a SKU's popularity and its storage space requirement. Product classes are ranked by increasing COI value and the classes with the lowest COI are stored in the most desirable locations.

The implementation of the above policies depends on the types of warehouse systems and therefore may have different variations, for example:

Storage Location with Shelves



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(1) If storage space is measured in units (e.g., shelves and bays), each unit can be treated as an individual product by appropriately apportioning demand. This is most commonly used in unit load warehouses (e.g., Hausman et al., 1976), [10] and sometimes in less-than-unit-load warehouses (e.g., Jarvis and McDowell, 1991), [11]. Since each unit load occupies the same amount of storage space, the popularity policy based on the apportioned popularity is essentially the same as the COI policy. However, it is different from the popularity policy without apportioning. For example, suppose product A has three unit loads and a popularity of three picks per day, and product B has one unit load and a popularity of two picks a day. The popularity policy without apportioning will rank product A ahead of product B. On the other hand, if product A is treated as three products (denoted as A1, A2, and A3), each of them will have an apportioned popularity of 1 pick per day. So the popularity policy based on the apportioned popularity will now rank product B ahead of product A1, A2, and A3, which can be easily verified to be equivalent to the COI policy.

(2) The definition of "the most desirable locations" depends on the system as well as the travel pattern. For example, if traversal routing policy is used for traveling in a conventional multi-parallel-aisle system, the desirability of locations are measured in terms of aisles where the most desirable locations are in the aisle that is closest to the I/O point. This leads to the so-called organ pipe storage location assignment, for example, see Jarvis and McDowell (1991), [11].

The above three policies are simple and flexible enough to be implemented in different warehouse systems. Among them, the COI policy has been the most comprehensively studied one. The COI policy was first described by Heskett (1963, 1964), [12] & [13] without a proof of its optimality. Kallina and Lynn (1976), [14] discussed the implementation of the COI policy in practice. It has been proved that the COI policy is optimal in minimizing the material handling cost in dedicated storage when some assumptions are satisfied:

(1) The objective is to minimize the long-term average order picking cost.

(2) The travel cost depends only on locations. Examples that do not satisfy this assumption include the case when the travel cost is item dependent or when there are multiple I/O points, and products have different probability of moving from/to the I/O points, i.e., it does not satisfy the factoring assumption as defined in Mallette and Francis (1972), [15].

(3) When dual or multi-command order picking is used, there is no dependence between the picked items in the same picking tour.

(4) Certain routing policies are assumed for multi command order picking, e.g., Jarvis and McDowell (1991), [11] assume the traversal routing policy for the conventional multi-aisle order picking system

(5) There are no compatibility constraints that limit the storage location assignment, e.g., certain items must and/or cannot be put together

Table 2.1 summarizes the results on COI-based dedicated storage and its optimality in different order picking systems based on the above assumptions; Table 2.2 provides a group of related heuristic algorithms for dedicated storage when these assumptions cannot be satisfied, and therefore the COI rule is not directly applicable. Comparing dedicated storage with random storage, the former has the advantage of locating fast-moving and compact SKUs close to the I/O points, and therefore is beneficial for efficient material handling. However, it also requires more storage space since sufficient storage locations must be reserved for the maximum inventory of each product. Class-based storage provides an alternative that is in between and has the benefits of both dedicated and random storage. The implementation of class based storage (i.e., the number of classes, the assignment of products to classes, and the storage locations for each class) has significant impact on the required storage space and the material handling cost in a warehouse. Research on this problem has been largely focused on AS/RS, especially single command AS/RS. Hausman et al. (1976), [10] show that for single-command AS/RS with the Chebyshev metric, the ideal shape of storage regions is **L**-shaped. For such systems, the problem reduces to determining the number and boundaries of the classes. Explicit analytical solutions for the class boundaries can be derived for the case with 2 or 3 classes, as shown by Hausman et al. (1976), [10] ; Kouvelis and Papanicolaou (1995),[16] and Eynan and Rosenblatt (1993), [17]. For the general n-class case, Rosenblatt and Eynan (1989) and Eynan and Rosenblatt (1994), [18] suggest a one-dimensional search procedure to find the optimal boundaries. The implementation of class-based storage in multi-command AS/RS is discussed in Guenov and Raeside (1992), [19]

Table 2.1

COI-based dedicated SLAP policy and it's optimally in different systems

	Single-command	Dual-command	Multi-command	Carousel
COI rules and its variants	Mallette and Francis (1972), [20] Harmatuck (1976), [21]	Malmborg and Krishnakumar (1987), [22] Malmborg and Krishnakumar (1990), [23]	Malmborg and Krishnakumar (1989), [24] Jarvis and McDowell (1991), [11]	Bengu (1995), [25]; Vickson (1996), [26]; Vickson and Lu (1998), [27]

Table 2.2

Other dedicated SLAP policies with different complications

Citation	Problem summary	Algorithm
Montulet et al. (1998), [28]; Lee (1992), [29]; Rosenwein (1994), [30]; Brynzer and Johnson (1996), [31]; Van iydgeysdeb and Zhu (1992), [32]; Liu and Lu (1999), [33]; Malmborg (1995), [34];	The objective to minimize the peak operations cost items are not independent such that some items are more likely to appear on the same order	Branch and bound Cluster analysis, space filling curve based heuristics
	All items of any SKU must be located in the same aisle in a multi-aisle AS/RS system	Random search plus stimulated annealing Stimulated annealing; Genetic algorithms
Lai et al. (2002), [35]; Zhang et al. (2000), [36]; Zhang et al. (2002), [37];	Storage location assignment is constrained by product size; all items of the same product must be place at adjacent locations; and travel costs are item dependent	A heuristic similar to COI
Hwang et al. (2003), [38]	Product weight is considered and the objective is to minimize work (a function of weight and distance) involved in order picking	

2.2.3.3 Storage Location Assignment Problem based on No Information (SLAP/NI).

If no information is available on the characteristics of the arriving items, only very simple storage policies can be constructed. In this case the most frequently used policies are

(1) Closest-Open-Location (COL),
(2) Farthest-Open-Location (FOL)

(3) Random (RAN), and
(4) Longest-Open-Location (LOL). The first two policies pick an open location based on its distance to the receiving dock; the last policy picks the location that has been vacant for the longest time. It is not known if there is any significant performance difference between them.

In practice, SLAP/PI is much more common than SLAP/II and SLAP/NI. Random, dedicated, and class-based storage are three popular used storage strategies, and each of them has its advantages and disadvantages. The selection of storage strategy is a strategic decision, which affects warehouse design and has long-term effects. For example, if random storage is used instead of dedicated storage, the warehouse might have a smaller size but require more effort to accurately track the inventory. This topic is further discussed in Section 2.5 of Gu et al. (2005), [39]. Once a storage strategy is selected, its implementation is an operational problem. The implementation of random storage is relatively straightforward. For dedicated and class-based storage, the implementation involves assigning products/classes to storage location. The COI policy has been extensively studied in the literature and is considered as more effective than the other two policies. In class-based storage, additional decisions are to determine the number of classes and to assign products to classes. Current results on these decisions have been focused mainly on AS/RS and need to be further developed for other storage technologies. All of the above research on SLAP assumes that replenishment lot sizes of the SKUs are given. However, Wilson (1977), [40] demonstrates that the lot sizing problem and the SLAP should be considered simultaneously in order to achieve an optimal total cost including both inventory cost and material handling cost. Algorithms for the integrated lot sizing and SLAP problem can be found in Wilson (1977),[40]; Hodgson and Lowe (1982), [41]; Malmborg et al. (1986), [42]; Malmborg and Deutsch (1988),[43] and Malmborg et al. (1988),[44]. The version of the SLAP problem studied in the literature is most often static, i.e., it assumes that the incoming and outgoing material flow patterns are stationary over the planning horizon. In reality, the material flow changes dynamically due to factors such as seasonality and the life cycles of products. Therefore, the storage location assignment should be adjusted to reflect changing material flow requirements. One possibility is to relocate those items whose expected retrieval rate has increased (decreased) closer to (farther from) the I/O point. Such relocations are only beneficial when the expected saving in order picking outweighs the corresponding relocation cost. Therefore, decisions must be made carefully concerning which set of items to be relocated, where to relocate them, and how to schedule the relocations. Another type of relocation might take place as a result of the uncertainty in incoming shipments. For example, Roll and Rosenblatt (1987), [45] describes the situation when the storage area is divided into separate zones and any incoming shipment must be stored within a single zone. It might happen that none of the zones has sufficient space to accommodate an incoming shipment. In such cases, it is advisable to free some space in a certain zone to accommodate the incoming shipment by shifting some stored products in that zone to other zones. Table 2.3 gives a summary of the literature on various dynamic storage location assignment problems.

In class-based storage, additional decisions are to determine the number of classes and to assign products to classes. Current results on these decisions have been focused mainly on AS/RS and need to be further developed for other storage technologies.

2.3 Order picking

Different order picking methods can be employed in a warehouse, for example, single-order picking, batching and sort-while-pick, batching and sort after- pick, single-order picking with zoning, and batching with zoning (Yoon and Sharp, 1996), [50]. Each order picking method consists of some or all of the following basic steps: batching, routing and sequencing, and sorting.

Table 2.3

Dynamic storage location assignment problem

Citation	Problem statement	Method
Christofides and Collof (1972), [46]	The set of items to be relocated and their destinations are given, and the problem is to route the relocation tour to minimize the total relocation cost	Two-stage heuristics that is optimal in a restricted case
Muralidharan et al. (1995), [47]	The set of high-demand items to be relocated and their destinations are given, and the problem is to route the relocation tour to minimize the total relocation cost	A nearest-neighbor heuristic and an insertion heuristic
Jaikumar and Solomon (1990), [48]	Determine the items to be relocated and their destinations with the objective to find the minimum number of relocations that results in a throughput satisfying the throughput requirement in the following busy periods	Optimal ranking algorithm
Sadiq et al. (1996), [49]	Determine the relocation schedule in face of the dynamically changing order structure, ie., relocate items that are more likely to appear in the same order in clusters.	Rule of thumb procedure based on cluster techniques
Roll and Rosenblatt (1987),[45]	Using zone storage without splitting, it might happen that none of the zones has sufficient space to accommodate an incoming shipment. The problem is how to shift some stored products in a certain zone to other zones in order to free space for the incoming shipment.	Rule of thumb procedure

2.3.1 Batching

The batching problem is part of planning for order picking. Orders are received and subsequently released for fulfillment. Given a set of released orders, the problem is to partition the set into batches, where each batch will be picked and accumulated for packing and shipping during a specific time window, or ''pick wave.'' The time required to pick the items in any batch should not exceed the time window or pick wave duration. If zone picking is employed, the batch should balance pick effort across the zones to achieve high picker utilization, while minimizing pick time so that the number of pickers required is minimized. The batching problem can be stated as given:

(1) Warehouse configuration.

(2) Pick wave schedule.

(3) A set of orders to pick during a shift. Determine:

Planning for Order Picking

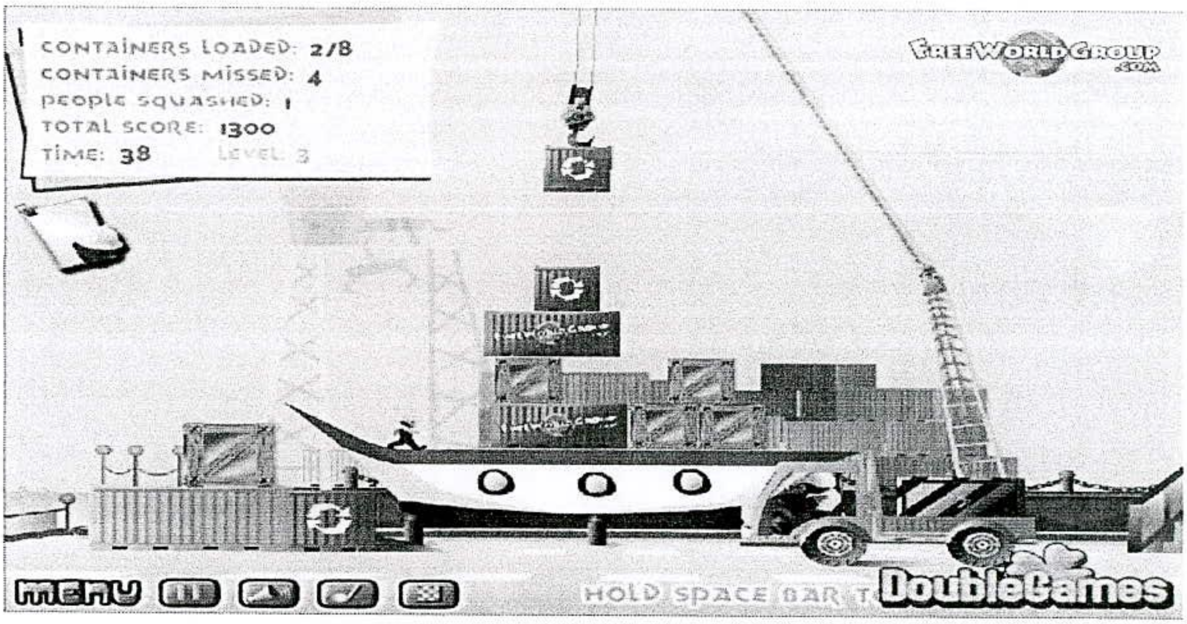


Image -2.4

A partition of orders for assignment to waves and picker subject to performance criteria and constraints such as:

Picker effort, imbalance among pickers, time slots, picker capacity, and order due dates. In creating an abstract statement of the problem, there are potentially two levels of partitioning

(1) Partitioning in time (into pick waves);

(2) Partitioning among pickers in a wave or zone. Constraints include the picker capacity during the time interval associated with a pick wave, and perhaps time constraints on when an order should be completed. Partitioning into time slots is essentially a ‘‘bin packing’’ type problem, where the goal is to balance the pick time among the time slots or pick waves. The difficulty, of course, is that the time required

to pick a batch is not known until the batch has been determined, partitioned among individual picker, and the pickers have been routed through the warehouse.

Partitioning of the orders among the pickers is a variation of the classical Vehicle Routing Problem (VRP), in which ''stops'' are assigned to routes and the objective is to minimize the total route distance or time. However, in the order-batching problem, assigning an order to a picker's route implies that all the picking locations for the SKUs in this order are assigned to this route. This is similar to the pick-up and delivery vehicle routing problem, or the dial-a-ride problem, where a service request consists of a pick-up location and a drop-off location with time precedence. In the order partitioning problem, there may be many stops (SKUs) associated with a single service request (order) but there are no precedence constraints.

2.3.2 Sequencing and routing

The sequencing and routing decision in order picking operations determines the best sequence and route of locations for picking and/or storing a given set of items. The objective is typically to minimize the total material handling cost. This problem is a warehouse-specific Traveling Salesman Problem (TSP), where the picking/storing location of an item is given. The problem where there are several candidate locations for the retrieval or storage of an item is more complex and few research results are available, although it is often found in practice. The TSP in the warehouse is special because of the aisle structure of the possible travel paths. The published research focuses on four classes of warehouse systems, i.e., conventional multi-parallel-aisle systems, man-on-board AS/RS systems, unit-load AS/RS systems, and carousel systems

2.3.2.1 Sequencing and routing for man-on-board AS/RS

The routing problem for man-on-board AS/RS is a TSP with a Chebyshev distance metric. The literature on this problem has been focused primarily on efficient heuristics. Gudehus (1973), [51] describes the band heuristic, which divides the rack into two equal height horizontal bands; the points in the lower band are visited in the increasing x-coordinate direction, while the points in the upper band are visited in the opposite direction. If the tour must visit many points, the rack may be divided into several pairs of horizontal bands. Goetschalckx and Ratliff (1988), [52] propose a convex hull algorithm based on the property of Chebyshev metric that some points not on the convex hull can be inserted into it without incurring additional travel distance. The algorithm constructs the convex hull of all the picking locations, then those free insertion locations for each segment of the convex hull are identified and inserted into the convex hull, and then the remaining points are sequentially inserted into the tour in a way that minimizes the increase in tour length for each insertion. The band algorithm is easy to implement and computationally efficient, but might give inferior solutions in some cases. On the other hand, the convex hull algorithm is effective in finding short tours, but is difficult to implement (to find the convex hull and free insertion points) and less computationally efficient.

2.3.3 Sorting

Sorting is required when multiple orders are picked together. It can be performed either during the picking process (sort-while-pick) or after the picking process (sort-after-pick). Sort-while-pick is quite straightforward and is typically modeled by inflating the item extraction time. For sort-after pick, a separate downstream sorting system is used to perform the sorting function. A number of questions are related to the operation of the sorting system. Sorting systems used in warehouses usually include an accumulation conveyor, a recirculation conveyor, and exit lanes, and they operate simultaneously on all the orders in a single pick-wave. Items for a pick wave arrive at the accumulation conveyor where they wait to be released into the sorting process. They are put onto the recirculation conveyor through an induction point after the items in the previous pick-wave finish their sorting process (in some cases, the items are allowed to enter the recirculation conveyor before the previous wave has totally finished its sorting). The orders are assigned to sorting lanes according to order-to-lane assignment rules. Items circulate in the recirculation conveyor and enter the assigned sorting lane if all items of the preceding order assigned to that lane have been sorted. If not, the items bypass the sorting lane and re-circulate. Eventually, sorted orders are removed from sorting lanes, checked, packed, and shipped. Therefore, the operation problem for sorting involves decisions such as wave-releasing and order-to-lane assignment so that the orders can be efficiently sorted in a given wave.

In summary, the sequencing and routing problem is the most studied problem in warehouse operation. Most of the research assumes that the locations to be visited are given. The problem when multiple candidate locations are available for the retrieval or storage of an

SKU remains an interesting and challenging research problem (for example, see Daniels et al., 1998), [53]. Also, in a warehouse setting, batching is closely related to sequencing, and therefore those problems require a joint solution method. Furthermore, because of the confined and narrow travel paths in a warehouse, another relevant variant of the sequencing and routing problem would consider congestion when there is multiple order picking tours executed at the same time in the same area.

It is clear that the past research has focused strongly on storage and order picking. This is not surprising since these are the two warehouse functions that have the largest impact on the overall warehouse operational performance including storage capacity, space utilization, and order picking efficiency. On the other hand, the development of research is not well balanced. Some problems received far more attention from the research community than others. The aim of the present research work, is to investigate the possibility of identifying similar items from the past demand and store them in the same place so that order picking become more easy in term of travel distance.

CHAPTER- 3

DEVELOPMENT OF ALGORITHM

In this section, the problem environment, necessary concepts, formulas and algorithm are developed and discussed.

3.1 The Problem Environment

The problem, which is selected to study, is similar to production type warehouse. In a production type warehouse, parts/materials are stored and retrieved to use in assembly/manufacturing processes. Warehouses to store spare parts are very similar to production type warehouse. Here, spare parts are stored and retrieved for maintenance purposes. Maintenance work can be scheduled or unscheduled. The unscheduled maintenance is important in the sense that it is related with the unexpected downtime cost. This downtime cost will be minimized if the spare parts required for the maintenance work can be retrieved quickly from the warehouse. The demand for spare parts for a particular maintenance work depends upon the type of maintenance work and has unique requirements. For example, spare parts required for maintenance of Injection Pump and Engine Head of internal combustion engine might be different in type and in quantity. All the parts required for a particular maintenance work can be thought of as spare_part_set. The spare_part_set for these two types of maintenance work hardly have any common intersection. If it is possible to identify the spare_part_set for a particular maintenance work, it can be kept in one place so that the searching and retrieval time can be minimized.

3.2 Methodology

The methodology consists of the following steps:

3.2.1 Identifying spare_part_set

The demand for spare parts for a particular type of maintenance can be found from the issue register of the warehouse. Let us assume that

i = Type of maintenance, $i = 1, 2 \ldots I$

t = Time of maintenance, $t = 1, 2 \ldots n$

D_{it} = The Demand_set is the set of spare parts demanded for i-th maintenance at time period t and

P_i = spare_part_set for ith type of maintenance.

From these past Demand_Set the spare_part_set can be determined with the following formula:

$$P_i = \bigcup_{t=1}^{n} D_{it} \qquad For \quad i = 1,2,\dots\dots.I \qquad \dots \ \textbf{(3.1)}$$

3.2.2 Calculation of the Weight(popularity) of a spare_part_set

This weight is used to identify a spare_part_set as fast moving or slow moving. Generally, the fast moving items are kept near to the issue counter as opposed to the slow moving items. As the fast moving items are used more frequently, a simple way of determining the weight could be annual frequency of usages of all the items in a spare_part_set. It is equal to the total number of all items issued/used in each spare_part_set per year. The higher the frequency of usages of items more the weight.

3.2.3 Assignment of spare_part_set to Shelves

Assignment of each spare_part_set to shelves according to the following steps:

1. Arrange the shelf number in ascending order of distance. Name this list as A.
2. Arrange the **spare_part_set** in descending order of weight. Name this list as B.
3. Take a spare_part_set from the top of the list B
4. Assign this set to the shelves from the top of the list A.
5. Continue 3 and 4 until the list B is empty.

3.2.4 Traveling Distance Calculation

It stands the distance between the issue counter from where the storekeeper has to travel to collect an item from the shelf and come back to the issue counter. To collect n number of items from the shelf with minimum travel distance is a traveling sales man problem. According to the traveling method of the order picker, the researches are classified into several classes; rectilinear travel, Chevyshev travel (i.e. the travel time of the order picker is the maximum of the isolated horizontal and vertical travel times), etc.Van den Berg (1996), [54] presented a survey of methods and models that have appeared in the literature for the planning and control of warehousing systems. The warehousing systems with the Chevyshev travel have received considerable interests since the study of Hausman, Schwarz, and Graves (1976), [10]. And these literatures can be classified again into two groups according to the shape of the warehousing system. One is the square or rectangular Automated Storage/Retrieval System (AS/RS) in which the storage/retrieval devices can move in vertical and horizontal directions, only. The travel distance between two points in two dimensional coordinate is given by the following formula:

$$d_{i,j} = |x_i - x_j| + |y_i - y_j| \quad \forall i, j \quad \dots (3.2)$$

And the total distance traveled to collect n items is given by the following formula:

$$D = d_{o,i} + d_{i,j} + d_{j,k} + d_{k,l} + \dots + d_{(n-1),n} + d_{n,o} \quad \dots (3.3)$$

Where, $d_{i,j}$ = The distance between two points (x_i, y_i) and (x_j, y_j)

$d_{o,i}$ = The distance between input point (x_o, y_o) and (x_i, y_i)

$d_{n,o}$ = The distance between input point (x_n, y_n) and (x_o, y_o)

(x_o, y_o) = The input output point.

To collect next item from the existing position, we choose the nearest item from the existing position.

CHAPTER- 4

EXPERIMENTAL INVESTIGATION AND RESULTS

4.1 Objectives

In this chapter a simulation experiment is presented. The objective of the experiment is to investigate the performance of the methodology described in the previous chapter in terms of travel distance to collect all the items of a demand. For this purpose, three warehouses are considered. The first one, in which the spare parts are stored in alphanumerical order and the second one, in which the spare parts are stored according to the algorithm described in chapter 3 and in the third one, the spare parts are stored randomly. The details of the experiment are described in the subsequent sections.

4.2 Experimental Design

For the experimental purpose, we consider a single-aisle storage rack, which has 42 storage locations. Each storage location is reserved for a spare part. These spare parts are stored in these locations. The schematic diagrams are shown in figure 4.1 and figure 4.2. Furthermore, we assume that there are seven (7) types of maintenance work and all these spare parts are required by these maintenance works. The spare parts required for a particular maintenance type is called spare_part_set and the total number spare parts in the set varied from 4 to 8 in year. The demand of a spare part for a particular maintenance work is random and it is varied from 2to 10 per year. spare_part_set for each maintenance type, the frequency of usages of each parts in the spare_part_set (SPS) is called demand set is shown in table 4.1. The weight of a spare_part_set (SPS) is the sum of all frequency of usages in the demand set are also shown in table 4.1. The random number generation scheme for selecting a maintenance type is shown in table 4.2. For example, if the generated random number is 0.55, the maintenance type selected is 4, and if it is 0.90 the maintenance type selected is 3 and so on. For example, let the maintenance type selected is 1 and the total number of parts required for this maintenance is 3. Now, 3 parts are selected from the set [6,42,7,36,28,15] randomly according to the random number generated scheme as shown in table 4.3. For Example, if the random number generated is 0.45, the spare part required is 7, and if it is 0.625 the spare parts required is 42, and so on.

The random number generation scheme for selecting spare parts required for a particular type of maintenance are shown in table 4.3 to table 4.9. Show the simulation results.

Table 4.10 shows the travelling distance for original system.

Table 4.11 shows the travelling distance for modified system.

Table 4.12 shows the travelling distance for modified system.

Table 4.13 shows the comparison of travelling distances for all systems.

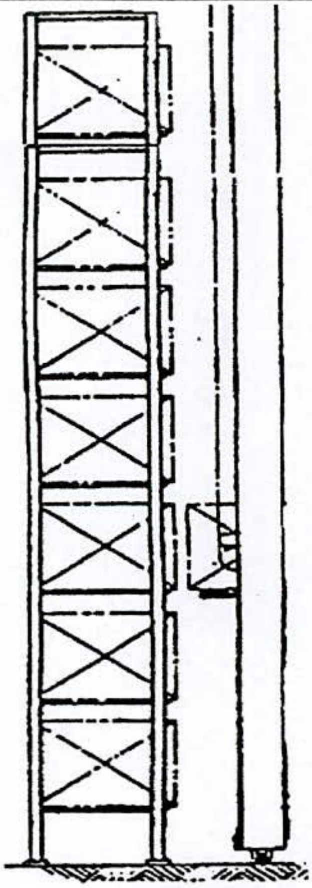


Figure -4.1
Side view of the warehouse

Loc. 1	**Loc. 8**	**Loc. 15**	**Loc. 22**	**Loc. 29**	**Loc. 36**
Loc. 2	**Loc. 9**	**Loc. 16**	**Loc. 23**	**Loc. 30**	**Loc. 37**
Loc. 3	**Loc. 10**	**Loc. 17**	**Loc. 24**	**Loc. 31**	**Loc. 38**
Loc. 4	**Loc. 11**	**Loc. 18**	**Loc. 25**	**Loc. 32**	**Loc. 39**
Loc. 5	**Loc. 12**	**Loc. 19**	**Loc. 26**	**Loc. 33**	**Loc. 40**
Loc. 6	**Loc. 13**	**Loc. 20**	**Loc. 27**	**Loc. 34**	**Loc. 41**
Loc. 7	**Loc. 14**	**Loc. 21**	**Loc. 28**	**Loc. 35**	**Loc. 42**

Figure -4.2
Front view of the warehouse

Table 4.1 : Weight calculation for spare part set

Maintenance Type	Spare_part_set (1- 42)	Demand-set (2-10)	Weight
1	[6,42,7,36,28,15]	[2,5,7,3,4,7]	28
2	[14,9,24,32,18,22,16]	[3,9,8,2,8,5,7]	42
3	[25,21,34,41,5]	[9,4,3,7,3]	26
4	[26,1,35,31,13,11]	[5,8,5,2,3,8]	31
5	[8,4,2,3,17,20,10,40]	[2,7,3,8,3,4,3,6]	36
6	[29,33,12,19]	[2,6,4,5]	17
7	[27,39,38,37,23,30]	[4,4,8,5,10,8]	39

Table 4.2 : Random number generation scheme for maintenance type sets of random numbers

Maintenance Type	Weight	Probability	Cumulative	Range
2	42	42/219 = 0.191	0.191	$0 < R \leq 0.191$
7	39	0.178	0.369	$0.191 < R \leq 0.369$
5	36	0.164	0.533	$0.369 < R \leq 0.533$
4	31	0.141	0.674	$0.533 < R \leq 0.674$
1	28	0.127	0.81	$0.674 < R \leq 0.81$
3	26	0.118	0.919	$0.810 < R \leq 0.919$
6	17	0.077	1	$0.919 < R \leq 1$
total	219	1		

Table 4.3: Random number generation scheme for selecting a spare part for maintenance type (1).

Maintenance Type (1)	Spare-parts No.	Demand	Probability	Cumulative	Range
	15	7	0.25	0.25	$0< R \leq 0.25$
	7	7	0.25	0.5	$0.25< R \leq 0.5$
	42	5	0.179	0.679	$0.5<R\leq0.679$
	28	4	0.143	0.822	$0.679<R\leq0.822$
	36	3	0.107	0.929	$0.822<R\leq0.929$
	6	2	0.0714	1	$0.929<R\leq1$
Total		28			

Table 4.4: Random number generation scheme for selecting a spare part for a maintenance type (2).

Maintenance Type (2)	Spare-parts No	Demand	Probability	Cumulative	Range
	9	9/42	0.214	0.214	0<R ≤ 0.214
	24	8/42	0.19	0.404	0.214<R≤ 0.404
	18	8/42	0.19	0.594	0.404<R≤0.594
	16	7/42	0.166	0.76	0.594<R≤0.76
	22	5/42	0.119	0.879	0.76<R≤0.879
	14	3/42	0.0714	0.95	0.879<R≤0.950
	32	2/42	0.0476	0.99	0.950<R≤1

Table 4.5 : Random number generation scheme for selecting a spare part for a maintenance type (3).

Maintenance Type (3)	Spare-parts No	Demand	Probability	Cumulative	Range
	25	9/26	0.346	346	0<R≤0.346
	41	7/26	0.269	0.615	0.346<R≤0.615
	21	4/26	0.153	0.768	0.615<≤0.768
	34	3/26	0.115	0.883	0.768<R≤0.883
	5	3/26	0.115	0.998	0.883<R≤1

Table 4.6: Random number generation scheme for selecting a spare part for a maintenance type (4).

Maintenance Type (4)	Spare-parts No	Demand	Probability	Cumulative	Range
	11	8/31	0.258	0.254	0<R≤0.258
	1	8/31	0.258	0.516	0.258<R≤0.516
	35	5/31	0.161	0.0677	0516<R≤0.677
	26	5/31	0.161	0.838	0.677<R≤0.838
	13	3/31	0.096	0.934	0.838<R≤0.934
	31	2/31	0.0645	0.99	0.934 <R≤1

Table 4.7:Random number generation scheme for selecting a spare part for a maintenance type (5).

Maintenance Type (5)	Spare-parts No	Demand	Probability	Cumulative	Range
	3	8/36	0.222	0.222	0<R≤0.222
	4	7/36	0.194	0.416	0.222<R≤0.416
	40	6/36	0.166	0.582	0.416<R≤0.582
	20	4/36	0.111	0.693	0.582<R≤0.693
	17	3/36	0.083	0.776	0.693<R≤0.776
	10	3/36	0.083	0.859	0.776<R≤0.859
	2	3/36	0.083	0.942	0.859<R≤0.942
	8	2/36	0.055	0.997	0.942<R≤1

Table 4.8: Random number generation scheme for selecting a spare part for a maintenance type (6).

Maintenance Type (6)	spare-parts	demand	probability	cumulative	rang
	33	6	0.35	0.35	0.0 <R ≤0.35
	19	5	0.29	0.64	0.35<R≤0.64
	12	4	0.23	0.87	0.64<R≤0.87
	29	2	0.11	0.99	0.87<R≤0.99
Total		17			

Table 4.9: Random number generation scheme for selecting a spare part for a maintenance type (7).

Maintenance Type (7)	spare-parts	deman d	probability	cumulative	rang
	23	10	0.256	0.256	0 <R ≤0.256
	38	8	0.205	0.461	0.256<R≤0.461
	30	8	0.205	0.666	0.461<R≤0.666
	37	5	0.128	0.794	0.666<R≤0.794
	39	4	0.102	0.896	0.794<R≤0.896
	27	4	0.102	0.998	0.896<R≤0.998
Total		39			

4.3 Sample Calculation of Travelling Distance

Distance travelled to collect all the spare parts [6,42,7,36,28,15] for maintenance type 1 for original system (figure 4.3), when parts are stored in alpha-numerical order, for modified system (figure 4.5), when parts are stored according to the algorithm developed in this study once random system (figure 4.6) when parts are stored randomly are shown bellow:

- Original system

  Total distance travelled = 3+6+4+12+6+14+5 = 50

- Random system

  Total distance travelled = 13+2+2+2+2+2+15 = 42

- Reorganized system according to the proposed methodology

  Total distance travelled = 13+2+2+2+2+2+15 = 38

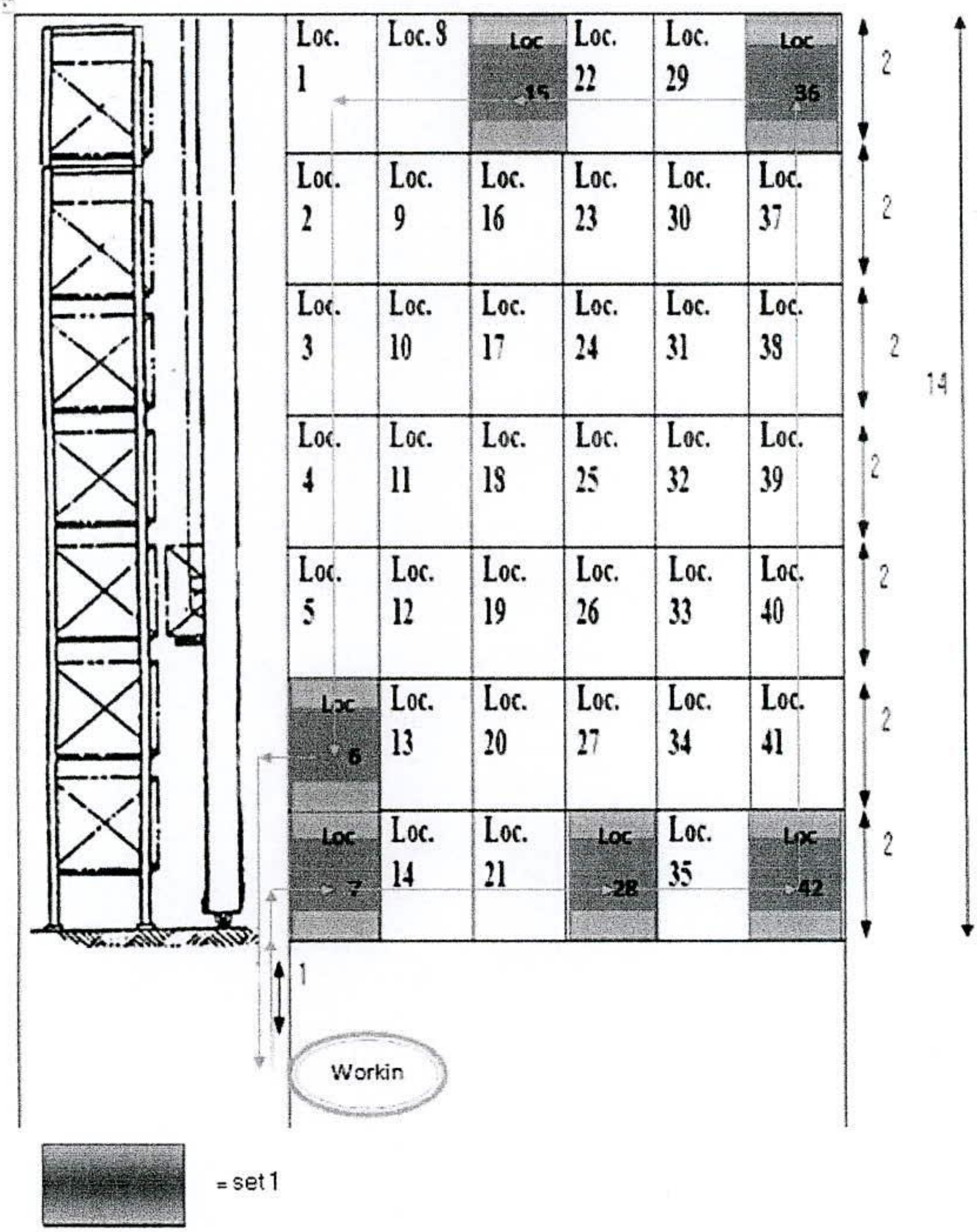


Figure 4.3. Front view of the warehouse for Set 1

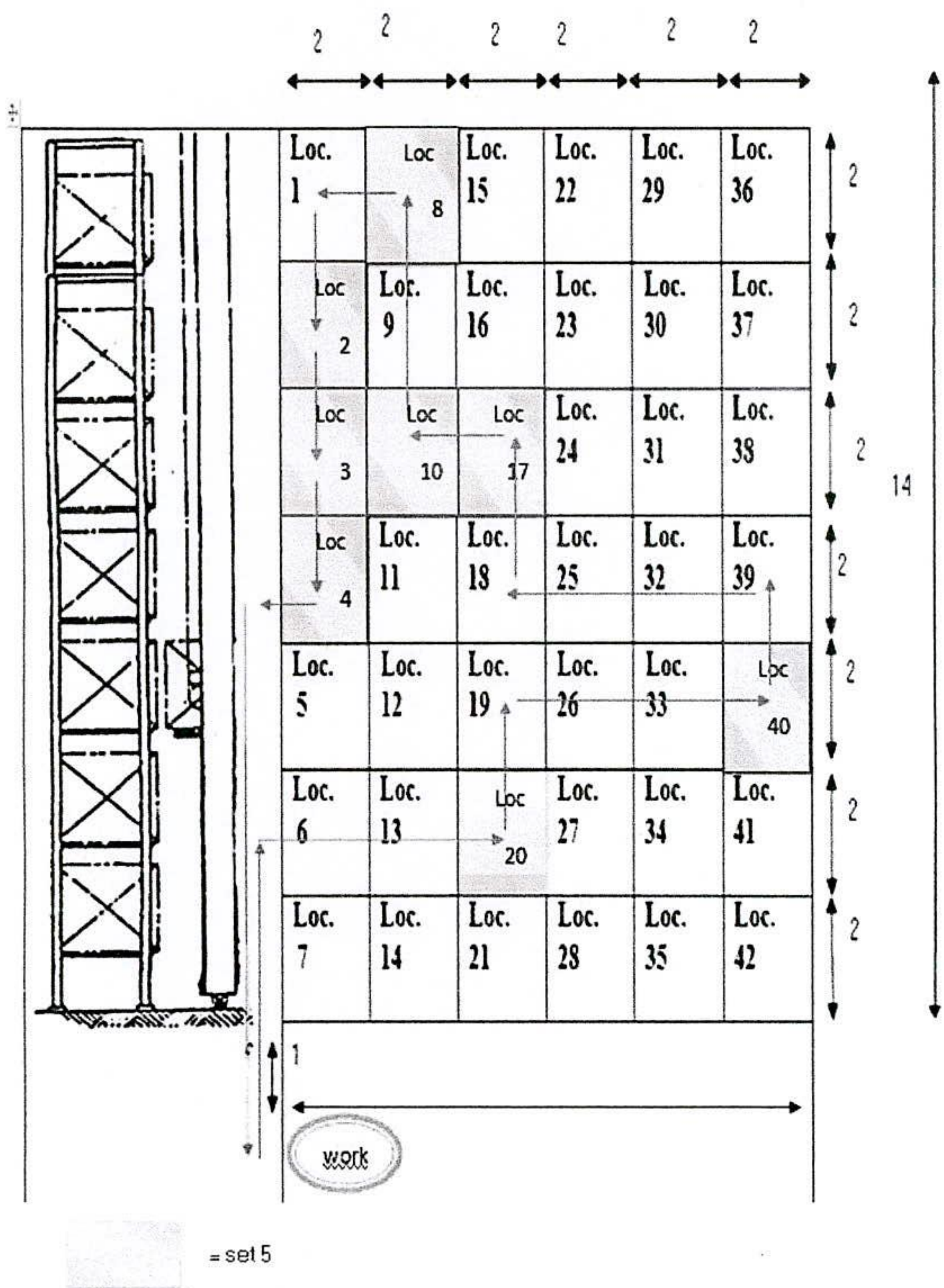


Figure 4.4. Front view of the warehouse for Set 5

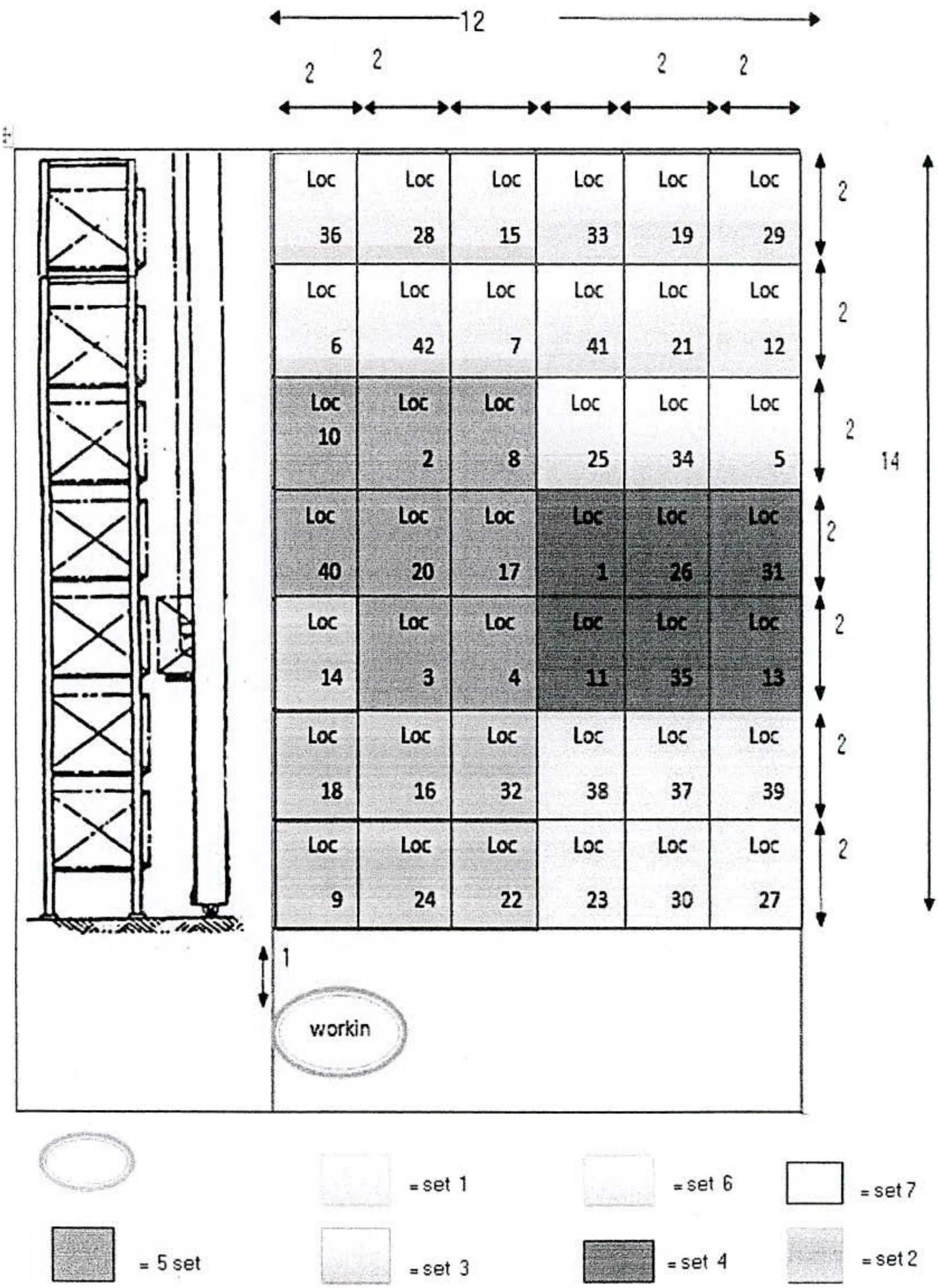


Figure 4.5 : Front view of the warehouse for modified System

Table 4.10: Travelling distance for original system

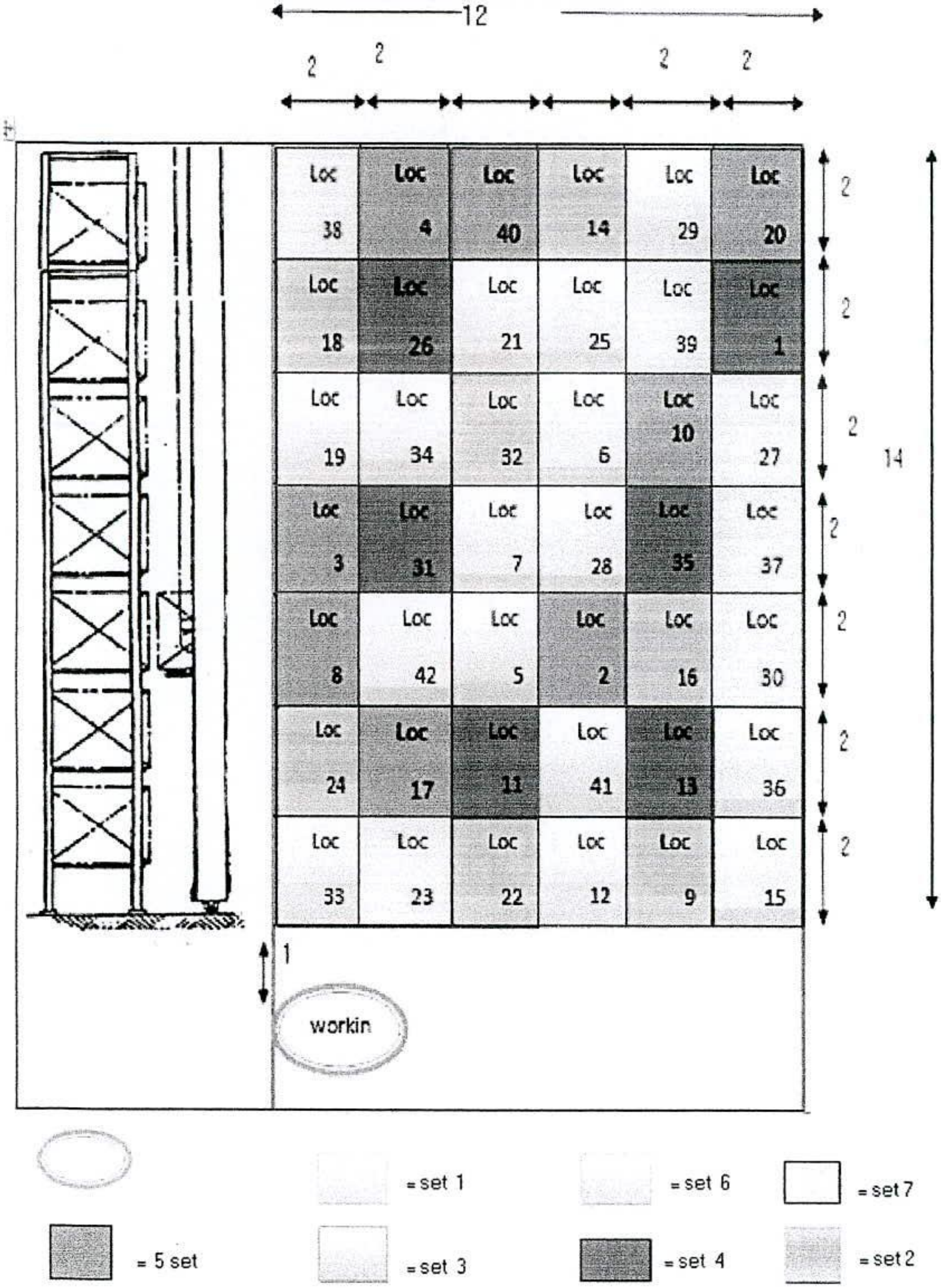


Figure 4.6: Front view of the warehouse for Random System

Table 4.10: Travelling distance for original system

Maintenance Types	Spare_part_set (1- 42)	Travelling Distance to Collect the Spare Parts	Total Distance
1	[6,42,7,36,28,15]	3+ 6+4+12+6+14+5	50
2	[14,9,24,32,18,22,16]	5+7+4+3+4+3+2+15	43
3	[25,21,34,41,5]	7+8+8+2+6+7	38
4	[26,1,35,31,13,11]	7+4+8+11+6+6+11	53
5	[8,4,2,3,17,20,10,40]	9+8+10+2+4+4+2+2+9	50
6	[29,33,12,19]	9+2+11+2+6+15	45
7	[27,39,38,37,23,30]	11+8+4+2+2+19	46

Table 4.11: Travelling distance for modified system

Maintenance Types	Travelling distance for modified	Total Distance
1	13+2+2+2+2+2+15	38
2	3+2+2+2+2+2+2+7	22
3	21+2+2+2+2+16	45
4	13+2+2+2+2+2+15	38
5	11+2+2+2+2+2+2+8	33
6	25+2+2+2+21	52
7	9+2+2+2+2+2+11	30

Table 4.12: Travelling distance for Random system

Maintenance Types	Travelling distance for random	Total Distance
1	9+4+2+2+10+2+13	42
2	4+8+8+6+8+4+4+7	49
3	11+4+8+2+4+13	42
4	9+4+4+6+8+4+11	46
5	7+2+8+2+6+6+6+6+7	50
6	3+6+14+12+11	46
7	5+12+2+2+4+10+15	50

Table 4.13: Comparison of travelling distance

Maintenance Types	Distance for modified	Distance for Original	Distance for Random
1	38	50	42
2	22	43	49
3	45	38	42
4	38	53	46
5	33	50	50
6	52	45	46
7	30	46	50

4.3 Experimental Results

The experiment is conducted by generating the random demand for different types of maintenance works. For each experiment the traveling distance to collect all the items for both the arrangements are calculated and summarized in table 4.14

Table 4.14: Simulation Result

Experiment	Maintenance type	Spare –parts	Traveling distance for original arrangement	Traveling distance for random arrangement	Traveling distance for modified arrangement
1	2	9,24,18,22,14	38	50	22
2	6	33,19,12	31	34	51
3	2	9,18,22,14	42	46	22
4	5	3,4,20,10,17	31	54	30
5	7	23,38,37,39	47	54	30
6	6	12,29,19	46	46	51
7	2	32,22,24,9	44	42	18
8	2	9,18,16,22,14	43	46	22
9	2	32,24,16,9	43	42	18
10	6	12,29,19,33	47	46	51
11	4	11,1,35,13	46	46	38
12	3	25,21,5,34	35	38	45
13	4	31,26,35	29	42	38
14	4	11,1,13,31	46	46	38
15	6	29,33,12,19	45	46	52
16	5	2,8,4,17	35	46	30
17	7	38,30,27,39	46	50	30
18	2	14,16,18,22	43	46	22
19	2	32,14,18	35	46	22
20	4	1,26,11,13	42	46	38
21	7	23,27,38,37	46	50	30
22	4	26,13,31	38	42	38
23	1	7,28,6,42	29	34	38
24	1	7,28,36,6	50	42	38
25	3	25,21,34,41	38	38	43
26	7	23,30,39	46	46	30
27	6	12,19,33	30	34	51
28	4	11,1,35,26	46	46	34
29	7	23,38,30,27	46	50	30
30	7	27,39,38,30	47	50	30
31	1	15,42,28,6	50	42	38
32	5	8,2,10,17,3,4	39	50	30
33	4	1,35,13,31	52	46	38

34	2	9,18,22,14,32	50	50	22
35	7	23,30,37,27	47	42	30
36	6	33,19,12,29	47	46	51
37	2	14,16,18,24,9	37	46	20
38	2	24,18,22,14,32	48	46	22
39	2	9,24,18,16	38	42	14
40	5	40,8,17,10	51	50	30
41	1	7,42,28,36	50	38	38
42	1	15,7,28,6	43	42	38
43	1	7,15,6	38	46	38
44	7	23,38,30,37,39,27	46	50	30
45	6	29,12,19	46	46	51
46	6	33,19,12	30	34	51
47	3	5,34,31	39	34	47
48	1	6,36,28,42	50	42	34
49	4	11,1,31,26	50	50	38
50	1	7,42,28,36	50	38	38
51	2	16,14,9,24,32,18,22	43	54	22
52	6	29,33,12,19	45	46	52
53	5	8,4,2,3,17,20,10,40	50	54	33
54	4	26,11,1,13,35,31	53	46	38
55	1	6,42,7,36,28,15	53	60	38
56	3	25,21,34,41,5	38	46	45
57	6	19,12,33,29	45	46	52
58	7	27,39,38,37,23,30	46	50	30
59	1	42,6,7,28,36,15	53	60	38
60	5	8,2,4,3,20,17,10,40	50	54	33
61	2	16,14,9,24,32,18,22	43	54	22
62	7	30,23,38,37,39,27	46	50	30
63	4	26,1,35,31,13,11	53	46	38
64	3	41,25,21,34,5	38	46	45
65	6	29,19,33,12	45	46	52
66	1	15,28,36,7,42,6	53	60	38
67	5	40,10,17,20,3,4,8,2	50	54	33
68	4	11,13,31,35,1,26	53	46	38
69	7	27,38,39,23,37,30	46	50	30
70	2	16,9,32,22,18,24,14	43	54	22
71	2	16,14,18,22,9,24,32	43	54	22
72	6	33,12,19,29	45	46	52
73	3	25,21,34,41,5	38	46	45
74	7	30,27,39,23,38,37	46	50	30

75	1	6,42,7,36,28,15	53	60	38
76	7	37,39,38,27,23,30	46	50	30
77	5	8,4,2,3,17,20,10,40	50	54	33
78	3	25,21,34,31,5	38	46	45
79	1	6,42,7,36,28,15	53	60	38
80	2	16,22,18,32,14,24,9	43	54	22
81	4	11,13,31,35,26,1	53	46	38
82	6	29,19,33,12	45	46	52
83	7	30,23,27,37,38,39	46	50	30
84	5	8,40,4,10,2,20,3,17	50	54	33
85	1	15,28,7,6,42,36	53	60	38
86	3	5,41,34,21,25	38	46	45
87	2	14,9,24,32,18,22,16	43	54	22
88	4	26,1,35,31,13,11	53	46	38
89	7	38,27,39,30,37,23	46	50	30
90	6	12,33,29,19	45	46	52
91	1	6,7,15	38	42	38
92	6	29,33,12,19	45	46	52
93	3	41,34,25	38	38	43
94	5	3,2,4,8,17	38	46	30
95	4	26,35,31	38	42	35
96	2	9,24	38	26	10
97	7	39,38,37,30	46	50	30
98	5	17,20,10,8	38	54	30
99	1	6,42,36,28	50	42	34
100	5	2,3,4,8,10	34	46	31
Total			**4407**	**4696**	**3523**

After 100 number of experiments, it is seen from the figure 4.10 and table 4.18 that average distance travelled for all the system become almost stable. The average distance travelled for original system is 43.98m and for random system it is 46.96 and for reorganized system it is 35.23.

For 100 experiments, it is seen for table 4.14.

Total distance traveled for the original system = 4407 m.

Total distance traveled for the modified system = 3523 m

Reduction of travel distance from original system to modified system = 884 m.

$$= \frac{884}{4407} \times 100 = 20\ \%$$

For 100 experiments, it is seen for table 4.14.

Total distance traveled for the random system = 4696 m.

Total distance traveled for the modified system = 3523 m

Reduction of travel distance from random system to modified system = 1173 m.

$$= \frac{1173}{4696} \times 100 = 25\ \%$$

For 100 experiments, it is seen for table 4.14.

Total distance traveled for the random system = 4696 m.

Total distance traveled for the original system = 4407 m

Increase of travel distance from original system to random system = 289 m.

$$= \frac{289}{4696} \times 100 = 06\ \%$$

In original system to random system have no reduction of travel distance but increase. From these experiments we observed that only original system to modified system is more reduction than original system to random system and random system to modified system. So we can state that original system to modified system is more efficient than others system.

Table 4.15: Cumulative of Average No-1 for Original Arrangement from Simulation Result

Experiment	Maintenance type	Spare –parts	Traveling distance for original arrangement	Cumulative No-1	Average No- 1
1	2	9,24,18,22,14	38	38	38
2	6	33,19,12	31	69	34.5
3	2	9,18,22,14	42	111	37
4	5	3,4,20,10,17	31	142	35.5
5	7	23,38,37,39	47	189	37.8
6	6	12,29,19	46	235	39.1667
7	2	32,22,24,9	44	279	39.8571
8	2	9,18,16,22,14	43	322	40.25
9	2	32,24,16,9	43	365	40.5556
10	6	12,29,19,33	47	412	41.2
11	4	11,1,35,13	46	458	41.6364
12	3	25,21,5,34	35	493	41.0833
13	4	31,26,35	29	522	40.1538
14	4	11,1,13,31	46	568	40.5714
15	6	29,33,12,19	45	613	40.8667
16	5	2,8,4,17	35	648	40.5
17	7	38,30,27,39	46	694	40.8235
18	2	14,16,18,22	43	737	40.9444
19	2	32,14,18	35	772	40.6316
20	4	1,26,11,13	42	814	40.7
21	7	23,27,38,37	46	860	40.9524
22	4	26,13,31	38	898	40.8182
23	1	7,28,6,42	29	927	40.3043
24	1	7,28,36,6	50	977	40.7083
25	3	25,21,34,41	38	1015	40.6
26	7	23,30,39	46	1061	40.8077
27	6	12,19,33	30	1091	40.4074
28	4	11,1,35,26	46	1137	40.6071
29	7	23,38,30,27	46	1183	40.7931
30	7	27,39,38,30	47	1230	41
31	1	15,42,28,6	50	1280	41.2903
32	5	8,2,10,17,3,4	39	1319	41.2188

33	4	1,35,13,31	52	1371	41.5455
34	2	9,18,22,14,32	50	1421	41.7941
35	7	23,30,37,27	47	1468	41.9429
36	6	33,19,12,29	47	1515	42.0833
37	2	14,16,18,24,9	37	1552	41.9459
38	2	24,18,22,14,32	48	1600	42.1053
39	2	9,24,18,16	38	1638	42
40	5	40,8,17,10	51	1689	42.225
41	1	7,42,28,36	50	1739	42.4146
42	1	15,7,28,6	43	1782	42.4286
43	1	7,15,6	38	1820	42.3256
44	7	23,38,30,37,39,27	46	1866	42.4091
45	6	29,12,19	46	1912	42.4889
46	6	33,19,12	30	1942	42.2174
47	3	5,34,31	30	1972	41.9574
48	1	6,36,28,42	50	2022	42.125
49	4	11,1,31,26	50	2072	42.2857
50	1	7,42,28,36	50	2122	42.44
51	2	16,14,9,24,32,18,22	43	2165	42.451
52	6	29,33,12,19	45	2210	42.5
53	5	8,4,2,3,17,20,10,40	50	2260	42.6415
54	4	26,11,1,13,35,31	53	2313	42.8333
55	1	6,42,7,36,28,15	53	2366	43.0182
56	3	25,21,34,41,5	38	2404	42.9286
57	6	19,12,33,29	45	2449	42.9649
58	7	27,39,38,37,23,30	46	2495	43.0172
59	1	42,6,7,28,36,15	53	2548	43.1864
60	5	8,2,4,3,20,17,10,40	50	2598	43.3
61	2	16,14,9,24,32,18,22	43	2641	43.2951
62	7	30,23,38,37,39,27	46	2687	43.3387
63	4	26,1,35,31,13,11	53	2740	43.4921
64	3	41,25,21,34,5	38	2778	43.4063
65	6	29,19,33,12	45	2823	43.4308
66	1	15,28,36,7,42,6	53	2876	43.5758
67	5	40,10,17,20,3,4,8,2	50	2926	43.6716
68	4	11,13,31,35,1,26	53	2979	43.8088
69	7	27,38,39,23,37,30	46	3025	43.8406
70	2	16,9,32,22,18,24,14	43	3068	43.8286
71	2	16,14,18,22,9,24,32	43	3111	43.8169

72	6	33,12,19,29	45	3156	43.8333
73	3	25,21,34,41,5	38	3194	43.7534
74	7	30,27,39,23,38,37	46	3240	43.7838
75	1	6,42,7,36,28,15	53	3293	43.9067
76	7	37,39,38,27,23,30	46	3339	43.9342
77	5	8,4,2,3,17,20,10,40	50	3389	44.013
78	3	25,21,34,41,5	38	3427	43.9359
79	1	6,42,7,36,28,15	53	3480	44.0506
80	2	16,22,18,32,14,24,9	43	3523	44.0375
81	4	11,13,31,35,26,1	53	3576	44.1481
82	6	29,19,33,12	45	3621	44.1585
83	7	30,23,27,37,38,39	46	3667	44.1807
84	5	8,40,4,10,2,20,3,17	50	3717	44.25
85	1	15,28,7,6,42,36	53	3770	44.3529
86	3	5,41,34,21,25	38	3808	44.2791
87	2	14,9,24,32,18,22,16	43	3851	44.2644
88	4	26,1,35,31,13,11	53	3904	44.3636
89	7	38,27,39,30,37,23	46	3950	44.382
90	6	12,33,29,19	45	3995	44.3889
91	1	6,7,15	38	4033	44.3187
92	6	29,33,12,19	45	4078	44.3261
93	3	41,34,25	38	4116	44.2581
94	5	3,2,4,8,17	38	4154	44.1915
95	4	26,35,31	38	4192	44.1263
96	2	9,24	38	4230	44.0625
97	7	39,38,37,30	46	4276	44.0825
98	5	17,20,10,8	38	4314	44.0204
99	1	6,42,36,28	50	4364	44.0808
100	5	2,3,4,8,10	34	4398	43.98
			4398		

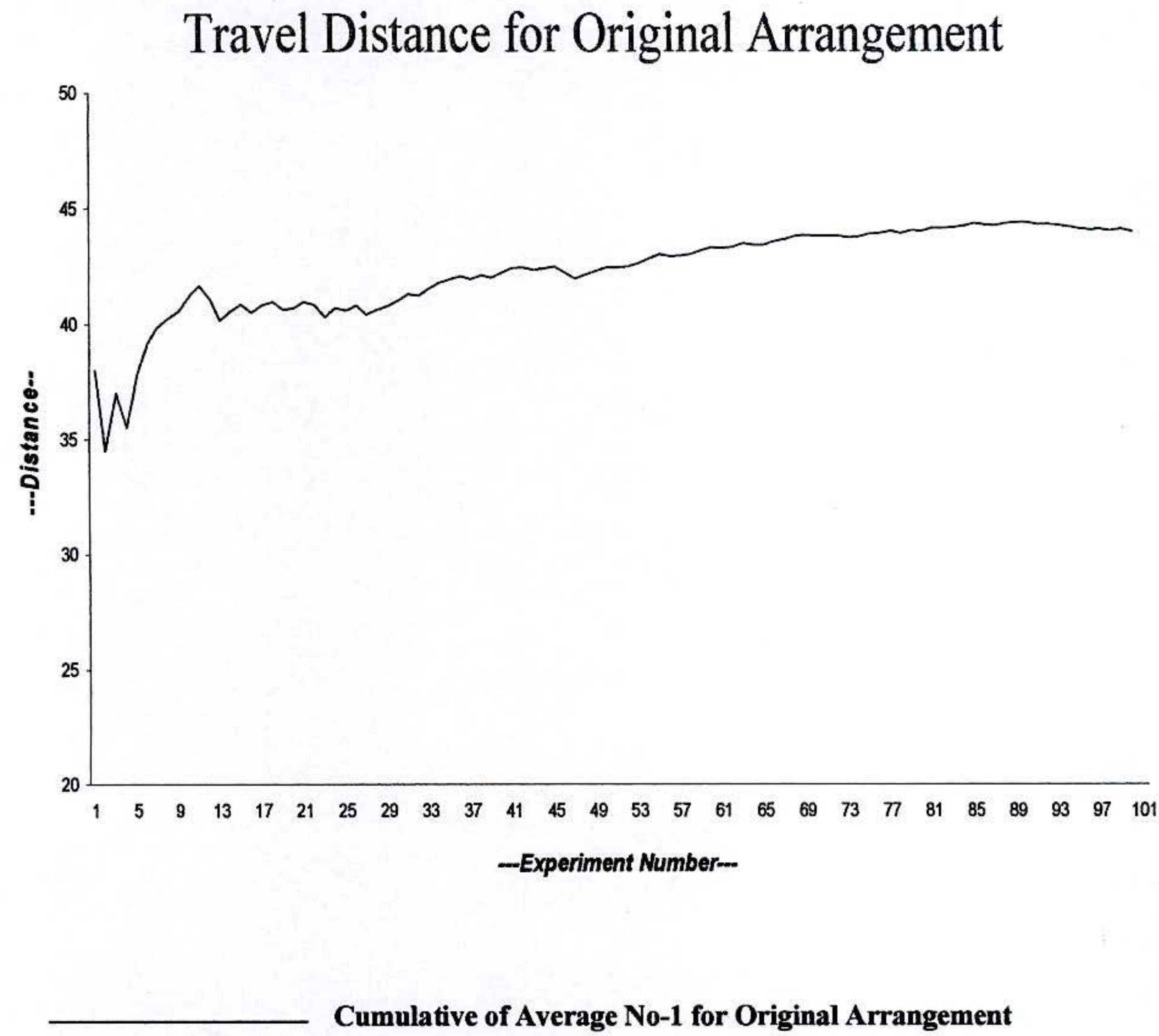


Figure No-4.7 : Travel Distance for Original Arrangement

Table 4.16
Cumulative of Average No-2 for Modified Arrangement from Simulation Result

Experiment	Maintenance type	Spare –parts	Traveling distance for modified arrangement	Cumulative No- 2	Average No- 2
1	2	9,24,18,22,14	22	22	22
2	6	33,19,12	51	73	36.5
3	2	9,18,22,14	22	95	31.666667
4	5	3,4,20,10,17	30	125	31.25
5	7	23,38,37,39	30	155	31
6	6	12,29,19	51	206	34.333333
7	2	32,22,24,9	18	224	32
8	2	9,18,16,22,14	22	246	30.75
9	2	32,24,16,9	18	264	29.333333
10	6	12,29,19,33	51	315	31.5
11	4	11,1,35,13	38	353	32.090909
12	3	25,21,5,34	45	398	33.166667
13	4	31,26,35	38	436	33.538462
14	4	11,1,13,31	38	474	33.857143
15	6	29,33,12,19	52	526	35.066667
16	5	2,8,4,17	30	556	34.75
17	7	38,30,27,39	30	586	34.470588
18	2	14,16,18,22	22	608	33.777778
19	2	32,14,18	22	630	33.157895
20	4	1,26,11,13	38	668	33.4
21	7	23,27,38,37	30	698	33.238095
22	4	26,13,31	38	736	33.454545
23	1	7,28,6,42	38	774	33.652174
24	1	7,28,36,6	38	812	33.833333
25	3	25,21,34,41	43	855	34.2
26	7	23,30,39	30	885	34.038462
27	6	12,19,33	51	936	34.666667
28	4	11,1,35,26	34	970	34.642857
29	7	23,38,30,27	30	1000	34.482759
30	7	27,39,38,30	30	1030	34.333333
31	1	15,42,28,6	38	1068	34.451613
32	5	8,2,10,17,3,4	30	1098	34.3125

33	4	1,35,13,31	38	1136	34.424242
34	2	9,18,22,14,32	22	1158	34.058824
35	7	23,30,37,27	30	1188	33.942857
36	6	33,19,12,29	51	1239	34.416667
37	2	14,16,18,24,9	20	1259	34.027027
38	2	24,18,22,14,32	22	1281	33.710526
39	2	9,24,18,16	14	1295	33.205128
40	5	40,8,17,10	30	1325	33.125
41	1	7,42,28,36	38	1363	33.243902
42	1	15,7,28,6	38	1401	33.357143
43	1	7,15,6	38	1439	33.465116
44	7	23,38,30,37,39,27	30	1469	33.386364
45	6	29,12,19	51	1520	33.777778
46	6	33,19,12	51	1571	34.152174
47	3	5,34,31	47	1618	34.425532
48	1	6,36,28,42	34	1652	34.416667
49	4	11,1,31,26	38	1690	34.489796
50	1	7,42,28,36	38	1728	34.56
51	2	16,14,9,24,32,18,22	22	1750	34.313725
52	6	29,33,12,19	52	1802	34.653846
53	5	8,4,2,3,17,20,10,40	33	1835	34.622642
54	4	26,11,1,13,35,31	38	1873	34.685185
55	1	6,42,7,36,28,15	38	1911	34.745455
56	3	25,21,34,41,5	45	1956	34.928571
57	6	19,12,33,29	52	2008	35.22807
58	7	27,39,38,37,23,30	30	2038	35.137931
59	1	42,6,7,28,36,15	38	2076	35.186441
60	5	8,2,4,3,20,17,10,40	33	2109	35.15
61	2	16,14,9,24,32,18,22	22	2131	34.934426
62	7	30,23,38,37,39,27	30	2161	34.854839
63	4	26,1,35,31,13,11	38	2199	34.904762
64	3	41,25,21,34,5	45	2244	35.0625
65	6	29,19,33,12	52	2296	35.323077
66	1	15,28,36,7,42,6	38	2334	35.363636
67	5	40,10,17,20,3,4,8,2	33	2367	35.328358
68	4	11,13,31,35,1,26	38	2405	35.367647
69	7	27,38,39,23,37,30	30	2435	35.289855
70	2	16,9,32,22,18,24,14	22	2457	35.1
71	2	16,14,18,22,9,24,32	22	2479	34.915493

72	6	33,12,19,29	52	2531	35.152778
73	3	25,21,34,41,5	45	2576	35.287671
74	7	30,27,39,23,38,37	30	2606	35.216216
75	1	6,42,7,36,28,15	38	2644	35.253333
76	7	37,39,38,27,23,30	30	2674	35.184211
77	5	8,4,2,3,17,20,10,40	33	2707	35.155844
78	3	25,21,34,41,5	45	2752	35.282051
79	1	6,42,7,36,28,15	38	2790	35.316456
80	2	16,22,18,32,14,24,9	22	2812	35.15
81	4	11,13,31,35,26,1	38	2850	35.185185
82	6	29,19,33,12	52	2902	35.390244
83	7	30,23,27,37,38,39	30	2932	35.325301
84	5	8,40,4,10,2,20,3,17	33	2965	35.297619
85	1	15,28,7,6,42,36	38	3003	35.329412
86	3	5,41,34,21,25	45	3048	35.44186
87	2	14,9,24,32,18,22,16	22	3070	35.287356
88	4	26,1,35,31,13,11	38	3108	35.318182
89	7	38,27,39,30,37,23	30	3138	35.258427
90	6	12,33,29,19	52	3190	35.444444
91	1	6,7,15	38	3228	35.472527
92	6	29,33,12,19	52	3280	35.652174
93	3	41,34,25	43	3323	35.731183
94	5	3,2,4,8,17	30	3353	35.670213
95	4	26,35,31	35	3388	35.663158
96	2	9,24	10	3398	35.395833
97	7	39,38,37,30	30	3428	35.340206
98	5	17,20,10,8	30	3458	35.285714
99	1	6,42,36,28	34	3492	35.272727
100	5	2,3,4,8,10	31	3523	35.23
			3523		

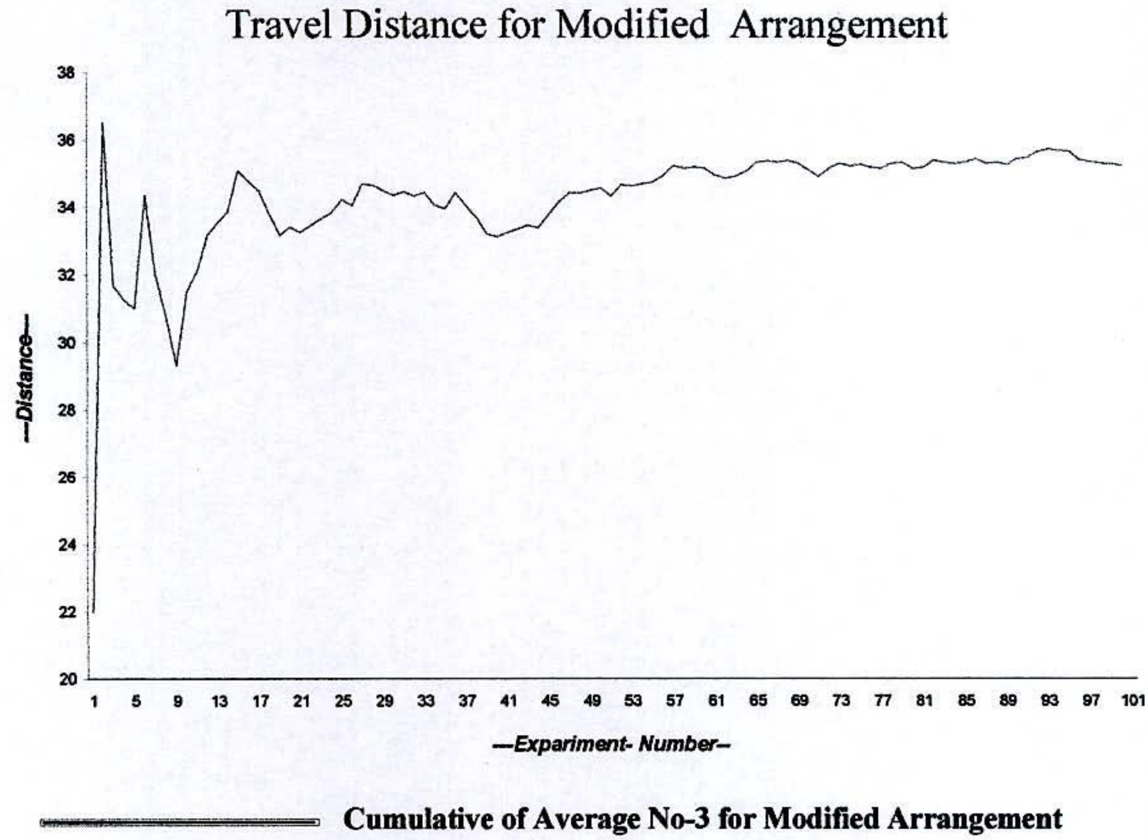


Figure No-4.8 : Travel Distance for Modified Arrangement

Table 4.17
Cumulative of Average No-3 for Random Arrangement from Simulation Result

Experiment	Maintenance type	Spare –parts	Traveling distance for random arrangement	Cumulative No- 3	Average No-3
1	2	9,24,18,22,14	50	50	50
2	6	33,19,12	34	84	42
3	2	9,18,22,14	46	130	43.33333
4	5	3,4,20,10,17	54	184	46
5	7	23,38,37,39	54	238	47.6
6	6	12,29,19	46	284	47.33333
7	2	32,22,24,9	42	326	46.57143
8	2	9,18,16,22,14	46	372	46.5
9	2	32,24,16,9	42	414	46
10	6	12,29,19,33	46	460	46
11	4	11,1,35,13	46	506	46
12	3	25,21,5,34	38	544	45.33333
13	4	31,26,35	42	586	45.07692
14	4	11,1,13,31	46	632	45.14286
15	6	29,33,12,19	46	678	45.2
16	5	2,8,4,17	46	724	45.25
17	7	38,30,27,39	50	774	45.52941
18	2	14,16,18,22	46	820	45.55556
19	2	32,14,18	46	866	45.57895
20	4	1,26,11,13	46	912	45.6
21	7	23,27,38,37	50	962	45.80952
22	4	26,13,31	42	1004	45.63636
23	1	7,28,6,42	34	1038	45.13043
24	1	7,28,36,6	42	1080	45
25	3	25,21,34,41	38	1118	44.72
26	7	23,30,39	46	1164	44.76923
27	6	12,19,33	34	1198	44.37037
28	4	11,1,35,26	46	1244	44.42857

29	7	23,38,30,27	50	1294	44.62069
30	7	27,39,38,30	50	1344	44.8
31	1	15,42,28,6	42	1386	44.70968
32	5	8,2,10,17,3,4	50	1436	44.875
33	4	1,35,13,31	46	1482	44.90909
34	2	9,18,22,14,32	50	1532	45.05882
35	7	23,30,37,27	42	1574	44.97143
36	6	33,19,12,29	46	1620	45
37	2	14,16,18,24,9	46	1666	45.02703
38	2	24,18,22,14,32	46	1712	45.05263
39	2	9,24,18,16	42	1754	44.97436
40	5	40,8,17,10	50	1804	45.1
41	1	7,42,28,36	38	1842	44.92683
42	1	15,7,28,6	42	1884	44.85714
43	1	7,15,6	46	1930	44.88372
44	7	23,38,30,37,39,27	50	1980	45
45	6	29,12,19	46	2026	45.02222
46	6	33,19,12	34	2060	44.78261
47	3	5,34,31	34	2094	44.55319
48	1	6,36,28,42	42	2136	44.5
49	4	11,1,31,26	50	2186	44.61224
50	1	7,42,28,36	38	2224	44.48
51	2	16,14,9,24,32,18,22	54	2278	44.66667
52	6	29,33,12,19	46	2324	44.69231
53	5	8,4,2,3,17,20,10,40	54	2378	44.86792
54	4	26,11,1,13,35,31	46	2424	44.88889
55	1	6,42,7,36,28,15	60	2484	45.16364
56	3	25,21,34,41,5	46	2530	45.17857
57	6	19,12,33,29	46	2576	45.19298
58	7	27,39,38,37,23,30	50	2626	45.27586
59	1	42,6,7,28,36,15	60	2686	45.52542
60	5	8,2,4,3,20,17,10,40	54	2740	45.66667
61	2	16,14,9,24,32,18,22	54	2794	45.80328

62	7	30,23,38,37,39,27	50	2844	45.87097
63	4	26,1,35,31,13,11	46	2890	45.87302
64	3	41,25,21,34,5	46	2936	45.875
65	6	29,19,33,12	46	2982	45.87692
66	1	15,28,36,7,42,6	60	3042	46.09091
67	5	40,10,17,20,3,4,8,2	54	3096	46.20896
68	4	11,13,31,35,1,26	46	3142	46.20588
69	7	27,38,39,23,37,30	50	3192	46.26087
70	2	16,9,32,22,18,24,14	54	3246	46.37143
71	2	16,14,18,22,9,24,32	54	3300	46.47887
72	6	33,12,19,29	46	3346	46.47222
73	3	25,21,34,41,5	46	3392	46.46575
74	7	30,27,39,23,38,37	50	3442	46.51351
75	1	6,42,7,36,28,15	60	3502	46.69333
76	7	37,39,38,27,23,30	50	3552	46.73684
77	5	8,4,2,3,17,20,10,40	54	3606	46.83117
78	3	25,21,34,41,5	46	3652	46.82051
79	1	6,42,7,36,28,15	60	3712	46.98734
80	2	16,22,18,32,14,24,9	54	3766	47.075
81	4	11,13,31,35,26,1	46	3812	47.06173
82	6	29,19,33,12	46	3858	47.04878
83	7	30,23,27,37,38,39	50	3908	47.08434
84	5	8,40,4,10,2,20,3,17	54	3962	47.16667
85	1	15,28,7,6,42,36	60	4022	47.31765
86	3	5,41,34,21,25	46	4068	47.30233
87	2	14,9,24,32,18,22,16	54	4122	47.37931
88	4	26,1,35,31,13,11	46	4168	47.36364
89	7	38,27,39,30,37,23	50	4218	47.39326
90	6	12,33,29,19	46	4264	47.37778
91	1	6,7,15	42	4306	47.31868
92	6	29,33,12,19	46	4352	47.30435
93	3	41,34,25	38	4390	47.2043
94	5	3,2,4,8,17	46	4436	47.19149

95	4	26,35,31	42	4478	47.13684
96	2	9,24	26	4504	46.91667
97	7	39,38,37,30	50	4554	46.94845
98	5	17,20,10,8	54	4608	47.02041
99	1	6,42,36,28	42	4650	46.9697
100	5	2,3,4,8,10	46	4696	46.96
			4696		

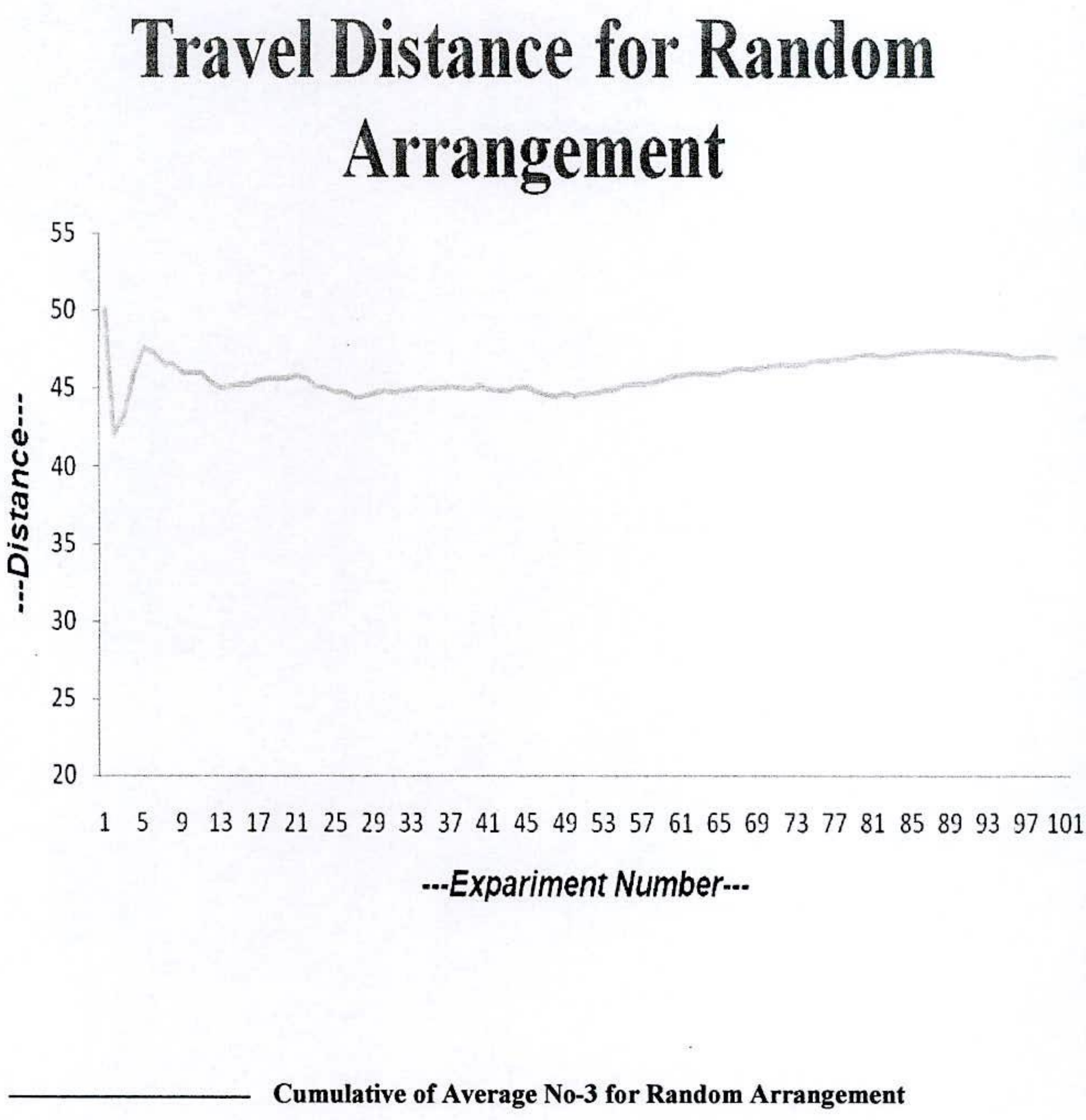


Figure No 4.9 : Travel Distance for Random Arrangement

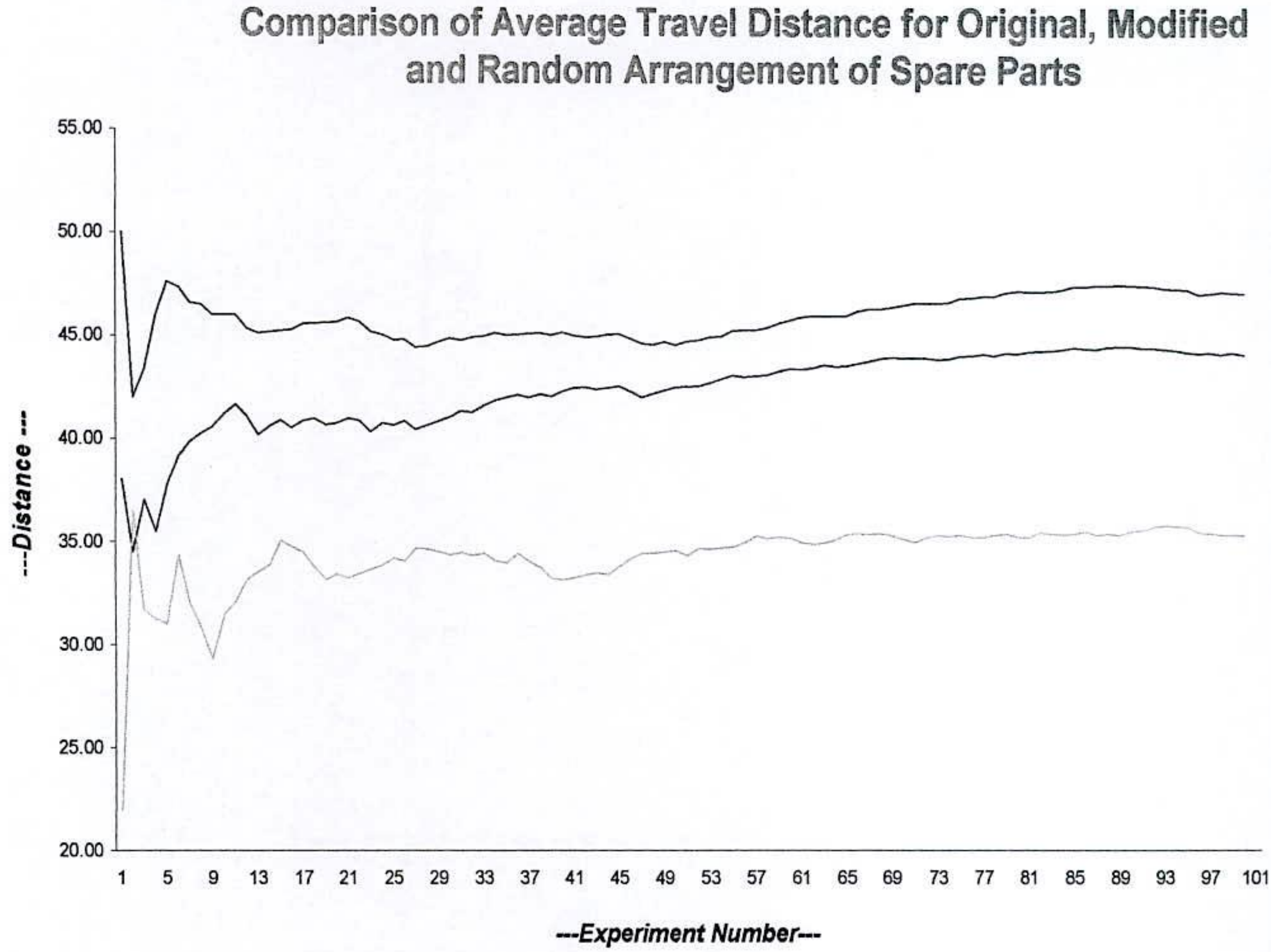
Table 4.18: Comparison of Cumulative Average No-1, 2, 3 for Original, Modified and Random Arrangement from Simulation Result

Experiment	Maintenance type	Spare –parts	Original Average No-1	Modified Average No- 2	Random Average No- 3
1	2	9,24,18,22,14	38	22	50
2	6	33,19,12	34.5	36.5	42
3	2	9,18,22,14	37	31.66667	43.33333
4	5	3,4,20,10,17	35.5	31.25	46
5	7	23,38,37,39	37.8	31	47.6
6	6	12,29,19	39.16667	34.33333	47.33333
7	2	32,22,24,9	39.85714	32	46.57143
8	2	9,18,16,22,14	40.25	30.75	46.5
9	2	32,24,16,9	40.55556	29.33333	46
10	6	12,29,19,33	41.2	31.5	46
11	4	11,1,35,13	41.63636	32.09091	46
12	3	25,21,5,34	41.08333	33.16667	45.33333
13	4	31,26,35	40.15385	33.53846	45.07692
14	4	11,1,13,31	40.57143	33.85714	45.14286
15	6	29,33,12,19	40.86667	35.06667	45.2
16	5	2,8,4,17	40.5	34.75	45.25
17	7	38,30,27,39	40.82353	34.47059	45.52941
18	2	14,16,18,22	40.94444	33.77778	45.55556
19	2	32,14,18	40.63158	33.15789	45.57895
20	4	1,26,11,13	40.7	33.4	45.6
21	7	23,27,38,37	40.95238	33.2381	45.80952
22	4	26,13,31	40.81818	33.45455	45.63636
23	1	7,28,6,42	40.30435	33.65217	45.13043
24	1	7,28,36,6	40.70833	33.83333	45
25	3	25,21,34,41	40.6	34.2	44.72
26	7	23,30,39	40.80769	34.03846	44.76923
27	6	12,19,33	40.40741	34.66667	44.37037

28	4	11,1,35,26	40.60714	34.64286	44.42857
29	7	23,38,30,27	40.7931	34.48276	44.62069
30	7	27,39,38,30	41	34.33333	44.8
31	1	15,42,28,6	41.29032	34.45161	44.70968
32	5	8,2,10,17,3,4	41.21875	34.3125	44.875
33	4	1,35,13,31	41.54545	34.42424	44.90909
34	2	9,18,22,14,32	41.79412	34.05882	45.05882
35	7	23,30,37,27	41.94286	33.94286	44.97143
36	6	33,19,12,29	42.08333	34.41667	45
37	2	14,16,18,24,9	41.94595	34.02703	45.02703
38	2	24,18,22,14,32	42.10526	33.71053	45.05263
39	2	9,24,18,16	42	33.20513	44.97436
40	5	40,8,17,10	42.225	33.125	45.1
41	1	7,42,28,36	42.41463	33.2439	44.92683
42	1	15,7,28,6	42.42857	33.35714	44.85714
43	1	7,15,6	42.32558	33.46512	44.88372
44	7	23,38,30,37,39,27	42.40909	33.38636	45
45	6	29,12,19	42.48889	33.77778	45.02222
46	6	33,19,12	42.21739	34.15217	44.78261
47	3	5,34,31	41.95745	34.42553	44.55319
48	1	6,36,28,42	42.125	34.41667	44.5
49	4	11,1,31,26	42.28571	34.4898	44.61224
50	1	7,42,28,36	42.44	34.56	44.48
51	2	16,14,9,24,32,18,22	42.45098	34.31373	44.66667
52	6	29,33,12,19	42.5	34.65385	44.69231
53	5	8,4,2,3,17,20,10,40	42.64151	34.62264	44.86792
54	4	26,11,1,13,35,31	42.83333	34.68519	44.88889
55	1	6,42,7,36,28,15	43.01818	34.74545	45.16364
56	3	25,21,34,41,5	42.92857	34.92857	45.17857
57	6	19,12,33,29	42.96491	35.22807	45.19298
58	7	27,39,38,37,23,30	43.01724	35.13793	45.27586
59	1	42,6,7,28,36,15	43.18644	35.18644	45.52542
60	5	8,2,4,3,20,17,10,40	43.3	35.15	45.66667

61	2	16,14,9,24,32,18,22	43.29508	34.93443	45.80328
62	7	30,23,38,37,39,27	43.33871	34.85484	45.87097
63	4	26,1,35,31,13,11	43.49206	34.90476	45.87302
64	3	41,25,21,34,5	43.40625	35.0625	45.875
65	6	29,19,33,12	43.43077	35.32308	45.87692
66	1	15,28,36,7,42,6	43.57576	35.36364	46.09091
67	5	40,10,17,20,3,4,8,2	43.67164	35.32836	46.20896
68	4	11,13,31,35,1,26	43.80882	35.36765	46.20588
69	7	27,38,39,23,37,30	43.84058	35.28986	46.26087
70	2	16,9,32,22,18,24,14	43.82857	35.1	46.37143
71	2	16,14,18,22,9,24,32	43.8169	34.91549	46.47887
72	6	33,12,19,29	43.83333	35.15278	46.47222
73	3	25,21,34,41,5	43.75342	35.28767	46.46575
74	7	30,27,39,23,38,37	43.78378	35.21622	46.51351
75	1	6,42,7,36,28,15	43.90667	35.25333	46.69333
76	7	37,39,38,27,23,30	43.93421	35.18421	46.73684
77	5	8,4,2,3,17,20,10,40	44.01299	35.15584	46.83117
78	3	25,21,34,41,5	43.9359	35.28205	46.82051
79	1	6,42,7,36,28,15	44.05063	35.31646	46.98734
80	2	16,22,18,32,14,24,9	44.0375	35.15	47.075
81	4	11,13,31,35,26,1	44.14815	35.18519	47.06173
82	6	29,19,33,12	44.15854	35.39024	47.04878
83	7	30,23,27,37,38,39	44.18072	35.3253	47.08434
84	5	8,40,4,10,2,20,3,17	44.25	35.29762	47.16667
85	1	15,28,7,6,42,36	44.35294	35.32941	47.31765
86	3	5,41,34,21,25	44.27907	35.44186	47.30233
87	2	14,9,24,32,18,22,16	44.26437	35.28736	47.37931
88	4	26,1,35,31,13,11	44.36364	35.31818	47.36364
89	7	38,27,39,30,37,23	44.38202	35.25843	47.39326
90	6	12,33,29,19	44.38889	35.44444	47.37778
91	1	6,7,15	44.31868	35.47253	47.31868
92	6	29,33,12,19	44.32609	35.65217	47.30435
93	3	41,34,25	44.25806	35.73118	47.2043

94	5	3,2,4,8,17	44.19149	35.67021	47.19149
95	4	26,35,31	44.12632	35.66316	47.13684
96	2	9,24	44.0625	35.39583	46.91667
97	7	39,38,37,30	44.08247	35.34021	46.94845
98	5	17,20,10,8	44.02041	35.28571	47.02041
99	1	6,42,36,28	44.08081	35.27273	46.9697
100	5	2,3,4,8,10	43.98	35.23	46.96



Cumulative of Average No-1 for Original Arrangement

Cumulative of Average No-2 for Modified Arrangement

Cumulative of Average No-3 for Random Arrangement

Figure No : 4.10 Comparison of average travel distance for Original, Modified and Random Arrangement of Spare Parts

4.3 Experimental Results

Cumulative of Average No-1 for Original Arrangement in figure no-4.7 show that it's travelling distance maximum is 43 and minimum is 37. Travelling distance of Cumulative range is 37 units to 43 units.

Cumulative of Average No-2 for Modified Arrangement in figure no-4.8 show that it's traveling distance maximum is 38 and minimum is 22. Travelling distance of Cumulative range is 22 units to 38 units.

Cumulative of Average No-3 for Random Arrangement in figure no-4.9 show that it's traveling distance maximum is 50 and minimum is 42. Travelling distance of Cumulative range is 42 units to 50 units.

From figure no- 4.10 we can state that Traveling distance of Cumulative of Average No-2 for modified system is lowest distance area than Travelling distance of Cumulative of Average No-1 for Original system and Travelling distance of Cumulative of Average No-3 for Random system others two system. Modified system is more efficient than others two system.

CHAPTER- 5

Conclusion

In the present research study we have seen that the spare parts required for a maintenance work is a sub-set of a super – set and if it is possible to identify the super set, it will be possible to keep this super-set in one place that will reduce the searching time and also reduces the travel distance. In the present simulation study it is found that on the average 20% of the travel distance is reduced if we keep the spare parts demanded for a particular maintenance type at the same place.

For further study, the developed model can be extended for multi rack warehouse system.

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