Redesign of the Layout and the Materials Flow of a Production Plant

A Master Thesis Conducted at the Production Plant of Moxba-Metrex

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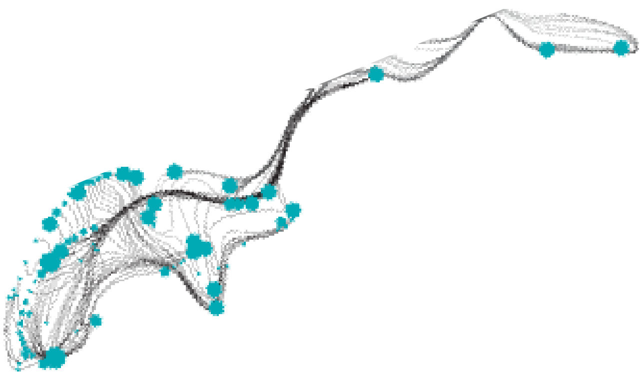

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Preface

Upon completion of this thesis, I am finishing the master program in Industrial Engineering and Management at University of Twente, Enschede. I look back the whole master program with a smile and confidence for the fact that I have learnt a lot; I have gained useful knowledge and work and life experience that have made me look the future with pride and optimism. I am also left with the enduring memories of the city of Enschede, the city I have experienced another facet of life in.

Glory be to the almighty God who has been the sources my health and strength. I would also like to take this opportunity to thank those who made this thesis possible. First of all my supervisors: Matthieu van der Heijden and Peter Schuur, I sincerely thank you for your willingness to be my supervisors and for all your guidance and critical review of my work.

I am also grateful to the people at Moxba-Metrex. I would like to express my gratitude to René, the general manager, who have arrange everything to make this thesis possible and whom I enjoyed discussing my work with. It is also my pleasure to thank to Dick, the plant manager, who helped me formulate the assignment, and for his guidance and cooperation on my visits to the plant. Leon, thank you too, you facilitated my work by providing the necessary data and information on time.

My sincere thanks also go to all my friends and fellow students who, without them, the two years master program would have felt longer.

Desta A. Hailemariam,
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Management Summary

Moxba-Metrex is undergoing changes. The changes mainly arise from three areas: from the need to improve the inefficiencies in the existing logistic processes, from the introduction of new lines of products, and from the need to build new facilities in view of expanding some of the existing facilities. This research has focused on identifying and improving the inefficiencies related to the logistic processes, developing improved layouts of the existing and new departments, and designing the material flow paths connecting the departments so that the handling and transportation efforts are minimized.

We started the research by investigating and analyzing the existing logistic processes. Based on the location of some of the processing machines, we took two scenarios. We followed Muther's systematic layout planning (SLP) as a procedural solution approach, and applied a pair-wise exchange improvement algorithm to develop layouts of the existing and new departments for both scenarios. We then determined the locations of the machines within each department, the locations of the docks of the warehouses, and the input/output points. We also designed the material flow paths connecting the departments for both scenarios using the shortest r-flow network approach introduced by Chhajed and Montreuil.

After developing the detailed layouts of the departments, we calculated the transportation cost of producing a big bag of finished materials for each scenario and compared their costs with cost of producing a big bag of finished materials in the existing layout. Finally, we selected the layout that should be implemented from these two scenarios using the transportation cost and other qualitative criteria.

The main conclusions of our research are:

1. The inefficiencies in the logistic processes arise from three areas:

    - There is no separate receiving area reserved for the incoming materials. As a result the incoming materials are directly stored in random locations in the warehouses which in turn causes the handling and relocation of materials during the retrieval of the materials to be high.

    - There is no temporary storage area for the work-in-processes that the work-in-processes are transported back to the warehouses for temporary storage. This is long distance transportation which needs a lot of handling and transportation efforts.

    - Some facilities (facilities required for washing, cleaning, and inspection of the bins) which are required for consecutive processes are located in different locations. As a result the materials which have been processed in one of these facilities have to be transported for long distances to get them to the next facility.

2. The inefficiencies in the logistic processes can be improved in two ways:

    - Providing temporary storage areas for the receiving of the incoming materials and for the work-in-processes. The separate receiving area can be used for the temporary storage of incoming materials and can give the workers time to identify the types of the incoming materials, and time to arrange their storage locations. The temporary storage for the work-in-processes can avoid the transportation of the work-in-processes back to the warehouses.

    - Combining the facilities that are required for the consecutive processes in single locations. By locating the facilities required for consecutive processes together, the transportation and handling efforts required for moving the materials among the consecutive processes are reduced.

3. The following table summarizes the total distance materials are transported every day and the transportation cost of producing a big bag of finished materials for the existing layout and the layouts from the two scenarios.

Layout options	Transortation distance per day	Tranportation cost per meter	Big bags produced each day	Internal transporation cost of producing a big bag of finished product
Existing layout	30360	€ 0.13	31	€ 127.32
Scenario 1 (new Plan)	27886	€ 0.13	46	€ 78.81
Scenario 2 (new plan)	30368	€ 0.13	46	€ 85.82

Comparing the transportation cost, we concluded that:

- Compared to the transportation cost of producing a big bag of finished materials in the existing layout (which is about €127), the layout of the departments in Scenario 1 improves this transportation cost per big bag of a finished material by about €48. About 16,790 big bags of materials being produced every year, this layout results in annual cost reduction of about €805,920.

- The transportation cost for producing a big bag of finished materials in Scenario 1 is €79 which is €7 less compared to that of Scenario 2. About 16,790 big bags of materials being produced every year, this layout results in annual cost reduction of about €117,530 compared to that of the layout in Scenario 2.

- Compared to the current location of the finished product warehouse, extending the finished product warehouse to make use of the space near the Production department brings an annual saving of €76,348.

Given the results of our study, we would like to give the following recommendations.

1. We believe that the layout of the departments from Scenario 1 (see Figure 6.14 on page 63) results in reasonable improvement (a saving of €48 per big bag of finished materials) in the transportation cost of materials. Therefore, we recommend Moxba-metrex for its implementation.

2. The reduction in the transportation cost partly comes from the improvements in the logistic processes. We therefore recommend that:

   - The separate areas for the receiving of the incoming materials and for the temporary storage of the work-in-processes be made available.

   - The facilities that are required for the consecutive processes be combined and located together at a single department.

3. Further research has to be made on the following areas:

   - The storage and retrieval systems of the materials should be improved, and the sizes of the internal packaging containers should be increased.

   - The capacities of the facilities in the Production departments should be improved to increase the utilizations of the facilities in the other departments (i.e., the Handling department and the raw material warehouse)

Contents

Chapter 1
Introduction

1.1 Company Description

Moxba-Metrex is a Dutch company, specialized in the responsible processing of spent catalyst and recycling of metal containing residues. Moxba started as a trading company in 1974 which was later joined by Metrex; as a result of the merger the company is transformed from just trading company to having its production site in Heerlen.

While Moxba (in Almelo) is responsible for the commercial activities, i.e., purchasing of the spent catalysts from refineries around the world, arranging the transportations for the incoming and outgoing materials, and selling of the processed products, Metrex is solely responsible for the treatment and recycling of the spent catalysts and/or metallic residues. The company also offers services such as arranging documents, licenses, the organization of transport and waste projects, and general consultancy services.

The production plant

The existing production plant in Heerlen treats and recycles a range of spent catalysts and/or metallic residues in the two main processing ovens: the Fluid Bed Oven (FBO) and the Rotary Tube Oven (RTO). The incoming materials are temporarily stored in a raw material warehouse (RM-Warehouse) until they are ready for treatment and recycling. The treated materials are stored in a finished product warehouse (FP-Warehouse).

The materials that are treated in these two ovens are different and they require different processes. The process charts of these materials are depicted in Figure 1.1.

(a)

(b)

Figure 1.1: The process chart for the materials treated in the (a) FBO and (b) RTO

The processing departments

There are basically two processing departments – the Handling department and the Production department. The machines required for the pre-treatment process – the banker, the sieve machine, shredder, and separator – are located in the Handling department; the FBO and RTO are located within the Production department. The processing of the spent catalysts starts in the Handling department where the sampled incoming materials are sieved and mixed to facilitate the thermal treatment.

In the Production department, the mixed materials are thermally treated in a fluidized bed oven (FBO). The final outputs coming out of these processes are metal-concentrated semi-finished materials, which are now ready to be transported for the final process in another factory.

Logistical processes

As can be seen from Figure 1.1 (b), the materials that need to be treated in the RTO don't require the pre-treatment processes such as sampling, sieving, and mixing; and their process flow is simple: from the RM-Warehouse to the RTO and then from the RTO to the FP-Warehouse. Here we present the processes that are accompanied by handling and/or transportation of the materials.

Receiving of the incoming material

The incoming materials come in three forms of containers: drums (barrels), bins, or big bags. These materials are directly stored randomly in the RM-Warehouse in a kind of block stacking until they are required by the subsequent processes.

Sampling and Analysis

Every incoming material has to be sampled to know the percentage of the metallic contents that the spent catalyst contains; to do this every bin or barrel has to be retrieved from its temporary storage place, be lifted down by the forklift to the floor, open the lid, take a sample that will be taken to the laboratory, close the lid, and then return it to its previous location. In the laboratory, the samples are analyzed for their metallic contents; as a result of the analysis the percentage of metals that each bin, drum, or big bag contains is known and this result is used as an input for mixing.

Sieving and Separation

All the incoming materials are not treated and recycled in the Metrex. There are certain materials such as the ceramics that are not treated in the ovens. These materials need to be separated before the spent catalysts go to the mixers; sieving is used to separate the ceramics and other waste materials from the other materials that can be fed into the mixers. In addition, the spent catalyst may come in large lumps that these materials need to be broken into pieces in the shredder before they are fed into the mixers.

Mixing

As a result of the sampling and analysis, the metallic contents of the different bins, drums, or big bags are identified. When a catalyst with certain percentage of the metallic elements is required to be produced, the contents in different bins, drums, or big bags have to be mixed to produce the required percentage. The materials that come out of the mixers are now ready to be treated in the FBO.

The Demand and Supply of the materials

The spent catalysts are purchased from refineries all over the world. Several reasons have made the forecast of incoming materials uncertain. First, even though some of the suppliers are known, because there is no binding contract, it is not easy to forecast the volume of incoming materials from each supplier in advance. Second, because the spent catalysts are 'waste products' from the refineries, the quality of the incoming materials is uncertain. Moreover, since most of the materials are bought from other countries, transporting these materials needs a long time and is always uncertain. For the aforementioned and other reasons, there is always a need to look for new suppliers and new markets.

The materials treated in the plant in Heerlen are not final products – they are semi-processed metal-concentrated materials that need further processing. Most of the materials treated in Metrex are shipped to a leaching plant in Thailand which solely processes these materials to finished materials. So, ideally, a batch of materials treated in Metrex can be shipped to Thailand right after it is sampled. But, in practice the materials have to wait until the result of the analysis of the samples from the external samplers is known.

1.2 Research Plan

1.2.1 Problem Description

The existing facilities in Metrex are used for treating and recycling of two groups of materials whose process chart is shown in Figure 1.1. The company is planning to treat and recycle other new lines of products. These products require different treatment ovens. Currently, other people in the company are working on a project to install these additional treatment ovens called rotary batch ovens (RBOs). Moreover, there is a plan to build a new warehouse for the raw materials larger than the existing one. As a result of the construction of the new warehouse and the introduction of the additional treatments ovens, the locations of some of the processing facilities should be redesigned. Besides, there is a feeling that there are inefficiencies in the existing logistic processes related to receiving, storing, sampling, and handling of the materials. It is obvious that the introduction of the new facilities and redesign of the locations of existing facilities will have a direct impact on the material flows between these facilities and on the routing of the material handling trucks. To this end, there is a need to improve the logistic processes from the moment of receiving of the raw material to the moment of shipping the finished product to the customers while redesigning the layout of the facilities.

1.2.2 Objective of the Research

While installing the new ovens and building the new warehouse, it is valuable to investigate if changes in the layout of the facilities and the flow of the materials between these facilities are necessary to comply with the expansion. The goal of the research is therefore to determine the layout of the facilities keeping the expansion into account, and to redesign the logistical processes and practices and their material flows.

1.2.3 Research Questions

Figure 1.2 outlines the framework of the research. Based on the framework the following research questions are developed to structure the research.

I. Analysis of the existing processes, the facilities/departments required for these processes, the layout of the facilities, and the material flows between these facilities

The first step of the research is to understand the processes required for the treatment and recycling of the materials and the facilities/departments where these processes are carried out in. The layouts of the production facilities and the flow of materials between them have a big impact of the total production cost. Therefore, at this stage, we need to know the facilities whose locations are to be determined in the new layout and the processes which require improvement. As a result, we formulate the following research questions:

1. *What are the existing facilities whose locations are to be determined in the new layout? What new facilities may be required? What are the sizes and shapes of these facilities? What is the amount of the materials flow between each pair of facilities each day?*
2. *What logistic processes need improvement/modification in the new plan?*

II. Solution approaches to the layout problem and material flow designs

After identifying the facilities and the materials flows between each pairs of facilities, the next step is to look for solution approaches for our research problem. At this stage we do a literature review in search of models and algorithms for our problems. To this end, we state the following questions:

3. *What solution approaches can be used to solve our layout problem?*

4. *What models can be used for the design of material flow between each pairs of facilities*?

III. Improvements in the Logistic processes

While redesigning the layout and materials flows, some logistic processes and practices related the receiving, sampling, storing, and sieving of the incoming materials need to be analyzed in search of improving the materials handling requirements. Therefore, following research question should be answered.

5. *How should the receiving, sampling, storing, and sieving of the incoming materials be modified to comply with the new layout and material flows?*

IV. Applying the chosen solution approaches

Once the solution approaches for our research problem are chosen, the next step is to apply them for our research. At this stage we determine the location of the facilities in the new layout – we develop alternative layouts from which we choose one for implementation. For the chosen layout, we determine the location of the machines and the location of input/out points within each facility. Finally, we design the flow of the materials between each pairs of facilities. Hence, we formulate the following questions:

6. *Where should the facilities/departments be located in the new layout?*
7. *Where should the machines and input/output points be located within each facility?*
8. *How should the materials flow network look like?*

V. Implementation of the new plan

The final phase of the assignment is to provide recommendation on how the new plan should be implement.

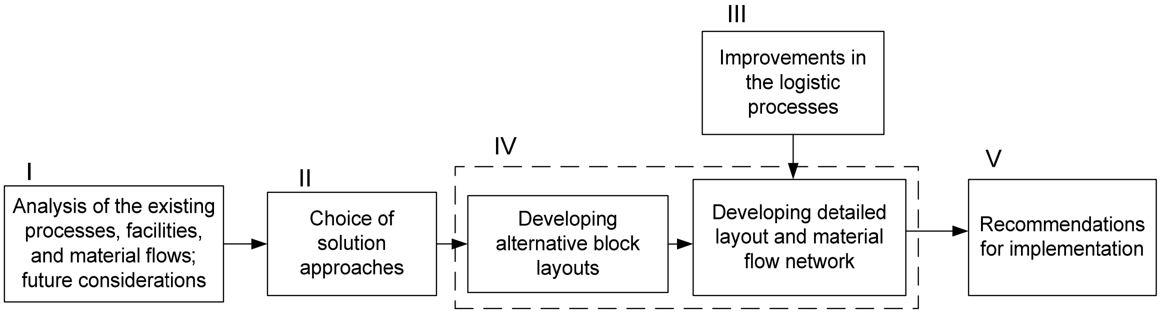


Figure 1.2: Framework of the research

1.3 Research Approach

We have divided the research into a number of research questions. The research approach is used as structure to answer these questions.

In the first groups of research questions we describe the existing processes, layout, and materials flow using descriptive diagrams such as processes flow diagrams, layout diagrams, and material flow diagrams. Meanwhile, we collect data about the location of the existing facilities: the shape and floor area requirements, location restrictions, and practical limitations; we also study the flow of the materials between departments and present their amount in a flow-to chart. We also scrutinize these processes and practices to see if elimination, combination, or modification of these processes is sought.

Searching for appropriate literature is done in parallel with the first groups of research questions. After looking for alternative solution approaches to the layout and to the material flow problems, we propose the solution approaches that can solve our research problem.

We then work on improving the logistic processes related to receiving, sampling, storing, and sieving of the incoming materials. Using the information collected from the first groups of research questions and the proposed solution approaches, we develop alternative block layouts (relative location of the facilities in the available floor area). Once the relative locations of the facilities have been determined, we determine the location of machines within each department and the input/output stations for all departments. We finalize developing the detailed layout by designing the materials flow paths that connect the departments. We then make our final selection of the layout and the materials flow to be implemented. Finally, we present the recommendations for implementing the proposed solutions

1.4 Outline of the Report

The remainder of the research is organized as follows. In Chapter 2, we describe the existing processes, layout, and materials flow. We identify the facilities whose locations have to be determined in the new layout and the processes that need improvement. We do literature review and propose our solution approaches in Chapter 3. Chapter 4 presents the improvements to logistic processes. In Chapter 5, we apply the proposed solutions approaches to develop alternative layouts. Determining the locations of the machines and the pickup and drop-off stations within each department and designing the material flow paths between the stations are addressed in Chapter 6. Chapter 7 continues with presenting recommendations for implementations of the proposed solutions.

Chapter 2
Description of the Existing Situation

In this chapter, we describe the existing situation in relation with the layout and the materials flow. We introduce the departments or facilities whose locations should be determined in the new plan, and describe the processes that need improvements. We start with the introduction in Section 2.1. Section 2.2 describes the existing layout; Section 2.3 presents the flow of the bins. In Section 2.4, we describe the logistic processes. We estimated the transportation distance of transporting materials in the existing layout in Section 2.5. Finally, we wind up the chapter with conclusions.

2.1 Introduction

The overall performance of an industrial firm is significantly affected by the design of its manufacturing facility. A facility is an entity that facilitates the performance of any job. It may be a machine tool, a work centre, a manufacturing cell, a machine shop, a department, a warehouse, etc. A facility layout is an arrangement of everything needed for production of goods or delivery of services (Drira, Pierreval et al. 2007). A well-designed facility layout results in efficient material handling, small transportation times, and short paths. This, in turn, leads to low work-in-process levels, effective production management, decreased cycle times and manufacturing inventory costs, improved on-time delivery performance, and consequently, higher product quality (Ioannou 2007).

The efficiency of a layout is typically measured in terms of material handling (transportation) cost. The material handling costs are directly influenced by the distances a unit load must travel (Meller and Gau 1996; Heragu 1997). Moreover, an efficient layout results in an effective material flow path with no backtracking, congestion, undesirable intersections with other paths, and bypassing (Drira, Pierreval et al. 2007).

An effective flow within a facility includes the progressive movement of materials, information, or people between departments. The following principles have been observed to frequently result in effective flow: maximize directed flow paths and minimize flow. A directed flow path is an uninterrupted flow path progressing directly from origination to destination. An uninterrupted flow path is a flow path with no backtracking and that does not create congestion, undesirable intersections with other paths, and bypassing. Backtracking, as shown in Figure 2.1, is the movement of a part from one facility to another preceding it in the sequence of facilities in the flow-line arrangement (A. Drira *et. al*. 2007). Backtracking increases the length of the material flow path.

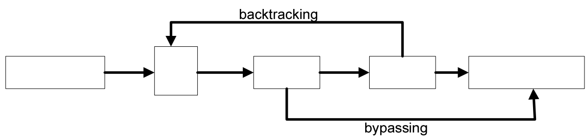


Figure 2.1: backtracking and bypassing

2.2 Overview of the Existing Layout

Figure 2.2 shows the block layout for the facilities in the production plant in Heerlen. The four departments which are used in processing and storing the products are: (1) Raw Materials Warehouse (RM-Warehouse), (2) the Handling department, (3) the Production department, and (4) Finished Product Warehouse (FP-Warehouse). Within the Handling department, there are two types of processing machines (two mixers and one sieve machine) and one auxiliary machine called banker – the banker is used as a buffer in which a large amount of incoming materials from the drums, bins, and big bags are emptied into. Within the Production department, there are two treatment ovens: the fluid bed oven (FBO) and the rotary tube oven (RTO)

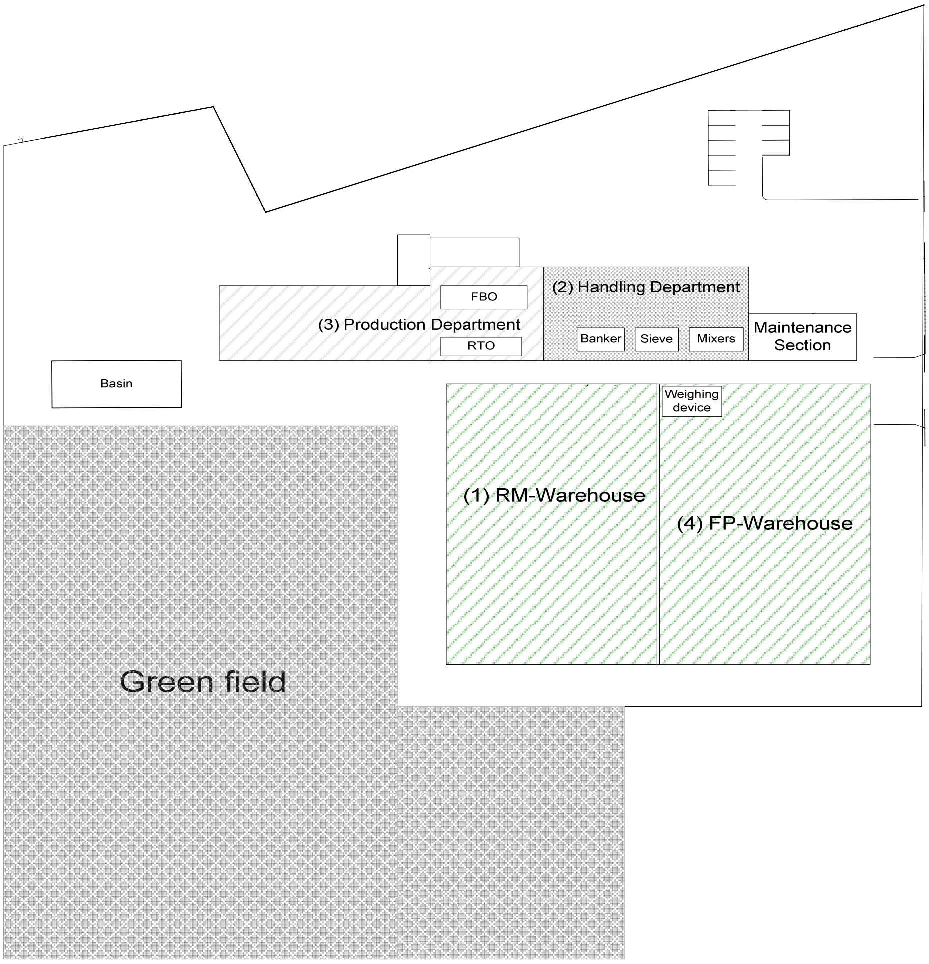


Figure 2.2: the layout of the existing departments of the production plant

Figure 2.3 (a) represents the simplified form of the existing layout for the four main departments. From the figure it is clear that the material flow principles (i.e. maximize directed flow paths and minimize flow) are violated – the transportation of the incoming materials into the RM-Warehouse bypassing the FP-Warehouse, the backtracking of the semi-processed materials from the Handling to the RM-Warehouse, the transportation of the finished products into the FP-Warehouse bypassing the RM warehouse, and the congestion created by these movements. As backtracking and bypassing flows increase the total distance that a unit load must travel, these movements should be eliminated or minimized. Since the material flow is directly influenced by the layout of the facilities, efficient rearrangement of the placements of the departments may result in significant improvement in terms of the distance that a unit load travels and ease the material flows. For instance, the placement of the departments shown is Figure 2.3 (b) would be an alternative arrangement of the departments to minimize the aforementioned problems.

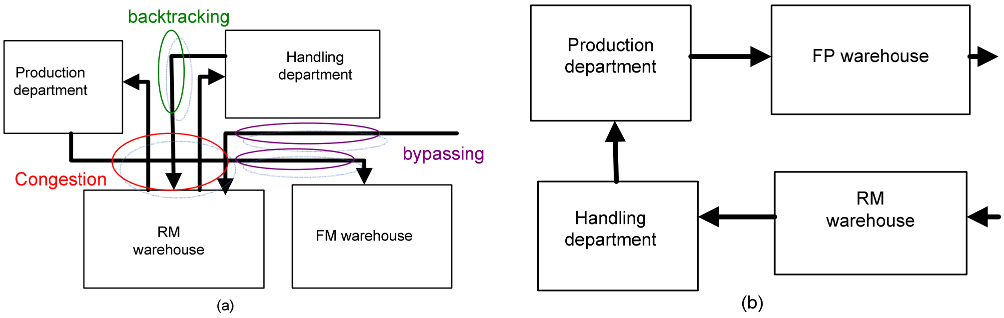


Figure 2.3: (a) the simplified overview of the existing layout and material flows and (b) possible improvement

On the other hand, at this moment, other people in Metrex are working on projects to build a new warehouse, and to install additional four production lines called Rotary Batch Ovens (RBOs). The size of the new warehouse is already known, but its location is not identified yet. Also, the sizes of the RBOs are known, but the area required to install these machines and their locations is yet to be determined.

When the new warehouse is built, the area which has been used for the old RM-Warehouse will be available for use for other facilities/departments.

In addition to the departments that are shown in Figure 2.2, there are other facilities that need to be built. Before describing these additional facilities, let's consider the types of materials processed in the plant, and how these materials flow through the departments.

Depending on the type of treatment that the materials require, the materials can be categorized into two groups: those that are treated in the RTO and those treated in the FBO. The flow of these two groups of materials is different. The flow of the first group is simple and straightforward as shown in Figure 2.4 (a).

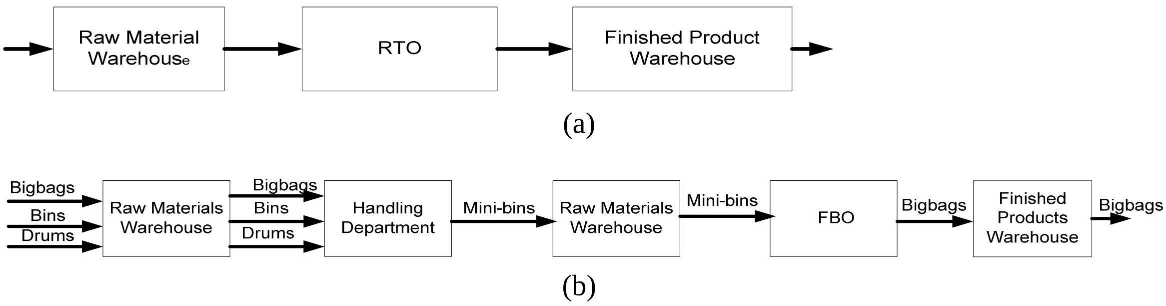


Figure 2.4: Schematic flow diagrams of materials treated in (a) RTO and (b) FBO.

The schematic flow of the materials that need to be treated in the FBO is shown in Figure 2.4 (b). These materials may come in three forms of containers: drums (barrels), bins, or big bags. The flow of these containers is similar: they start in the RM-Warehouse, they are then taken to the Handling department where their contents are emptied into the Banker; from this point on, these containers are not used for holding purpose (from the banker, the materials are transported to the sieve machine via a screw conveyor. In the sieve machine, materials that cannot be processed in mixer such as ceramics, wooden materials, and other wastes are separated. The fine materials that pass through the sieve are transported by a crew conveyor pass a shredder into the mixers). The materials coming out of the mixers are filled into special production bins called mini-bins; the mini-bins are then taken back to the RM-Warehouse. The contents of these mini-bins are emptied into the FBO is the Production department. The materials coming out of the FBO are contained in new big bags.

Here, it is important to note that because the materials are treated in a batch and because throughput of the Handling department is much greater than the throughput of the FBO, the materials coming out of the Handling don't directly go to FBO; instead, they are temporarily stored in RM-Warehouse. This practice has basic flaws: Firstly, as shown in Figure 2.5, the transportation of the Mini-bins from the Handling department to RM-Warehouse, and from the RM-Warehouse to the FBO causes backtracking and congestions on the routing of the forklifts. Secondly and more importantly, the efficiency of a layout is measured by the transportation cost that a unit load must travel (Meller and Gau 1996), and this practice has made the distance that the unit load must travel long. Thirdly, when the New Warehouse is built and the RM-Warehouse is not used anymore, taking the mixed materials back to the New Warehouse for temporary storage would require transportation of these semi-processed materials for long distances, which will be very expensive.

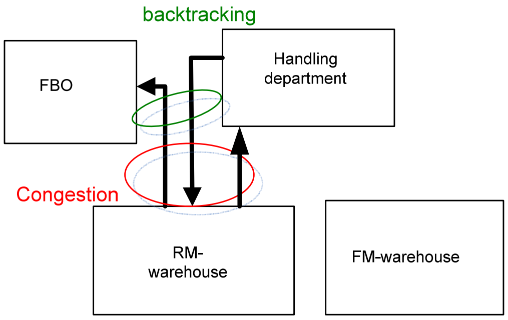


Figure 2.5: The schematic flow a unit load from RM-Warehouse to FBO

2.3 The Flow of the Bins

The bins are recyclable – all they need is cleaning, washing, and inspection. The bins, after their contents being emptied into the banker in the Handling department, are temporarily placed outside until they are cleaned and washed. Figure 2.6 shows the location of facilities used for cleaning, washing, and inspection of bins. The washing machine, which is used for cleaning and washing the bins, is placed in the Handling department, whereas the inspections are done at the rear end of the Production department (near to the basin) which is located far away from the Handling department. Furthermore, the bins, after their contents are emptied into the banker, don't directly go to the washing machine; instead they are moved to the outside for temporary storage until they are moved back to washing machine for cleaning. The bins, cleaned and washed, are then transported to the basin, which is located about 100m far from the washing machine, for leak inspection.

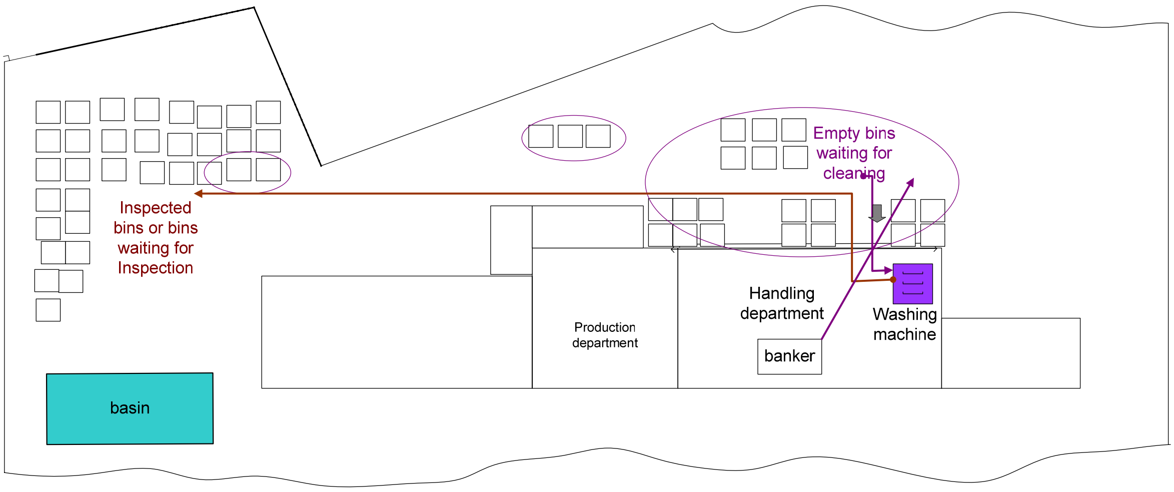


Figure 2.6: the storage location of bins and the locations facilities used for cleaning, washing, and inspection

2.4 The Logistic Processes

In lean philosophy activities in manufacturing setting can be classified as value-added and non-value-added activities. Melton (Melton 2005) defines non-value-added activities as activities or actions in the process that take service, resource, time, and space, but do not add to the value of the product itself or do not improve upon external customer requirements. These non value-added activities are regarded as 'waste'.

Value is added to the materials only at operations (the Sieve machine, the Mixers, and the FBO); none of the other activities (sampling, transportation, storage, loading, unloading, etc.), which seemingly are necessary, adds value to the finished product. It is true that, sometimes, waste is a necessary part of the process and cannot be eliminated; but it is also true that there is always a room for improvement. It is estimated that a unit load needs to be transported for about 450 meters from the time it is received until it is shipped; is all this distance necessary part of the process? Melton (Melton 2005) advocates that transportation is normally generated by poor processes or an inefficient plant layout; he adds that with better process layout and/or storage solutions, saving in transport distance and time can be attained. Here we shortly describe the processes that need improvements:

Receiving and Storage of Materials

The incoming materials are of various types. Some of the materials are processed a few days after their arrival, whereas others may stay for months in the raw materials warehouse. In the existing situations, incoming materials are stored randomly one over another (called block stacking) on the free spaces available. The problem with random allocation in block stacking is that one or more loads have to be relocated from their storage spot to retrieve another load (Park and Kim 2009). As a result of the random allocations, retrieval processes are invariably accompanied by large handling and transportation efforts.

The other flaw in the receiving and storage of materials is that there is no reserved location for receiving the incoming materials where they can be kept before they are put away. Before a product can be put away, an appropriate location must be determined. This is very important because where you store the product determines to a large extent how quickly and at what cost you can later retrieve it (Bartholdi and Hackman 2009).

Sampling, Sieving, and Separation of materials

There are certain materials (ceramic balls and other wastes such as woods) that come along with the materials that are treated in the FBO. The ceramic balls and the other wastes are not used for preparing the mixes and are not treated in Metrex; rather after collecting these ceramic balls in large containers, they are sold to other companies. Hence, before mixing, the ceramic balls and the other wastes are separated. The banker, the sieve machine, the separator, and the shredder used for this purpose are located in the Handling department. This means that the materials are transported for long distances from the raw material warehouse to the Handling department to get sieved, shredded, and separated.

Furthermore, the sampling is one of the laborious processes that need loading and unloading and transportation. For sampling, every bin, drum, or big bag requires to be retrieved from its location. The retrieval of these materials is accompanied by handling, transportation, and relocations of other materials.

The Weighing of the Big Bags

The location of machines or facilities that are used at some stage in processing materials has a big impact on the material flow. The weighing device is one of such facilities in our case. Every big bag of finished material has to be weighed. The weighing device for this purpose is placed in one corner of the FP-Warehouse. Each big bag has to be transported for approximately 40 meters for this purpose. Ideally, the big bags can be weighed just right after they are filled; so there is no obvious reason for placing the weighing device in the FP-Warehouse. Another point that makes locating the weighing device in the warehouse inefficient is that placing it in the warehouse causes the space utilization of the warehouse to be inefficient– the place where the device is located and the path (aisle) for the forklift that leads to the weighing device could have been used for storing the materials.

Sampling of the Finished Products

Sampling is one of the laborious routines in the production process. The samples for the finished materials are collected after the big bags are taken and stacked in the FP-Warehouse. To take the sample, either each big bag has to be opened and then tied or it has to be probed. In the former case, the opening and tying of the bags is time consuming and the workers are unnecessary wasting time in non-value added activities; in the latter case, the bags are punctured that their contents may be lost. Moreover, sometimes, because the big bags are placed in remote location, each sampling is accompanied by the relocation of other big bags – which cause unnecessary handling and movement of the materials.

2.5 Transportation Cost of the Existing Layout

The layout's efficiency is typically measured in terms of the material transportation and handling costs (Meller and Gau 1996; Heragu 1997) as expressed by Equation 2.1.

$$C_1 = \sum_i \sum_j (f_{ij}\, c_{ij}) d_{ij} \qquad (2.1)$$

Since it is difficult to determine exact c_{ij} values in Equation 2.1 for each pair of departments, approximate costs are assumed as opposed to the exact costs. For the time being, we assume the value of each c_{ij} is equal to 1 and consider the flow distance function (Equation 2.2) as surrogate cost function. Later, to evaluate the layout alternatives in the new plan, we will calculate the approximate value of the cost parameter. Since Equation 2.1 is a linear function of the cost parameter, its value will change linearly with the change in the value of c_{ij}.

$$C_2 = \sum_i \sum_j f_{ij}\, d_{ij} \qquad (2.2)$$

Table 2.1 shows the materials which require transportation, the average distance they are transported (d), and the quantity of the materials flow (f) every day. The distances (d) are rectilinear actual distances between pairs of departments. The flow data (f) is taken from material flow data in 2009 only for the existing materials. We assume that the amount flow will remain constant for over the coming years. In Table 2.1, we give the unit loads of each group of materials and the distance that each unit load travels. To this end, each day, materials are transported for about 30,360 meters by the forklifts.

Material type	Distance moved (d) in meters	Quantity (f)	f*d
Raw Materails (FBO)	153	90	13770
Raw Materails (RTO)	158	10	1580
Mixed materials	128	41	5248
Finished materials	127	31	3937
Bins	225	7	1575
Ceramics	80	5	400
Drums& Pallets	70	55	3850
		Total	**30360**

Table 2.1: the transportation and handling cost calculations

2.6 Conclusions

In this chapter, we have identified the departments whose locations have to be determined in the new plan. We will come up with the new departments and the relative locations of all the departments in Chapter 5.

In addition, we have discussed the logistic processes and practices that need improvements. The processes related to the receiving, sampling and sieving of the materials, the cleaning and inspection of the bins, the weighing of the finished products, and the way the materials are stored need improvements. We will come up with the improvements in Chapter 4.

The total distance the materials are transported and handled being the main criterion to evaluate the efficiency of a layout, we estimated the materials transportation per day of the existing layout to be 30,360 meters.

Chapter 3
Literature Review

In this chapter, we review the literature in relation to the design of facility layout and materials flow. We start by introducing the facility design problem in Section 3.1. Section 3.2 presents the models used to formulate the layout problem. In Section 3.3, we explain the solution approaches to the layout problem. Section 3.4 deals with layout of the machines and the locations of the input/output stations. We discuss the formulation and solution approach to the material flow network design in Section 3.5. In Section 3.6, we describe the criteria for evaluating layout alternatives. Section 3.7 discusses the data required for the layout decisions. After presenting the solution approaches for this research in Section 3.8, we close the chapter with conclusions.

3.1 The Facilities Design Problem

Researchers (Chhajed, Montreuil et al. 1992; Herrmann, Ioannou et al. 1995) classify the global problem of facility design into three interrelated tasks: (1) the layout problem – placing the manufacturing resources (machines, departments, or cells) within the available floor area (block layout), (2) the input/output station location, and (3) the determination of the network system to support material flow interaction between facilities. The layout problem is concerned with finding the most efficient arrangement of the facilities within the available floor area. Having the impact of material flow systems on the layout design described, some authors (Tompkins, White et al. 2003) suggest the simultaneous consideration of the first two design tasks; others adopted a sequential approach taking the complexity of the designs into account (Chhajed, Montreuil et al. 1992).

As presented by Drira and Pierreval (Drira, Pierreval et al. 2007), the layout problems addressed in scientific publications differ depending on such factors as: the workshop characteristics (e.g., the manufacturing systems, the facility shapes, the material handling system, and the layout evolution), the models (e.g., problem formulation, objectives and constraints), and the approaches used to solve them.

The output of the facility layout problem is a block layout, which specifies the relative location of each department. One then can perform further work to obtain the detailed layout, which specifies exact department locations, aisle structures, input/output (I/O) point locations, and the location of the machines/equipment within each department (Meller and Gau 1996).

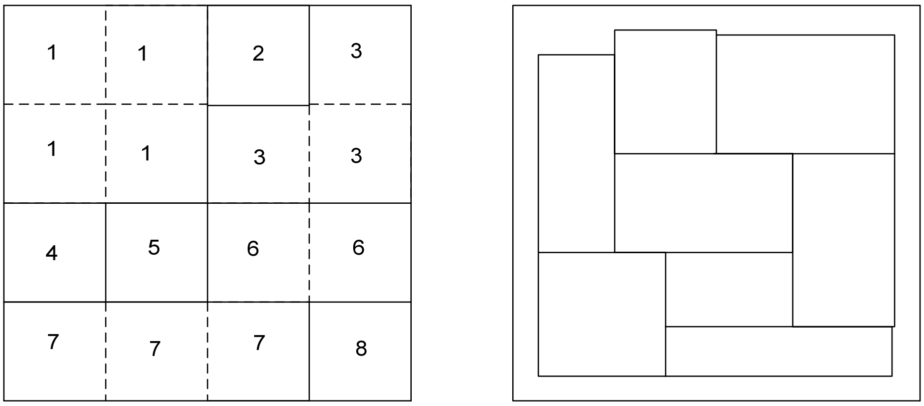
3.2 Mathematical Formulation of the Layout Problem

The objective of the layout design problem is to minimize the cost associated with projected interactions between departments. The interactions may reflect the cost of material-handling flows or the preference regarding adjacencies between departments, where the cost is calculated as the rectilinear distance multiplied by the material handling flow or adjacency score between the centers of department pairs. The problem is subject to two sets of constraints: department and floor area requirements and department location restrictions; that is, departments cannot overlap, must be placed within the facility, and some must be fixed to a location or cannot be placed in specific regions (Meller and Gau 1996; Castillo, Westerlund et al. 2005).

A layout can be represented either in a discrete or in a continuous fashion. With a discrete representation, an underlying grid is defined and all departments are composed of an integral number of grids. In a continuous representation, however, department dimensions are not restricted to an underlying grid pattern. Depending on the manner in which the problem is formulated, that is, discrete or continuous, the formulations found in the literature can lead to Quadratic Assignment Problems

(QAP) or Mixed Integer Programming (MIP), which are the most commonly encountered (Bozer and Meller 1997).

The associated optimization problem for the discrete representation, Figure 3.1 (a), is often addressed as QAP (Rosenblatt and Golany 1992; Drira, Pierreval et al. 2007). The plant site is divided into rectangular blocks with the same area and shape, and each block is assigned to a facility. On the other hand, the continuous representation of the layout, Figure 3.1 (b), is often addressed as Mixed Integer Programming Problems (Meller, Narayanan et al. 1998). All the facilities are placed anywhere within the planar site and must not overlap each other. The facilities in the plant site are located either by their centroid coordinates or by the coordinates of bottom-left corner, length and width of the facility.



(a) (b)

Figure 3.1: (a) Discrete and (b) Continuous representations

3.3 Solution Approaches

Heragu (Heragu 1997; Yang and Kuo 2003) and Yang and Kuo (Yang and Kuo 2003) argue that the layout problem has elements of both design and optimization problems. The layout design problem is ill-structured in the sense that quantitative as well as qualitative criteria must be considered. Considerable research has been published regarding the quantitative issue, which is primarily solved by analytical methods. However, an analytical approach usually yields a good solution to the described model, but not necessarily the real world problem. In the facility layout problem, there remain a number of non-quantifiable design objectives such as safety, security, noise control, flexibility in adjusting the layout, efficient movement of materials and personnel, ease of expansion, space utilization which must be considered in making the transition from a pure model to a practicable solution (Cambron and Evans 1991).

The solution approaches for the layout problem falls into two categories: algorithmic and procedural approaches. Algorithmic approaches usually simplify both the design constraints and objectives in order to reach a surrogate objective function, the solution of which can then be obtained. However, the resulting quantitative results often do not capture all the design objectives (Yang and Kuo 2003). Procedural approaches can incorporate both qualitative and quantitative objectives in the design process (Muther 1973). For these approaches, the design process is divided into several steps that are solved sequentially. However, procedural approaches have relied on experts' experience (Yang and Kuo 2003).

3.3.1 The Layout Improvement Algorithms

Several types of optimization approaches have been proposed in the literature: exact methods, such as branch and bound and approximated approaches, such as heuristics and meta-heuristics. They aim either at finding good solutions, which satisfies certain constraints given by the decision maker or at searching for an global or local optimum solutions given one or several performance objectives (Drira, Pierreval et al. 2007). Obtaining optimal solutions to the facility layout problem is not straightforward because the optimal solution approaches leads to either large-scale QAP or a large-scale mixed integer programming problem. Thus, most of the research has been aimed at developing heuristic procedures (Bozer, Meller et al. 1994).

Heuristic algorithms can be classified as construction type algorithms where a solution is constructed from scratch and improvement type algorithms where an initial solution is improved. Construction techniques produce an assignment based on the volume of trips between all pairs of departments per unit of time and the distances between all pairs of departments per unit time. Improvement procedures require an initial solution in addition to the input needed by the construction techniques. CRAFT (Computerized Relative Allocation of Facilities Technique) and MULTIPLE (MULTI-floor Plant Layout Evaluation) are popular improvement algorithms that uses pair-wise exchange (Bozer, Meller et al. 1994; Singh and Sharma 2006). Recently attentions have been focused on applying a Simulated Annealing approach to the layout problem. The great advantage of this is to avoid being caught in local optimal by sometimes accepting moves that worsen the objective function (Chwif, Barretto et al. 1998).

CRAFT uses a from-to chart as input data for the flow and attempts to minimize the material movement cost by pair-wise exchanges among departments. It starts with an initial layout, which represents the actual layout of an existing facility or a prospective layout developed by another algorithm, and look for improvement by pair-wise exchange of departments.

CRAFT begins by determining the centroids of the departments in the initial layout. The rectilinear distances between pair of department centroids are calculated and the values are stored in a distance matrix. It then considers all possible two-way or three-way department exchanges and identifies the best exchange, that is, the one that yields the largest reduction in layout cost. Once the best exchange is identified, CRAFT updates the layout according to the best exchange, and computes the new department centroids as well as the new layout cost to complete the first iteration. The next iteration begins with CRAFT once again the best exchange by considering all possible pair-wise exchanges in the updated layout. The process continues until no further reduction in layout cost can be obtained (Tompkins, White et al. 2003).

The limitation with CRAFT is that it can exchange only those departments that are either adjacent or equal in area. If two non-adjacent departments (with unequal areas) are exchanged, other departments must be "shifted"; otherwise, one of the departments being exchanged will be "split" (Heragu 1997). CRAFT is not capable of shifting the other departments, and splitting a department is not acceptable in a production facility (Tompkins, White et al. 2003).

3.3.2 The Systematic Layout Planning

A well known procedural solution approach for the layout problem is the Systematic Layout Planning (SLP), which is developed in the early 1970s by Muther (Muther 1973), is by far the most popular facility design approach in practice. A primary reason the SLP technique has remained popular for more than 30 years is its simple step-by-step approach to facility design (Tompkins, White et al. 2003). It consists of four phases: determining the location of the area where facilities will be laid out, establishing general overall layout, establishing detailed layout plans, and installing the selected layout. Of these phases, the second and the third phases are the most important. Establishing the general overall layout involves determining the flow of materials between facilities, examining special adjacency requirements, determining the space required for each facility, balancing it with the space available, incorporating practical constraints (e.g., budget, safety), and generating alternative layout plans (Heragu 1997).

Figure 3.2 outlines SLP procedure. It begins with the analysis of data collection fields including P (product), Q (quantity), R (routing), etc. to assure the validity of the input data at the design stage. In the flow material analysis (Step 2), all materials flow from all facilities are aggregated into a from-to chart that represents the flow intensity among departments. The step of 'activity relationships' (Step 3) performs qualitative analysis towards the closeness relationship decision among different departments.

The Step 4 positions departments spatially; those departments that have strong interaction and/or closes relationships are placed in proximity.

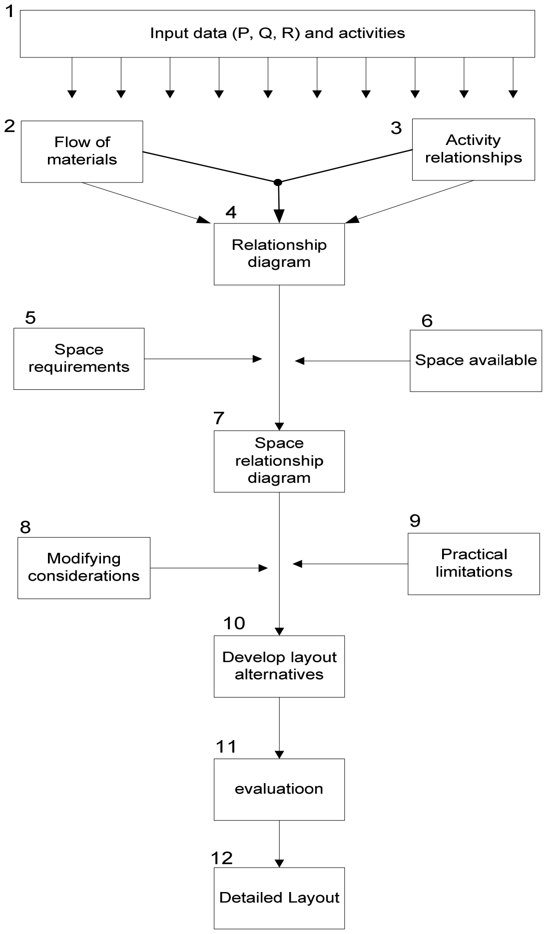


Figure 3.2: The Systematic Layout Planning Procedure.

The step of 'space requirements' (Steps 5 and 6) determine the amount of floor space to be allocated to each department. The 'space relationship diagram' adds departmental size information into the relationship diagram from step 4. Additional design constraints and limitation are considered before the start of block layout generation in Steps 8 and 9. Step 10 then develops layout alternatives as design candidates. Step 11 chooses the final design from these design candidates (Tompkins, White et al. 2003).

Once the relative position of each department is found, Step 12 follows with the detailed layout of the facilities. This includes locating the input/output locations, providing the layout and location of specific machines and equipments within the departments, determining the location of the docks in the warehouses, determining the flow of materials between departments, etc.

3.4 Layout of Machines and Locations of the Input/out Stations

3.4.1 Layout of Machines within Each Department

In principle, the layout of machines in each department can be determined in the same way the layout of the departments are determined. However, in most cases, the number of machines in each department is small that it is much easier to consider all possible layouts of the machines (enumeration method) and choose the best one based on the criteria being considered (Chhajed, Montreuil et al. 1992; Heragu 1997).

3.4.2 Locations of the Input/output Stations

Depending upon the particular case, an input/output station could be a door to a department, a floor location where unit loads enter and leave a department, or an automated transfer station integrated to autonomous robotic vehicle systems. In all cases, the locations of input/output stations have a strong impact on both the cost of flow among departments and the internal configuration of the departments.

While designing the input/output locations, it is important to decide how many stations are to be used for each department. Once the numbers of stations are identified, the next task is to specify all inter-station flows based on the station identified. This is similar to what is commonly done in specifying department flows for facilities layout problem, except that it is performed at the station level instead of the department level (Montreuil and Ratliff 1987). The objective is to obtain the set of locations which minimizes the total flow of materials on the materials flow network.

3.5 Material Flow Design

One of the important considerations in the design of a manufacturing facility is to determine the general flow pattern through the system for materials, parts, and the work-in-process inventory (Drira, Pierreval et al. 2007). The flow pattern refers to the overall pattern in which the product flows from beginning to end – that is, while it is being transformed from raw material through semi-finished product to the finished product.

Material flow between departments is a criterion often used to evaluate overall flow within a facility. A flow pattern typically consists of a combination of the four general flow patterns shown in Figure 3.3. An important consideration in combining the flow patterns shown in Figure 3.3 is the location of the entrance and exit. As a result of the plant layout, the location of the entrance (receiving department) and the exit (the shipping department) is often fixed at a given location and the flow within the facility confirms to these restrictions (Tompkins, White et al. 2003).

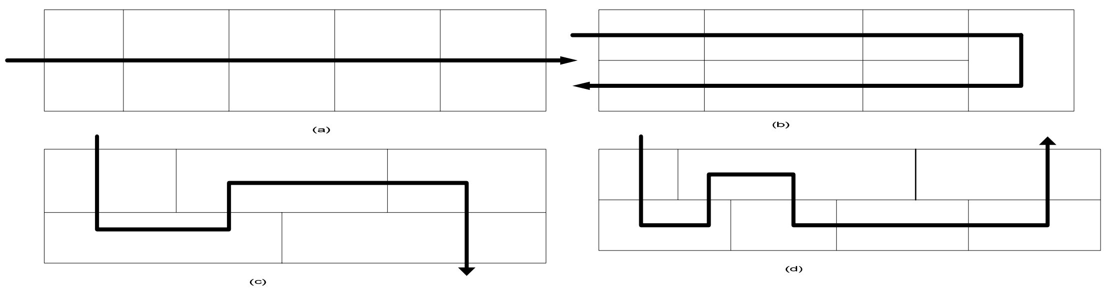


Figure 3.3: flow patterns – (a) straight line flow. (b) U-shape flow. (c) S-shape flow. (d) W-shape flow.

The general objective of the material flow network design is to minimize the sum of the fixed cost of network construction (fixed cost of path/aisle construction) and the variable cost of flows. Before making the network design decisions, there are certain things that need to be addressed (Chhajed, Montreuil et al. 1992). For example, the flow assumptions: Some situations require the interdepartmental material handling to occur along departmental boundaries (contours). On the other hand, the aisle structure may not be required to follow the departmental contours (free flow); direction: does the network permit unidirectional flow or can it support bidirectional flows? Distance metric used: when free flow is permitted, is the travel metric Euclidian, rectilinear, or some other norm?

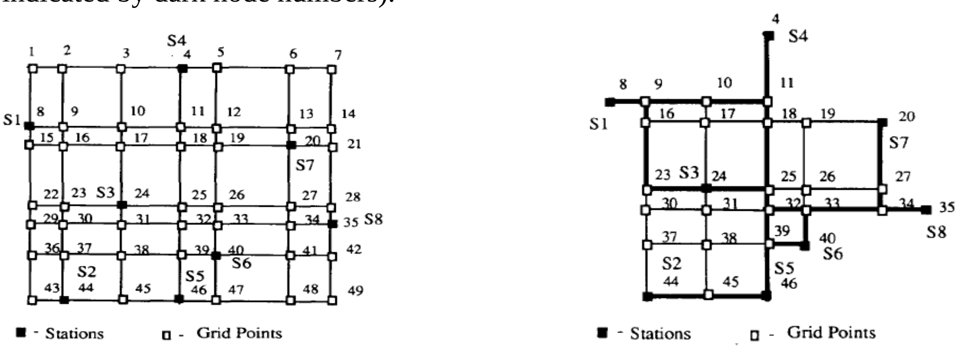
Chhajed and Montreuil (Chhajed, Montreuil et al. 1992) have developed a material flow design network model called the *Shortest rectilinear flow network problem (shortest r-flow network)* assuming free flow, an unidirectional, and the rectilinear travel norm. The model is shortly presented here. Let (a_i, b_i) be the x-coordinate and y-coordinate, respectively, of point *i*, then a path of length

$|a_i\text{-}a_j|$ $+|b_i\text{-}b_j|$ between input/output stations *i*, and *j*, consisting of arcs parallel to the axes is called an *r-path* (rectilinear length path*)*. Thus, the length of *r-path* is the rectilinear distance between the stations.

The objective is to minimize the cost of a network (fixed cost) which will permit flow between all pairs of stations which have flows between them, subject to the above assumptions. Since in such a network every flow takes an r-path, the variable cost (a function of distance traveled) is minimized when the length of the network (fixed cost) is minimized; and thus we focus on minimizing the fixed cost. The length of the network is taken as a surrogate objective for fixed cost; and hence, the objective is to minimize the total length of network (the sum of the arcs connecting the input/output stations of the departments in the network) of the r-flow network. The solution approach for the shortest r-flow network has three steps: the initialization, the simplification, and applying the algorithm.

Initialization

Given the locations (a_i, b_i) for each station on a two-dimensional coordinate system, draw a horizontal and a vertical line through each station. The intersection of each horizontal line and vertical line defines a grid point. The grid points, the station set and the collection of horizontal and vertical lines define a grid graph, G. The node set *V (G)* of this grid graph consists of the station set and the grid points (see Figure 3.5 (a) where the nodes are numbered 1 . . . . . 49 and the station locations are indicated by dark node numbers).



(a) (b)

Figure 3.5: (a) the flow set, station locations and the grid graph G, (b) reduced grid graph with the dark lines being part of the final solution.

Simplification

Some of the arcs in G can be removed without affecting the value of the solution to *shortest r-flow network*. For example, in Figure 3.5 (a), any flow using arcs from the set A = {(1, 2), (2, 3), (3, 4), (1, 8), (2, 9), (3, 10)} can use the arcs in the set {(8, 9), (9, 10), (10, 1 l), (4, 11)}. Thus the arcs in the set A can be deleted as shown in Figure 3.5 (b).

For each flow *f*, let *R (f, G)* represent the sub-graph formed by the intersection of G with the smallest rectangle (having sides parallel to the axes) enclosing *f*. Thus *R (f, G)* consists of precisely those arcs which may be used by *f* when some *r-path* is taken. For example, if G is the graph in Figure 3.5 (b) and *f*= (S3, S6) then *R (f, G)* will be the sub-graph induced by nodes {24, 25, 26, 31, 32, 33, 38, 39, 40}. For *f*= (S1, S3), *R (f, G)* will be the sub-graph induced by {8, 9, 10, 16, 17, 23, 24}.

Given a set of weights for every arc in G, the cost of a path is the sum of the weights of the arcs in the path. In designing the flow paths, each flow between any input/output stations is examined to see if both stations lie on the same horizontal or vertical line. Clearly, for such a case, the *r-path* for the pair is unique and it is the straight line segment joining the two stations. Thus all the arcs on this path will be in any optimal solution. We include these arcs in the final solution and set the cost of the arcs to zero. For example, in Figure 3.5 (b) the arcs on the unique path between (S4, S5) is in the optimal solution.

A unique *r-path* between two stations may exist in *R (f, G)* even when the two stations are not on the same line. This occurs if there is a single *r-path* between the stations in the rectilinear hull. In this case also, the unique r-path will be in the optimal solution.

After identifying those stations in the same line and those stations connected by a unique line, the network for the remaining stations is determined by the *Least Cost Algorithm*. If the all stations lie in the same line or are connected by unique lines, executing the algorithm may not be required.

Least Cost Algorithm

Assume that G is rectangular (otherwise add missing arcs and vertices and place a very high cost on these arcs) and that vertex A is the south-west vertex and B is the north-east vertex. Let there be M vertical lines and N horizontal lines in G. We create a directed grid graph D by directing the arcs in G as shown in Figure 3.6. An *r-path* in G is the same as a directed path in D from A to B. Number the nodes from 1 to *MN*, beginning with vertex A as 1 and moving from left to right and bottom to top (see Figure 3.6).

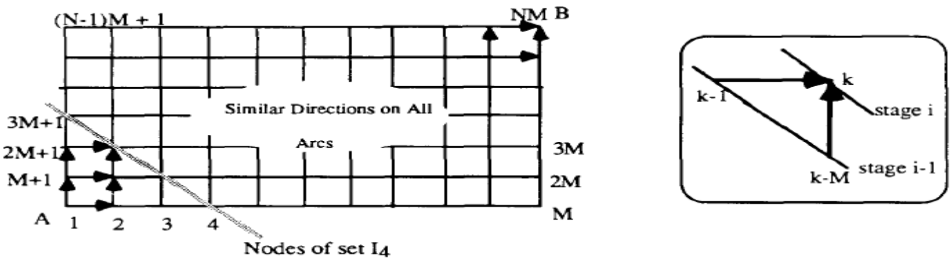


Figure 3.6: Grid graph with directions and a single DP representation

Define sets $I_1, I_2, \ldots, I_{M+N-1}$ recursively as follows:

$I_1 = \{1\}$.
$I_i = \{n: n \in V(D)$ and there exists a node $n' \in I_{i-1}$ such that there is a directed arc from n' to n in $G(D)\}$, for i =2, 3 . . . . . $M+N-1$. Let $w_{i,j}$ denote the weight on the arc from node *i* to node *j*. A recursive algorithm (dynamic programming) method to find the shortest directed path from A to B in D can be given follows. Let $f_i(k)$ denote the shortest directed path from A to k $\in I_i$.

$$f_1(1) = 0$$
$$f_i(k) = min\,\{f_{(i-1)}(k-1) + w_{k-1,k}\,, f_{(i-1)}(k-M) + w_{k-M,k}\}$$

The value for $f_i(k)$ for all $k \in I_i$ is found after determining $f_{i-1}(k')$ for all $k' \in I_{i-1}$. $f_{N+M-1}(NM)$ is the desired solution.

3.6 Layout Evaluation Criteria

3.6.1 Transportation and Handling Costs

The layout's efficiency is typically measured in terms of the material transportation and handling costs (Meller and Gau 1996; Heragu 1997) as expressed by Equation 3.1. These costs are approximated with the following parameters: c_{ij} (cost of moving a unit load of material unit distance between facilities *i* and *j*), interdepartmental flows, f_{ij} (the flow of materials from department *i* to *j*), and d_{ij} (the distance from department *i* to department *j*).

$$C_3 = \sum_i \sum_j C_{ij}\left(f_{ij} d_{ij}\right) \qquad (3.1)$$

This objective is based on the material handling principle that material handling costs increase with the distance the unit load must travel. The flow f_{ij} is a constant parameter. The objective is therefore to minimize the transportation distance by determining optimal locations of the departments.

Distances in Equation (3.1) are measured in variety of ways; here are two ways – the most accurate and widely used approximations: distance between input/output (I/O) points – this distance is measured between the specified I/O points of two departments and in some cases is measured along the aisles when traveling between the departments; centroid-to-centroid (CTC) – when the I/O points of the departments are not known, the department centroid is used to represent the department I/O point. For each of the distance measures mentioned above, rectilinear distance is the most common distance metric used (Meller and Gau 1996).

In our case, since the I/O points of each department are not known in advance, we use the centroid-to-centroid rectilinear distance given by Equation 3.2 to develop alternative layouts. We may use the actual aisle distance metric for evaluation purpose.

$$d_{ij} = |x_i - x_j| + |y_i - y_j| \qquad (3.2)$$

Where x_i and y_i denote the x and y coordinates of the centroid of department i, respectively.

Since it is difficult to determine exact c_{ij} values in Equation 3.1 for each pair of departments, approximate costs are assumed as opposed to the exact costs. Thus, if the same handling equipment is used for material transport, then the c_{ij}'s are all equal (Heragu 1997). In Moxba-Metrex the materials are transported by the same handling equipment (i.e., forklifts); hence, we assume the c_{ij}*'s* for all pairs of departments to be equal. Moreover, since c_{ij} is a function of different parameters (which includes apportioned fixed and variable costs of handling equipment, operating cost, associated labor cost, loaded and empty moves), determining the exact value is not easy. Hence, to develop the alternative layouts, we assume the value of each c_{ij} is equal to 1 and consider the flow distance function (Equation 3.3) as surrogate cost function. Later, to evaluate the layout alternatives in the new plan, we will calculate the approximate value of the cost parameter. Since Equation 3.1 is a linear function, its value will change linearly with the change in the value of c_{ij}.

$$C_4 = \sum_i \sum_j f_{ij}\, d_{ij} \qquad (3.3)$$

3.6.2 Other Criteria

The material transportation and handling costs described above represents the operating cost of a layout alternative. However, there are other additional criteria for final evaluation of layout alternatives. Lin and Sharp (Lin and Sharp 1999) provide a structured criterion set for plant layout evaluation problem. Here, we present some of the criteria that are relevant to our layout evaluation purpose.

1. Initial investment: Some of the layout alternative may use the existing facilities; others may require building of new facilities. When building a new facility is an option, the investment cost and the return that accrues from the investment should also be considered.

2. Space utilization: space is used for placement of production machinery and material handling equipments, for storage, for personnel needs, aisle space for personnel and material movements, and free space for future expansion. Modern industrial plants are constantly undergoing changes, and space may be reserved for future expansion or layout changes. A layout design of good space utilization would have two characteristics.
    a. A reasonable space utilization ratio in floor area and cubic space
    b. The free space is concentrated within a specific area or can be integrated for use by a new activity.
3. Building expansion: criterion building expansion is to estimate the ease of expanding the building space, or ease of adding facilities nearby. Very often a plant layout needs modifications once or more during its useful life. A good layout design would consider:
    a. The area available for the building to be expanded, and

    b. The disruption resulting from an expansion:

4. Aisle system: it measures the effectiveness of aisle arrangement to support the flow of material/personnel movements among functional departments. The considerations in the aisle criterion are :
    a) the total area served by the whole aisle system and
    b) Ease of access: this measures the availability of network connecting every pair of departments; the effectiveness of the network from the viewpoint of safety and traffic congestion
5. Other criteria related to environment, safety, security and legal considerations. These criteria include connection with external material handling methods and equipment, impact of the layout on traffic congestion, ergonomics, and aesthetic considerations, human-related safety considerations, workers comfort, property-related security, etc.

3.7 Data Requirements for Layout Decisions

The models for developing the block layout require the following parameters as inputs (Heragu 1997):

- Frequency of trips or flow of material or some other measure of interaction between facilities
- Shape and size of facilities
- Floor shape available
- Location restriction for facilities, if any
- Adjacency requirements between pairs of facilities, if any

While developing the block layout, the shapes of the departments are restricted to be rectangular. This is because when the centroid-to-centroid distance measure is used to measure the distance between two departments, and if L-shape or U-shape departments are considered, their centroids may lie out of the floor area of those departments that the distance calculations might be wrong. In the final layout, these rectangular shapes can be changed to L and U-shapes, if needed, depending on the available area and on the machine layout requirement within each department (Meller and Gau 1996).

3.8 Choices of Solution Approaches for our Research

In Section 3.2, we described that the discrete representation of the layout problem is solely applied to departments with equal area. Unequal area departments are often represented by continuous representations. The problem with continuous representations is that their solution approaches are computationally intractable and often don't capture the qualitative factors (Bozer and Meller 1997). In our research, since the departments we are considering are unequal in area, we represent the layout problem in continuous representation. However, in the algorithm we apply to solve the problem, we relax the continuous representation so that the problem can be solved in a discrete fashion.

The layout problem we solve in this research is characterized by quantitative, qualitative requirements, and practical limitations. The objective of this research is to develop the layouts such that not only the transportation and material handling cost are minimized, but also some qualitative requirements and practical restrictions are addressed. Our layout problem is characterized by the following qualitative requirements:

- The locations of the docks and paths for the trucks: when we develop the layout, we should also consider spaces required for movement, maneuvering, and parking of trucks and the location of docks for the warehouse. For example, when we locate the warehouses, we should also make sure that there is enough space for the docks, and there should be access road to the docks;
- Some departments, if they are to be built anew, require large investment. To avoid additional investment, the management prefers that these departments make use of the existing facilities;
- For safety and legal reasons access road to the main departments is required for the fire brigade;

- Space is needed for the movement of the materials and personnel, and while designing the layout, we should save enough space within or along the contours of the departments to allow the movement of materials and personnel.

Moreover, our layout problem is also characterized by the following practical restrictions:

- Some existing structures must remain intact: Due to the expensiveness of the existing buildings (the RM-Warehouse and FP-Warehouse), it is required that their walls be kept intact. Hence, when we determine the locations of the departments, it is required that either the departments lie within these building or outside of these buildings (i.e., the walls should be retained);
- Unequal departments: one of the restrictions in the layout problem is that the locations of departments should not overlap, and when the location of two unequal area departments are exchanged, overlap of departments is inevitable;
- Locations restrictions: some departments are restricted to specific zones of the floor area, and the locations of some other departments are fixed;
- For safety and aesthetic reasons facilities, like the basin, are not required to be located around the center of the available floor area.

Considerable research has been published regarding the quantitative models, which are primarily solved by analytical and computer based methods. However, analytical approaches usually yield good solutions to the described models, but not necessarily to the real world problems. In the facility layout problem, there remain a number of qualitative requirements and practical restrictions like those of listed above, which must be considered in making the transition from a pure model to a practicable solution; and it is important that we do not dismiss the qualitative requirements and practical restrictions in favor of a completely quantitative approach.

One way of considering the qualitative requirements and practical restrictions is to include penalties to the objective function that penalize the violations of these qualitative restrictions. Local search computer algorithms such as Simulated Annealing and Tabu Search have been used for relaxing these restrictions by sometimes accepting solutions that worsen the objective function (Meller and Bozer 1996; Chwif, Barretto et al. 1998). The Simulated Annealing algorithm attains this flexibility by adding penalty terms to the objective function that penalize the violation of the restrictions. The penalty terms are made to depend on the cooling parameter which controls the acceptance of inferior solutions and which its value is decreased gradually to zero during the iteration process.

The main advantage of the Simulated Annealing based computer algorithms is its ability to avoided being caught in local optima by sometimes accepting solutions that worsen the objective function. They are also computationally reasonable for small problem sizes and when the numbers of penalty terms are small. However, they also have the following drawbacks:

- As the numbers of qualitative requirements and practical restriction increases, the number of penalty terms increases that solving the layout problem in computer programs becomes increasingly complex;
- Because so many restrictions are considered at the same time, the resulting improvements might not be that much significant;
- Determining the relative quantitative values of the penalties to be assigned to the qualitative requirements and practical restrictions are not straight forward.

By and large, although it might be possible to augment penalties to the objective function for the violation of the qualitative requirements and practical restrictions, it is not guaranteed that the computer algorithms perform better than manual methods. Canen and Williamson (Canen and Williamson 1996) reason that visual methods for the layout problem performed better than computer algorithms. Moreover, according to other authors (Kusiak and Heragu 1987; Meller and Gau 1996) unequal-area layout problems of even small size cannot be solved for guaranteed by the computer algorithms.

The objective of this research is not to just obtain optimal quantitative results which don't take the qualitative restrictions and practical limitations into account, but to come up with reasonable improved layout fulfilling the qualitative requirements and practical restrictions as well. This research is motivated with the above described idea in mind. We would like to address the qualitative restrictions and practical limitations subjectively and systematically, while at the same time to deal with the quantitative matter objectively and analytically. In this research, we propose to use Muther's systematic layout planning (SLP) as a procedural solution approach to solve the layout problem. One of the steps in SLP is developing alternative layouts. The algorithm we propose here for developing layout alternatives is similar to the algorithm in CRAFT. However, unlike CRAFT which applies the algorithm in a computer program to develop the layout equal area departments, we apply the algorithm manually to develop the layout of unequal area departments. Also, we incorporate a step in the algorithm that addresses the fulfillment of the qualitative requirements and practical restrictions.

The algorithm begins with initial layout and it attempts to iteratively improve the layout by making a pair-wise exchanges. During the iterative procedure, the algorithm exchanges the centroids of a pair of departments. At each exchange, while the transportation distances are measure objectively by the distance based function (Equation 3.3), the qualitative requirements and practical restrictions are addressed subjectively and systematically. For example, if the departments being exchanged are non-adjacent and unequal in area, the location of one or both of the departments may overlap with that of other departments. In such cases, we avoid the overlap by systematically shifting the locations of one or both of the departments being overlapped to the nearest free area possible. In doing so, there may be infinitely many possibilities. However, considering all possibilities in the exchange process is very cumbersome. Instead, we formulate the selection rule for determining the location of the department that is being shifted as follows: when shifting the position of a department, we do it is such a way that the department to be shifted be located as near as possible to the department which has highest interdepartmental flow with. Since we are using the centroid-to-centroid rectilinear distance as a distance measure between departments, the location for the department being shifted would be at the shortest rectilinear distance from the department which has highest interdepartmental flow with. By doing so, we solve the continuous representation of the layout problem in a discrete fashion.

Figure 3.7 outlines the how the algorithm works. Starting with a given initial or current layout, the algorithms consider all two-way feasible exchanges between non-fixed departments. At every exchange, the algorithms checks if the qualitative requirements and practical restrictions are fulfilled; and if locations of the departments overlap, their locations are adjusted according to the rule formulated above. The impact on the layout cost is measured according to the flow distance objective function (Equation 3.3). The current-best total transportation distance for each iteration is stored as the best transportation distance so far (MIN). When all exchanges are evaluated, the algorithm selects the feasible exchange which yields the maximum reduction in the transportation distance, and the exchange procedure is restarted with the new layout. The search procedure terminates when no feasible transportation distance improving exchanges are identified in the current layout. An exchange is infeasible if it results in splitting of any department.

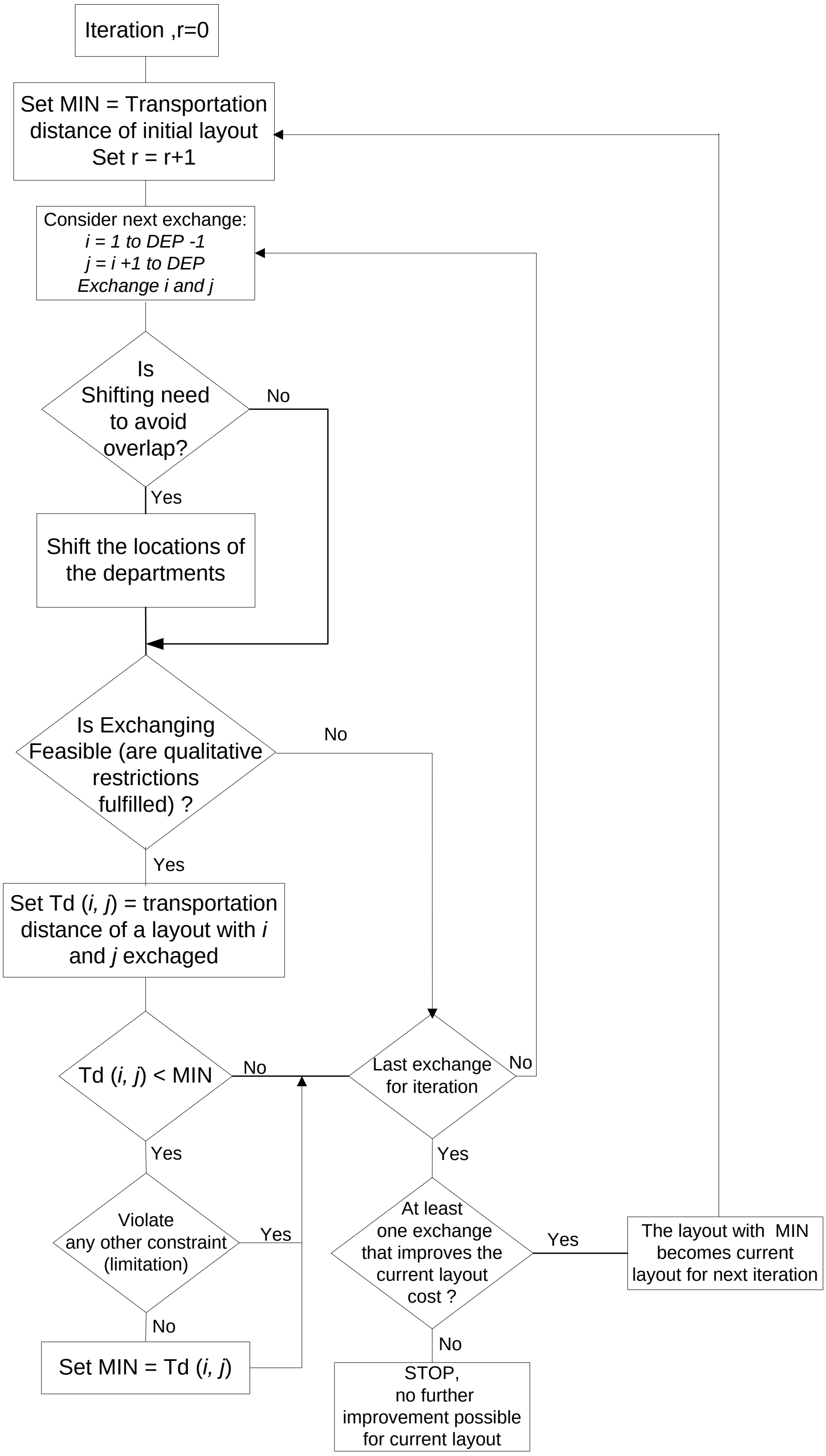


Figure 3.7: Flow chart of the algorithm.

The proposed algorithm is a type of steepest decent local search algorithm. The problem with such types of algorithms is that it can arrive in a local solution that is not optimal. To overcome such a problem, we modify the exchange procedure as follows:

The floor space available for locating the facilities is much greater than the total area requirement for all facilities. This means that there is extra free space available, and there will still be extra free space even after the new plan is implemented. While executing the algorithm, the exchange is done not only between departments, but it is also possible that a department can be moved to the free space available without exchanging it with other departments, i.e., instead of exchanging two departments, a department can also be exchanged with a free space. Hence, when we say exchange, it can be exchanging the locations of two departments or the moving of a department to a free space. When we move a department to a free space, there might be many ways locating the department within that free space. However, as we mentioned above, considering all possible exchanges are cumbersome. Instead, we apply the same selection rule mentioned above, i.e., when move a department to a free space, we do it is such a way that the department to be moved be located as near as possible to the department which has highest interdepartmental flow with.

Once the relative locations of the departments are developed, we determine the layout of the machines and the locations of the input/output stations. Since the number of machines in the department we are considering is small, we enumerate the possible layouts of the machines in each department so that the rectilinear material flow distance of the materials is minimized. We also located the input/output stations in such a way that the forklifts passing through these points will travel the shortest rectilinear distance possible.

After the layout of the departments is determined and the input/output locations of these departments are identified, we continue with solving the material flow network to aid the flow of materials between departments. For solving the material flow network we employ the shortest rectilinear flow network approach developed by Chhajed and Montreuil (Chhajed, Montreuil et al. 1992) and described in Section 3.5. We choose this approach for the following reasons:

1. It uses rectilinear distance measure as an input which is consistent to the choice we made for measuring the distance between departments while developing the layout.
2. It can be solved independently once the relative locations of the departments, and the input/output locations are identified
3. It results in a nearly optimal solution (Chhajed, Montreuil et al. 1992)

3.9 Conclusions

The layout problem has elements of both design and optimization problems. The solution approaches for the layout problem falls into two categories: algorithmic and procedural approaches. Algorithmic approaches usually simplify both the qualitative design constraints and objectives in order to reach a surrogate objective function, the solution of which can then be obtained. Procedural approaches, on the other hand, can incorporate both qualitative and quantitative objectives in the design process. For these approaches, the design process is divided into several steps that are solved sequentially.

In this research we propose to use Muther's systematic layout planning (SLP) as a procedural approach to solve layout problem at hand. One of the steps of SLP is developing layout alternatives. For developing layout alternatives, we propose to use the improvement algorithm discussed in Section 3.8 and depicted in the flow chart in Figure 3.7. Once the relative locations of the departments are determined and layout of the machines and the input/output locations of these departments are identified, we continue with solving the material flow network by applying the shortest *r-flow* network approach described in Section 3.5.

Chapter 4
Improvements in the Logistic Processes

In Chapter 2, we introduced the processes that need improvement. In this chapter, we discuss the improvements. The need for improvements arises from the current practices related to the receiving of the incoming materials, sampling of the incoming and finished products, the weighing of the finished products, and the storage practices in the warehouses. Value is added to the materials only at operations (the sieve machine, the mixers, and the FBO); none of the other activities (sampling, transportation, storage, loading, unloading, etc.), which seemingly are necessary, adds value to the finished product. Therefore, the processes that lead to unnecessary transportation and loading and unloading of the materials need to be improved. Here we provide the improvements for those processes.

4.1 Receiving of the Incoming Materials

Even though warehouses can serve quite different purposes, most of them share the same general pattern of material flow. Essentially, they receive bulk shipments, store them for a while; and then retrieve the materials for use. The organization of the flow takes place through the following physical processes: receiving, put-away, storage, and picking (retrieving) (Bartholdi and Hackman 2009).

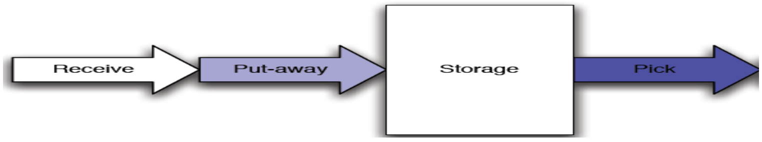


Figure 4.1: smooth flow of materials in a warehouse

A general rule in a warehouse is that materials should move continuously through the sequence of processes shown in Figure 4.1. Since the processes are interdependent, they should be planned and coordinated. Resources and required spaces should be assigned to effectuate the smooth movement.

Currently, the incoming materials are directly stored in random locations in the warehouse, i.e., there is no reserved location for receiving and staging of the incoming materials. The reason is that, currently, the receiving of the materials is not properly planned. However, receiving is a process that should be planned. Receiving begins with advance notification of arrival of materials and schedules the arrival of the trucks within a specified time window. Advance planning allows the warehouse to schedule receipt and unloading to coordinate efficiently with other activities within the warehouse.

Therefore, two things have to be considered for the receiving of the incoming materials to be efficient:

1. Planning the receiving processes –advance notification of arrival of materials includes the amount and type of materials that are expected to arrive and when. This should be accompanied with the information required for receiving and putting way of the materials. Knowing the arriving materials in advance helps to know what processes the material requires after receiving and to plan their storage locations depending on the types of the materials. Moreover, it is not uncommon to schedule the arrival of the trucks within a specified time of the day.
2. Assigning a dedicated place for receiving of the materials (hereafter called Receiving area) – a separate area should be reserved for the incoming materials in which they can be temporarily stored until they are sampled and put away. This is so because placing the incoming materials in random locations makes the retrieving these materials expensive. Moreover, since the majority of the incoming materials need sampling, taking the samples at random locations, and moving the materials to the floor only for sampling purpose requires a lot of handling and transportation efforts. If a separate area is reserved for receiving the

incoming materials, the samples can be taken there, and then moved to their actual storage place thereby mitigating the handling and transportation efforts that accompanied with sampling. Having said this, now we design the Receiving area.

Size of the Receiving area

An important decision here is the size of the area to be reserved for the receiving purpose. To estimate the area required for the receiving of the incoming materials, let's see how many materials are received each day; and how long these materials stay before they are sampled and sieved (sojourn time in the Receiving area). Table 5.1 shows the average number trucks and types of containers arriving each day. Three trucks per day being an average, there are times when the number goes to 8; and at some days no truck may arrive.

Average # of incoming	Average amount of incoming materials				Gross weight in tons
	Bigbags	Drums	Bins	pallets	
3	15	154	10	46	55311

Table 4.1: Average statistics of materials arriving each day

The area to be reserved for the Receiving area can be assumed like a separate storage area within the New Warehouse where the incoming materials are temporarily stored before they are sampled and sieved. The size of the area to be dedicated depends on how fast the sampling and handling of the incoming materials in done per day.

Based on the data from 2009, on average, 65,937 tons of incoming materials can be sieved each day. This means that every incoming material can be sampled and sieved at the day they are received. Therefore, the space that should be dedicated to the receiving area should be large enough to accommodate the 55311 tons of incoming materials, space required for the movement of forklifts and people, and additional space for uncertainties.

Each big bag, bin, and pallets requires 1.5 X 1.5 m^2 floor area. Assuming that the containers are stored in a form of block stacking with stack height of two, the rough estimate of total area required for the receiving of the materials is 164 m^2 (see Table 4.2). Moreover, with the introduction of the RBOs, additional materials are received, and additional area is required. The arrival rates of the materials to be treated in the RBOs are not known, but according to plant manager, the materials to be treated in the RBOs are estimated to be 10% of the existing materials. Taking these materials into consideration, the Receiving area is increased to 180 m^2. Suppose the Receiving area will have length of 10 meters, and if we allow 3 meters for the path of the forklifts, a total area about 20 m^2 is required for the movement of the forklifts within the Receiving area. This means about 210 m^2 is required for the receiving area.

type of containers	width	lenght	Amount	Total area requaired (m2)
big bags	1.5	1.5	15	16.875
bins	1.5	1.5	10	11.25
pallets	1.5	1.5	46	51.75
drums	0.75	0.75	154	43.3125
		Total area required		163.2

Table 4.2: Approximate calculation of the area required for the receiving area

Of course this is an approximate calculation assuming three trucks arrive each day; however, as we mentioned earlier, up to 8 trucks may arrive at a time, and in this case, an area of 210 m^2 is not enough. Therefore, to accommodate some contingencies in the arrival of the materials, an additional area is required. The Receiving area is an open area within the New Warehouse and its size can be enlarged or reduced easily without the general layout of the warehouse. Therefore, determining the exact area for the Receiving area is not that important. Here, we simply design the Receiving area such that it accommodate up to 6 trucks at a time. Hence, roughly a total area of 400 m^2 can be allocated for the Receiving area. In cases when more 6 trucks arrive at a time, either some of the incoming materials should be placed in the main storage area or receiving more than 6 trucks should be avoided by scheduling the receiving of some of the trucks for other days. As we said earlier, if the receiving of the incoming materials is properly planned, receiving more than 6 trucks can be avoided. Since some of the external transportation of the incoming materials is arranged by the personnel in Metrex, with proper planning, the arrival of the trucks can be influenced.

Having the area required for the receiving of the incoming materials determined, the next task is to locate this area within the New Warehouse. The location of the receiving area is directly related to the location of the docks for the incoming materials and the general flow of the materials within the warehouse. For an efficient flow of the materials within the warehouse, the receiving area should be located next to the receiving docks. We will come up with the location of the receiving area in Chapter 6.

4.2 Sampling of Materials

4.2.1 Sampling of the Incoming Materials

Most of the incoming materials need sampling. Sampling is one of the laborious and tedious processes. At the moment sampling for the incoming materials is done at the day or the next day the materials are received. Since there is no reserved space for receiving of the incoming materials, the materials are directly stored at random locations in the form of block stacking; and for sampling, the containers holding the materials have to be moved to the floor, open the lid, take sample, and then return the container back to the storage location. This is accompanied by transportation and unnecessary handling of the materials from which samples are taken, and possibly relocation of other materials.

The sampling process can be improved in two ways:

1. In the previous section we propose that a separate space be reserved for the receiving of the incoming materials. If the pre-treatment processes (i.e., sieving, separation, etc.) are to be done in the Handling department, then sampling can be done in the Receiving area before the materials are taken to their actual storage location. This will reduce the transportation and handling efforts, and eliminates the relocation of other materials as a result of sampling.
2. If the pre-treatment processes are to be done in the New Warehouse, the samples can be taken while sieving the materials. This virtually eliminates the efforts that are required for sampling at this moment. Actually, the main advantage of doing the pre-treatment processes in the New Warehouse is to improve the sampling process.

To see the cost advantage of combining the sampling process with sieving, let’s calculate the average distance materials are transported as a result of the sampling. For sampling every unit load has to be transported about 20 meters on average. From Table 4.1, we see that 15 big bags, 154 drums, 10 bins, and 46 pallets arrive every day. The big bags, the bins, and the pallets are handled individually, but up to 4 drums can be transported by a forklift at a time. In total, about 120 unit loads are transported for 20 meters each for sampling. This mean, by combining sampling with sieving about 2,400 (20X120) meters of transportation distances can be avoided each day.

4.2.2 Sampling of Finished Materials

The samples for the finished materials are collected after the big bags are taken and stacked in the FP-Warehouse. To take the sample, either each big bag has to be opened and then tied or it has to be probed. In the former case, the opening and tying of the bags is time consuming and the workers are unnecessary tied up in non-value added activities; in the latter case, the bags are punctured that their contents may be lost. Moreover, sometimes, because the big bags are placed in remote location, each sampling is accompanied by the relocation of other big bags – which cause unnecessary handling and movement of the materials.

The inefficiencies with sampling could have been avoided had the samples be taken when finished materials come out of the FBO: when the materials are filled into the big bags a sample of each bag can be collected into small containers, say test tube, and label the bag and the test tube with identical code – no need to go the warehouse to take the samples.

4.3 Weighing of the Finished Products

Every big bag of finished product has to be weighed. The weighing device for this purpose is placed in one corner of the FP-Warehouse. Each big bag has to be transported for approximately 30 meters for this purpose. This is unnecessary transportation that should be eliminated. Moreover, locating the weighing device in the warehouse causes the space utilization of the warehouse to be inefficient– the place where the device is located and the path (aisle) for the forklift that leads to the weighing device could have been used for storing the materials.

To improve the weighing of the finished materials, the weighing device should be placed in the Production department. The weighing device can be located on the floor in the outlet of the FBO so that the big bags can be placed on the weighing device when they are being filled with the finished materials. By doing so, the transportation and handling efforts can be eliminated.

4.4 The Storage and Retrieval Systems of Materials in the Warehouses

Various types of materials are stored in the Warehouses in Metrex. The Existing storage and retrieval system is a kind of block stacking storage system characterized by random storage allocation and random retrieval of materials. The main problem with the current storage and retrieval system is that because the materials are of various types and are stored randomly in the free spaces available, the handling and transportations of the materials are high during the retrieval processes.

Since designing the storage and retrieval systems is a big topic, and is not the main part of our research, here, we only provide the recommendations on how the current storage and retrieval systems can be improved.

The major considerations in designing block stacking storage system are to minimize the costs of storage and retrievals of materials and to maximize the space utilization of the warehouse. These considerations are usually addressed by determining optimal layout of the warehouse (lane depth and stack height of the block stacks) and by applying appropriate storage allocation and retrieval system of the materials (Park and Kim 2009). The improvements can come from improving the following areas:

1. Determining an optimal layout of the warehouse. This includes determining the lane depth and stacking height of the warehouse. The retrieval process and the floor space utilization are directly affected by the nature of the layout of the warehouse. Hence, having optimal lane depth and stacking height minimize the retrieval efforts and maximizes the space utilization.

2. The storage allocation and retrieval processes should also be improved. In the existing system, incoming materials are randomly allocated to the storage locations. The random allocations increase the number of handlings and transportations during retrieval process. This process can be improved by grouping unit loads of the same retrieval pattern and storing them in the same stack. Even though the incoming materials are of various contents and their exact content might not be known before sampling, their general content are known and a class-based storage allocation system can be used to store materials of similar retrieval pattern as the same stack. Furthermore, some of the materials are fast-moving that they might be required for production a few days after their arrival; whereas, others stay up to 6 months in the warehouse. Locating materials of different moving pattern at the same stack increases the

number relocation per retrieval. Hence, the fast-moving and slow-moving materials should be stored at different stacks.

3. Increasing the sizes of the packaging materials. This is especially applicable for the internal packaging of materials. In the new plan, we proposed the materials to be sieved in the New Warehouse before they are taken to their storage place; in this case, materials that are expected to be included in the same mix can be stored together in a bigger packaging material. Since the transportation and handling costs don’t depend on the size of the packaging material, having bigger packaging containers will also reduce the handling and transportation costs.

4.5 Conclusions

In this chapter we presented the improvements to logistic processes and practices related to the handling and transportation of the materials.

- The receiving of the incoming materials need to be planned; and there should be a reserved area for the receiving of the incoming materials.
- Sampling being one of the laborious processes, the handling and transportation efforts can be avoided if the sampling process is combined with the sieving process.
- The storage and retrieval system of the warehouses can be improved from three areas: determining optimal layout of the warehouses, having appropriate storage allocation and retrieval systems, and increasing the sizes of the packaging materials.

Chapter 5
Developing Alternative Layouts

5.1 Introduction

In this chapter we follow SLP step-by-step to develop alternative layouts. The steps in SLP can be grouped into three main phases: analysis, search, and evaluation. The analysis phase involves all of the data collection required to produce a good layout. Within the analysis phase, facility data is utilized to define the departmental relationships. The search phase of the SLP involves the actual alternative layout generation. Once alternative layouts are generated, in the evaluation phase, we choose the final layout that is going to be implemented based on the cost and non-cost criteria.

Before going through the steps, let's make some proposals regarding the new facilities that should be built. In Section 2.2, we described that the materials coming out of the mixers don't directly go to the next process; instead, they are transported back to the RM-Warehouse for temporary storage. To minimize the handling efforts and the other inefficiencies described in Section 2.2, a separate storage place should be dedicated to the work-in-processes that come out of the Handling department and that are waiting for treatment in the Production department. Hence, we propose a separate storage place for the work-in-processes hereafter called *WIP-Storage*. Moreover, in Section 2.3, we explained that the facilities required for cleaning, washing, and inspection of the empty bins are currently located in different places, and this has created unnecessary long distance movements of the bins. Hence, for efficient flow of the bins, we propose that the cleaning, washing, and inspection of the bins be done at a single location hereafter called *Bin-cleaning hall*.

In addition, in Section 2.4, we mentioned that sieving and sampling are done in different locations; we also mentioned that sampling is one of the laborious processes. By doing the sieving and the separation of materials in the New Warehouse have several advantages, namely:

- Sampling of the incoming materials, which is one of the laborious processes, can be done while sieving which largely reduces the handling and transportation requirements;
- It eliminates the unnecessary transportation of ceramics, hence decreasing total transportation requirements;
- Since the mixes are now done per Kg of the sieved and separated materials, the result of the mix will be more accurate and hence increase the quality of the final product. Moreover, since the materials going into the mixer are now of better quality, the throughput of the mixers would probably increase;
- The exact weight of the ceramic contents of each incoming material is known which makes the payment of the ceramics easier and more accurate.

On the other hand, doing sieving and separation of the incoming materials in the New Warehouse means that sieving and mixing are carried out in two separate places; and in this case every material is handled twice. This obviously increases the transportation and handling costs. The cost tradeoff between the options is not apparent until we make the detailed layout of the departments and the machine. Moreover, the location of the machines required for sieving and separation have a direct impact on the flow of the materials. To make a choice of where these machines should be located and incorporate their impact on the design of the layout and flow of the materials, we consider two scenarios on the location of these machines so that after developing alternative layouts using the two scenarios, we can make a final selection on where the machines should be located.

Scenario 1: we propose that the banker, the sieve machine, the separator, and the shredder be located in the New Warehouse so that the incoming materials would be sieved and separated after receiving. We name the separate section for the locating the banker, the sieve machine, shredder, and separator within the New Warehouse as *Handling section*. The mixing of the materials then takes place in a separate section; we hereafter name it *Mixing section*.

Scenario 2: the banker, the sieve machine, the separator, and the shredder are located in their current location (i.e., the Handling department).

To avoid confusion, hereafter, when we say machines, we mean the banker, the sieve, the separator, and the shredder excluding the mixers. The mixers are located in the Handling department in both scenarios. Hence, in Scenario 1, the machines are located in the New Warehouse, but in Scenario 2, the machines are located in the Handling department.

Taking the proposed new facilities and the scenarios presented above into account, we now follow the SLP step-by-step to develop the alternative layouts. We start with the first scenario. We discuss the second scenario in Section 5.3.

5.2 Scenario 1: The Machines are Located in the New Warehouse

5.2.1 Analyzing the Input Data

Step 1: Input data

Depending on the type of treatment that the materials require, the existing products can be categorized into two groups: those that are treated in the RTO and those treated in the FBO. The flow of these two groups of materials in different. The flow of these materials, which was described in Figure 2.4, is reproduced here in Figure 5.1 (a) and (b), respectively, incorporating new facilities and in this case the sieving and separation of the materials is carried out in the New Warehouse. In the new plan the incoming materials are stored in the New Warehouse; and the pre-treated materials coming out of the Handling department are temporarily stored in the WIP-Storage instead of taking them back to the New Warehouse.

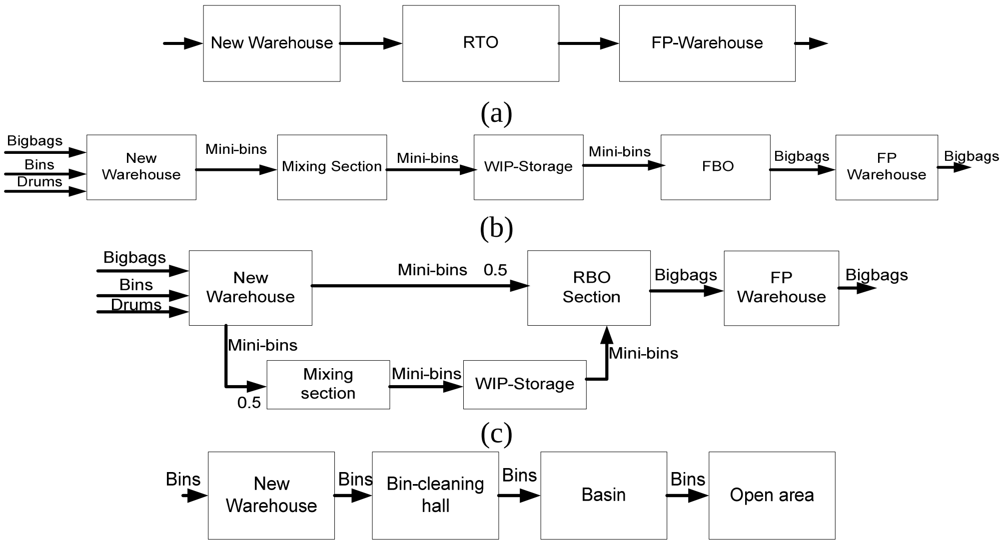


Figure 5.1: Schematic flow diagrams of materials treated in the (a) RTO, (b) FBO, (c) RBOs, and (d) bins.

In addition to the existing materials, with the introduction of the RBOs, there is a third group of materials whose flow is depicted in Figure 5.1 (c)**.** These are new materials to Metrex and are going to be treated in the RBOs. Before they are treated in the RBOs, these materials need to be sieved and separated. Some of these materials may need mixing, and some of them may not. Approximately, 50% of the materials need mixing. Accordingly, the flow of these materials is shown in Figure 5.1 (c).

The other types of materials that affect the arrangement of the facilities are the bins. In the new plan, the bins, after their content is emptied into the sieve machine in the New Warehouse, should be transported directly to the Bin-cleaning hall for cleaning and washing; and then from the Bin-cleaning hall to the basin for leak inspection. Once they are inspected, they are moved to an open area where they are kept until they are sent to customers for use. The flow these materials is depicted in Figure 5.1 (d).

Step 2: Flow of materials analysis.

This step makes use of the flow diagrams shown in Figure 5.1, and aggregates all the material flow among departments in order to determine the flow intensities. The materials are stored in three types of containers: bins, drums, and big bags. These containers differ in the way they are handled and transported – the bins and the big bags are handled and transported individually, whereas the drums are handled in a pallet in a bundle of four. Therefore, to make things simple, we hereafter represent the containers by a unit load. We define a unit load as a load that can be handled and transported by a forklift at a time. The material flow, therefore, represents the number of unit loads that are transported by a carrier from department *i* to department *j* per unit time. In Moxba Metrex all material transportations are done by forklifts. Hence, we consider the number of loaded forklifts traveled from department *i* to department *j* per day.

The size of the New Warehouse is big (50 X 100 m) compared to the other departments. Taking the centroid of the warehouse to measure the distance between the warehouse and other facilities would underestimate the actual distance. The distance measure would better be estimated if we divide the warehouse into two halves and treat the halves as two separate departments that should be located next to each other.

The activities in the New Warehouse can be categorized into three: Receiving of the incoming materials, pre-treatment of the materials (sampling, sieving, separating, etc.), and actual storage. The area in the warehouse should, then, be partitioned into three portions to accommodate the three groups of activities. The first half of the warehouse (New Warehouse 1) is used for the first two groups of activities, and the second half (New Warehouse 2) will be used for actual storage purpose.

For indicating the origination and destination of the flow from/to the New Warehouse, we use New Warehouse 1 and New Warehouse 2; and for determining the distance between the warehouse and other facilities, we use the centroids of the New Warehouse 1 and New Warehouse 2 depending on the type of the material that flows from the warehouse. For example, if the materials coming out of the warehouse are bins that need to be cleaned, their flow starts in New Warehouse 1 and their center is the centroid of New Warehouse 1; for those materials that are transported to the Mixing section, they originate from New Warehouse 2 and their center is the centroid of New Warehouse 2.

Facility name	New Warehouse1	New Warehouse2	FP Warehouse	Mixing section	Production department	RBO section	WIP-Storage	Bin-cleaning hall	Basin	Ceramic and Drums
New Warehouse1	0	100	0	0	0	0	0	7	0	60
New Warehouse2	0	0	0	80	10	10	0	0	0	0
FP-Warehouse	0	0	0	0	0	0	0	0	0	0
Mixing section	0	0	0	0	0	0	49	0	0	0
Production department	0	0	31	0	0	0	0	0	0	0
RBO section	0	0	15	0	0	0	0	0	0	0
WIP-Storage section	0	0	0	0	41	8	0	0	0	0
Bin-cleaning hall	0	0	0	0	0	0	0	0	7	0
Basin	0	0	0	0	0	0	0	0	0	0
Ceramic and Drums	0	0	0	0	0	0	0	0	0	0

Table 5.1: Flow-to chart of the facilities in Moxba-Metrex

The flow data is shown in a flow-to chart in Table 5.1. The numbers shown in the cells indicate the average number of unit loads transported from the departments in the vertical column to the departments in the horizontal row each day. For example, 31 unit loads are transported from the Production department to the FP-Warehouse every day. The data is taken from materials movements between departments in 2009 averaged over a day. We assume the will remain constant over the coming years.

Step 3: Activity relationship analysis

For our layout problem, the flow-to chart is used as the basis for quantitative analysis purposes. Activity relationships, the qualitative analyses, are investigated but are not used for the departmental relative positioning decisions; thus, further analyses are not presented here.

Step 4: Relationship diagram

Relationship diagram reveals a potential positioning decision among the functional areas. It provides a quick overview of the potential closeness relationship, and it is a prerequisite to the space relationship diagramming decision.

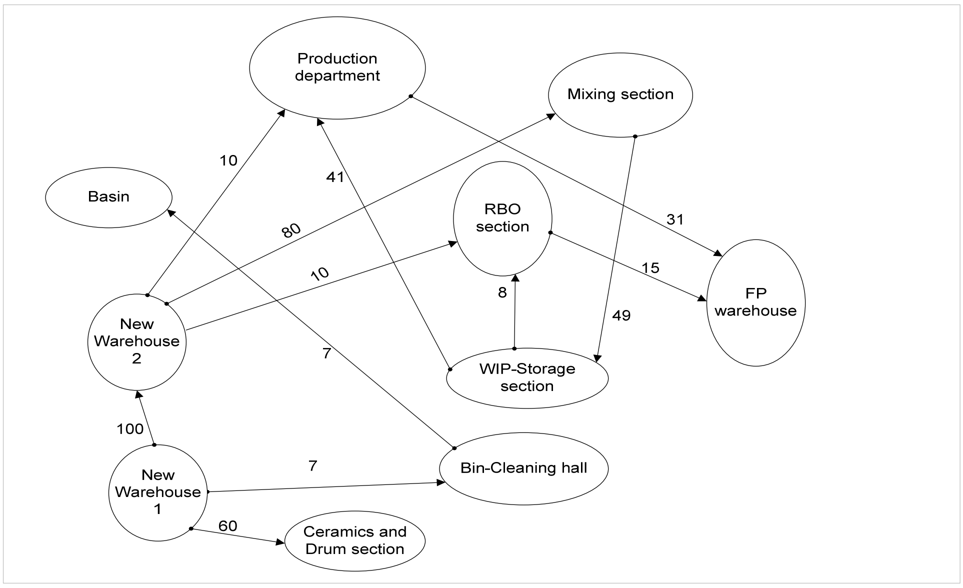


Figure 5.2: the relationship diagram

Figure 5.2 shows the relationship diagram for the departments in Moxba-Metrex plant. The departments are represented by oval circles and the material flow intensity by the directed arrows. The number in each arrow indicates the intensity of the flow and the direction of the flow is represented by the direction of the arrow. Intuitively, departments with high interdepartmental flow should be located next to each other, whereas departments with no interdepartmental flow can be located far from each other. For example, 80 unit loads are transported each day from the New Warehouse 2 to the Mixing section; an optimal layout should therefore place the Mixing section near to the New Warehouse. On the other hand, there is no direct flow between the New Warehouse and the FP-Warehouse; hence it is not necessary that New Warehouse be placed next to the FP-warehouse.

Step 5&6: The space requirements/available space

The area requirement for each department should be determined before constructing the space relationship diagram. The sizes of the existing departments are known. However, with the introduction of additional machines (RBOs) and with the improvement in logistic processes, the area requirement by some facilities may need modification. Also, the space required by the WIP-section and Bin-cleaning hall needs to be estimated. Since the RBOs are not installed yet, the floor space required for their installation has to be calculated.

Area requirement for the WIP section

The WIP-section is a temporary storage place for the materials mixed in the mixers and waiting to be treated in the FBO. The space requirement is estimated to store the maximum number of bins. The materials that are treated in the FBO on the Weekends are mixed in the week days and stored here. Hence the space required should be large enough to accommodate the space requirement for the weekend and partly for Monday. The space required should be then large enough to accommodate for the materials that are to be treated for three days. About 41 bins are treated per day in the FBO. Also, of the materials treated in the RBOs, about 8 bins of materials needs mixing each day, and these materials are kept in the WIP-section afterwards. Hence the space required should be large enough to store about 147 bins at a time which is about 166 m^2 (see Table 5.2). Suppose the WP-section will have length of 10 meters, and if we allow 3 meters for the path of the forklifts, a total area about 30 m^2 is required for the movement of the forklifts within the WIP-section. Therefore, roughly about 200 m^2 is required for the WIP-section.

type of containers	width	lenght	Amount	Total area requaired
bins	1.5	1.5	147	165.375

Table 5.2: Area calculation for the WIP-section

The area required for the RBOs

When determining the space required for locating the departments, extra space should allowed for operators movement, material handling movements, loading and unloading of materials, maintenance requirements, etc. in addition to the area required for installing machines in that department (Heragu 1997). The RBO section contains four lines of machines 6 meters in width and 23 meters in length. Hence, the total area required for installing the machines is 24X23 m^2. In addition, space is also required for loading and unloading, personnel movements, and other auxiliary activities like maintenance. This would increase the area required to be about 27X28 m^2.

The area required for the mixers (Mixing section)

The machines included within the existing Handling department are the banker, sieve machines, shredder, separating machine, and the mixers. In Scenario 1, we propose that all the machines except the mixers and bankers be placed in New Warehouse; hence, the area required for the Mixing section in this case is only for the mixers, the bankers in the Mixing section, the conveyors connecting the bankers and the mixers, the operator and material handling movements, loading and unloading space, and maintenance requirements. In Appendix 5, we give the dimensions and the arrangements of the facilities in the Mixing section. The exact area required for the Mixing section is not known, but according to the Logistic manager of the company, an area of 400 m^2 suffices.

The floor area requirements for all departments are summarized in Table 5.3.

Facility name	Length	Width	Area required
New Warehouse1	50	50	2500
New Warehouse2	50	50	2500
FP-Warehouse	60	40	2400
Mixing section	20	20	400
Production department	61	26	1586
RBO section	27	28	756
WIP-Storage section	20	10	200
Bin-cleaning hall	20	20	400
Basin	30	14	420
Ceramic & Drums section	30	20	600

Table 5.3: Facility area requirements

The floor space available for locating the facilities is much greater than the total area requirement for all facilities. This means that there is extra free space available, and there will still be extra free space even after the new plan is implemented

Step 7: Space relationship diagram

This step converts the relationship diagram into space relationship diagram by mapping each department's area into the relationship diagram as shown in Figure 5.3.

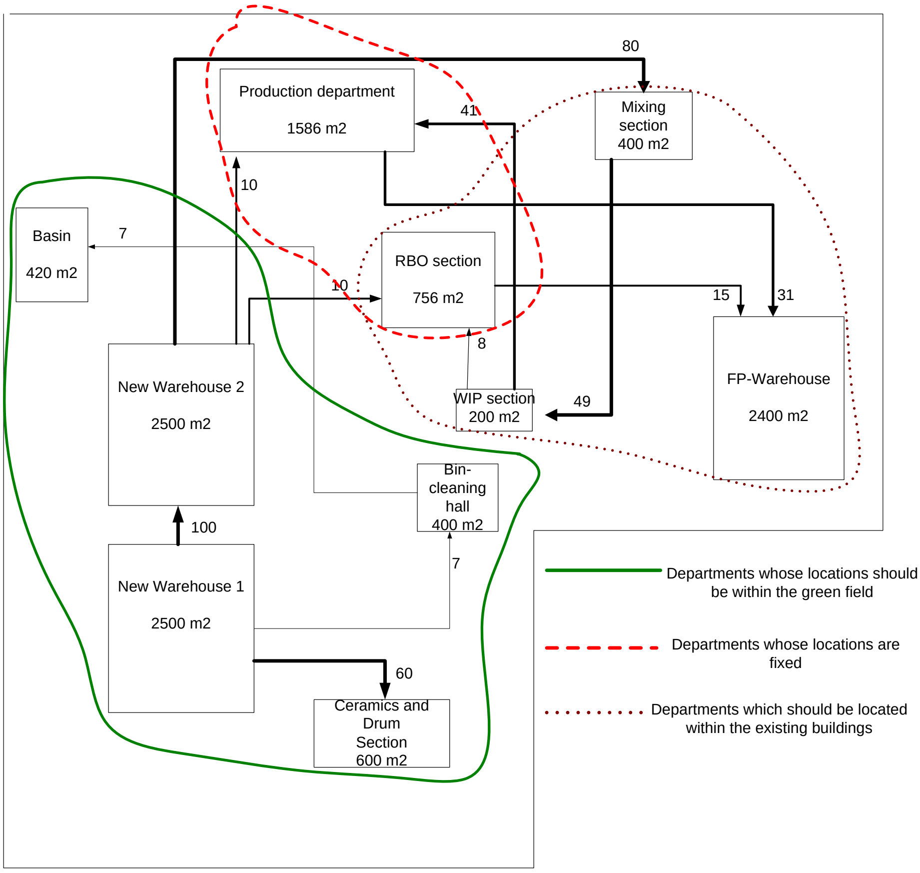


Figure 5.3: Space relationship diagram

Step 8&9: Practical limitations and modification considerations

The rectangular block represents the departments. The weights of the arrows connecting the departments indicate the intensity of the flow. Ideally, the departments that are connected by the heavy lines should be located adjacent to each other. The arrangement of the departments represents the existing layout. For the new facilities such as the WIP-section, the Bin-cleaning hall, and the Ceramics & Drum section, we located them in the empty space available irrespective of the best location the new plan.

Here we describe the practical restrictions and assumptions we should take into account before starting to develop the alternative layouts. In Figure 5.3, we circled the departments whose locations should be in the green field (shown in Figure 5.4). Those departments whose locations are fixed are circled in dashed red lines. The restrictions and assumptions are briefed as follows:

1. The location of the *Production department* is fixed and cannot be changed in the new plan. Moreover, because the RBOs are required to share the existing dust cleaning system with the RTO and FBO, their location is fixed and restricted to be within the RM-Warehouse and adjacent to the production department as shown in Figure 5.4.

2. For the *New Warehouse*, studies have been done on where it should be located. Since the warehouse is not built yet, its location can be changed. The location is however restricted within the green field shown in Figure 5.4. Also, the location of the *basin* is restricted to the peripheries of the green field i.e., it should not be located at the center.
3. Due to the expensiveness of the existing buildings (the RM-Warehouse and FP-Warehouse), it is required that the walls of these buildings be kept intact. Hence, when we exchange the locations of the departments, it is required either these departments lie within these building or outside of the buildings (i.e., the walls shouldn't be split).
4. Due to hazardousness of the raw materials, the facilities used for storing and processing these raw materials require a special building. For example, the Handling department, WIP-section, and the FP-Warehouse require special buildings. Since constructing new buildings for these facilities is expensive, it is required that these facilities be located within the existing special buildings (i.e., the RM-Warehouse and the FP-Warehouse).

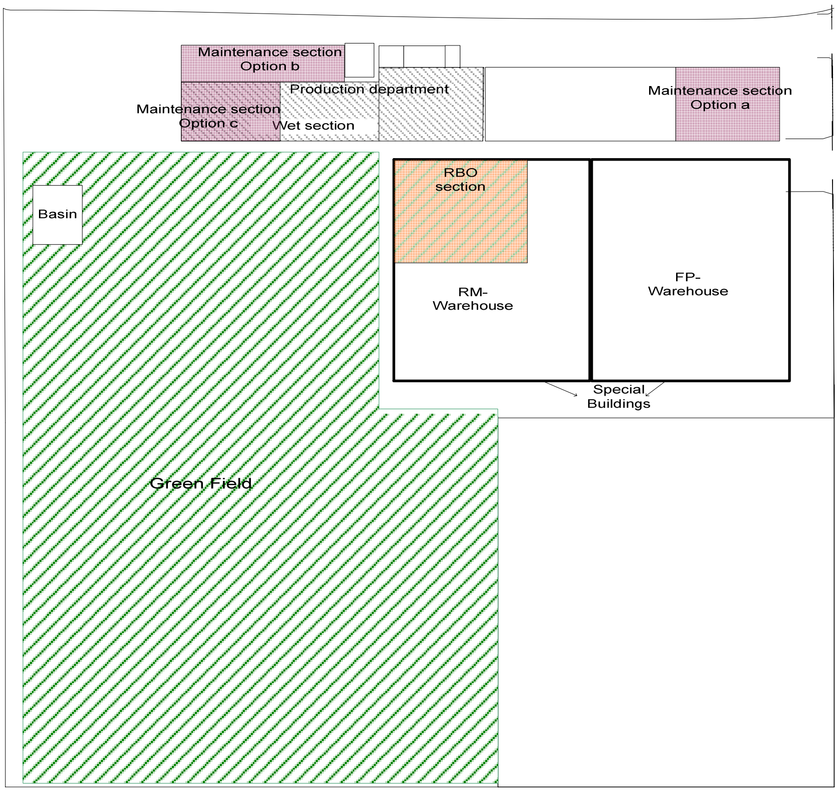


Figure 5.4: Location of the green field and the fixed departments

5. The *Ceramics & Drum section* is an open area for location the big containers that are used to collect the ceramics and scrapped drums. Moreover, the Bin-cleaning hall is a simple hall that does not need special building. To this end, the Ceramics & Drum section cannot be located within the special buildings, and even though the Bin-cleaning hall can be located within the RM-Warehouse, its location is preferred to be at the green field.
6. The *Maintenance section is* one of the departments whose location should be determined in the new plan. And for fast maintenance actions during urgent maintenance requirements, it is required that it shouldn't be located far away from the production facilities. We use the number of forklift movements between departments to evaluate the performance of an alternative layout. However, there are almost no materials movements between this section and other departments. Hence, we consider the determining the location of the maintenance department as a special case, and we don't include the Maintenance section in the exchange procedure. Instead, we identify its possible locations. In Figure 5.4, we have shown the possible location options for the maintenance section:
    a. At its current location, if the space is not assign for locating other departments;

b. At the free space next to the Wet section of the Production department – this space is an open area where large containers for the ceramics and used drums are located. In the new plan, we propose the Ceramics & Drum section be located at another location. Hence, this free space can be used for locating the Maintenance section.
c. Within the Wet section of the Production department. Part of the Wet section of the Production department is being used for performing the inspection of the cleaned bins. In the new plan, the cleaning and inspection of empty bins are performed in the Bin-cleaning section at another location. Therefore, this space can then be used for locating the maintenance section.

Of the three options, Option (a) is possible if the current location for the Maintenance section is not used for other purposes. If the Maintenance section is to be relocated, Option (c) is preferable because locating the Maintenance section in the Wet section of the Production departments doesn't need additional investment. Therefore, if the Maintenance section is to be relocated, we suggest its location to be in the Wet section.

5.2.2 Search for Alternative Layouts

Step 10: Developing alternative layouts

As we discussed in Chapter 3, we use the improvement algorithm (see Figure 3.7 for the flow chart of the algorithm) introduced in Section 3.8 for developing alternative layouts.

Starting with a given initial or current layout, the algorithm considers all pair-wise feasible exchanges between non-fixed departments. In every exchange, the algorithm checks if the locations of the departments need shifting to avoid overlap. The total transportation distance is measured according to the flow distance objective function given by Equation 5.1. This objective function forces departments with highest interdepartmental flow to be located next (near) to each other. The distance between two departments' centroid is calculated by the rectilinear distance measure given by Equation 5.2. The current-best total transportation distance for each iteration is stored as the best transportation distance so far (MIN). When all exchanges have been evaluated, the algorithm selects the feasible exchange which yields the maximum reduction in the transportation distance, and the exchange procedure is restarted with the new layout. While executing the algorithm, the exchange is done not only between departments, but it is also possible that a department can be moved to the extra free spaces available without exchanging it with other departments, i.e., instead of exchanging two departments, the space occupied by a department can also be exchanged with the free space. The search procedure terminates when no feasible cost improving exchanges are identified in the incumbent layout.

$$C5 = \sum_{i}\sum_{j} f_{ij}\, d_{ij} \qquad (5.1)$$

$$d_{ij} = |x_i - x_j| + |y_i - y_j| \qquad (5.2)$$

Before we begin executing the algorithm, we would like to make a remark on the exchange procedure. When we exchange the centroids of departments of equal in area or move a department to a free space of equal in area, the exchange (or moving) can be made deterministically without shifting the locations of the centroids of those departments, and without affecting the location of other departments. For example, looking at Figure 5.6 (a), the Mixing section (#3) and the Bin-cleaning hall (#7) are of equal area that their locations can be exchanged easily. However, when we exchange the centroids of unequal area departments, the centroid or a portion of one of department may overlap with the other departments; to avoid the overlap, we have to shift one or both of the locations the departments to the nearest surrounding area possible; and in doing so, there may be infinitely many possibilities. Similarly, when we move a department to a free space of larger in area, there are many possibilities of locating that department being moved within the free space. However, considering all possibilities in the exchange process is very cumbersome. Instead, we formulate the selection rule for determining the location of the department that is being shifted as follows: when shifting (or moving) the position of a department, we do it is such a way that the department to be shifted be located as near as possible to the department which has highest interdepartmental flow with. Since we are using the centroid-to-centroid rectilinear distance as a distance measure between departments, the location for the department being shifted would be at the shortest rectilinear distance from the department which has highest interdepartmental flow with.

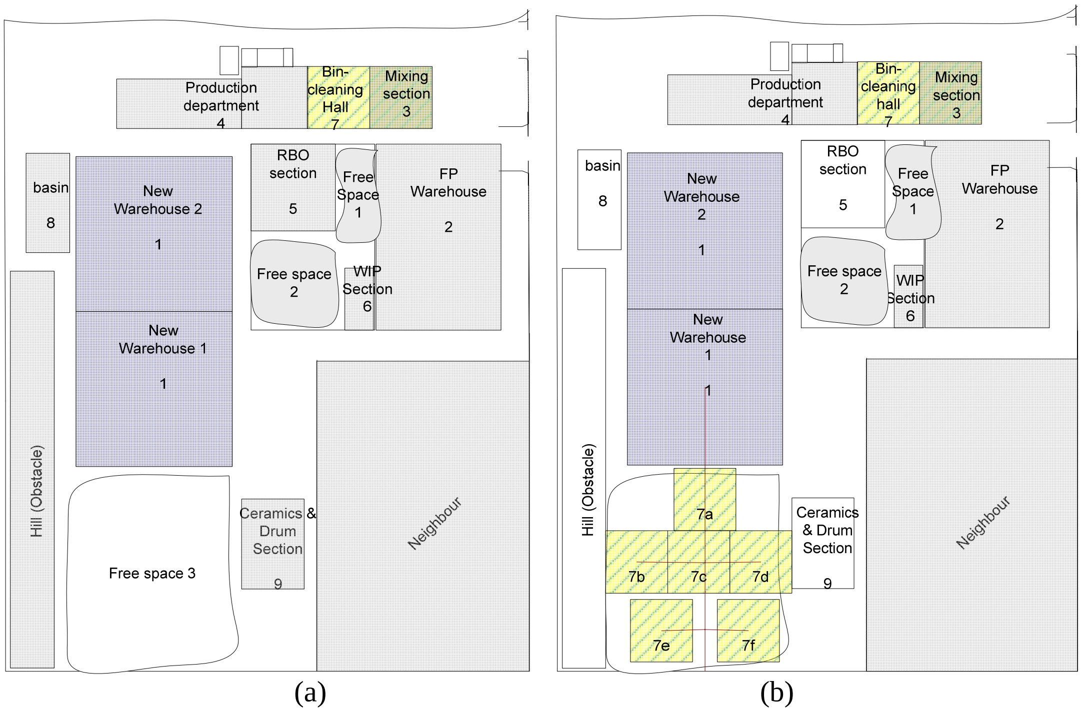


Figure 5.6: illustration of the exchange procedure – (a) initial layout, (b) one exchange instance

We illustrate this by an example: referring to layout in Figure 5.6 (a), suppose we want to move the Bin-cleaning hall (#7) to *Free Space 3*, Figure 5.6 (b) shows some of the possible locations of the Bin-cleaning hall after it being moved to Free Space 3. The Bin-cleaning hall has highest interdepartmental flow with the New Warehouse 1, and since we are considering the centroid-to-centroid distance, it should be located at the shortest rectilinear distance to New Warehouse 1. Hence, looking at Figure 5.6 (b), we select location *#7a* and discard the other location options from consideration.

To begin executing the algorithm, we start with the existing layout as initial layout. The tentative location of the New Warehouse has been identified, but its location can be change; we use this tentative location as its initial location. The locations of the other new departments are randomly placed in the free floor spaces as shown in Figure 5.6. The problem with the random placement of the new departments is that since the algorithm we are applying is path dependent, the quality of the final layout can depend on the initial layout. To reduce the effect of the initial layout on the final layout, we will locate the new departments in different locations in Scenario 2.

We use MS Excel for executing the algorithm (calculating the distances between the centroids of the departments and for calculating the layout cost for every exchange of all iterations). We also use MS Visio as visual aid for constructing the layout for all exchanges of all iterations.

Table 5.4 summarizes the exchange options for the first iteration and the corresponding total transportation distance of the each exchange option. We start with the initial layout (with total material transportation distance per day = 35,318 meters) shown in Figure 5.6. We proceed with performing feasible pairs of department exchanges or moving a department to the free spaces. The best exchange option for the first iteration is moving the 'Mixing section' to the free space within the RM-Warehouse (Free space 2) which is shown in Figure 5.7. Of course this is apparently justifiable in the sense that since the New Warehouse and the Mixing section have the highest interdepartmental flow, a reasonable solution should place them near to each other. This exchange reduces the initial transportation distance per day to 27,985 meters. The layout formed by the best exchange option in iteration 1 is then used as initial layout for iteration 2.

Exchange number	Exchange option	Total transportation distance of each
Initial		35318
1	New Warehouse *with* the Ceramics & Drum section	39191
2	Mixing section *with* the WIP-section	29852
3	Mixing Section *with* Bin-cleaning section	33848
4	WIP-section *with* the Bin-cleaning section	29524
5	Bin-cleaning section *with* the Ceramics & Drum section	42328
6	Basin *with* the Ceramics & Drum section	36290
7	Move the Bin-cleaning section to Free space 2	34650
8	Move the Mixing section to Free space 2	27985
9	Move the WIP-section to Free space 1	31934
10	Move the Bin-cleaning section to Free space 3	34870
11	Move the Basin to Free space 3	36200
12	Move the New Warehouse to Free space 3	40507
13	Move the Ceramics & Drum section to Free space 3	33758

Table 5.4: the exchange options of iteration 1

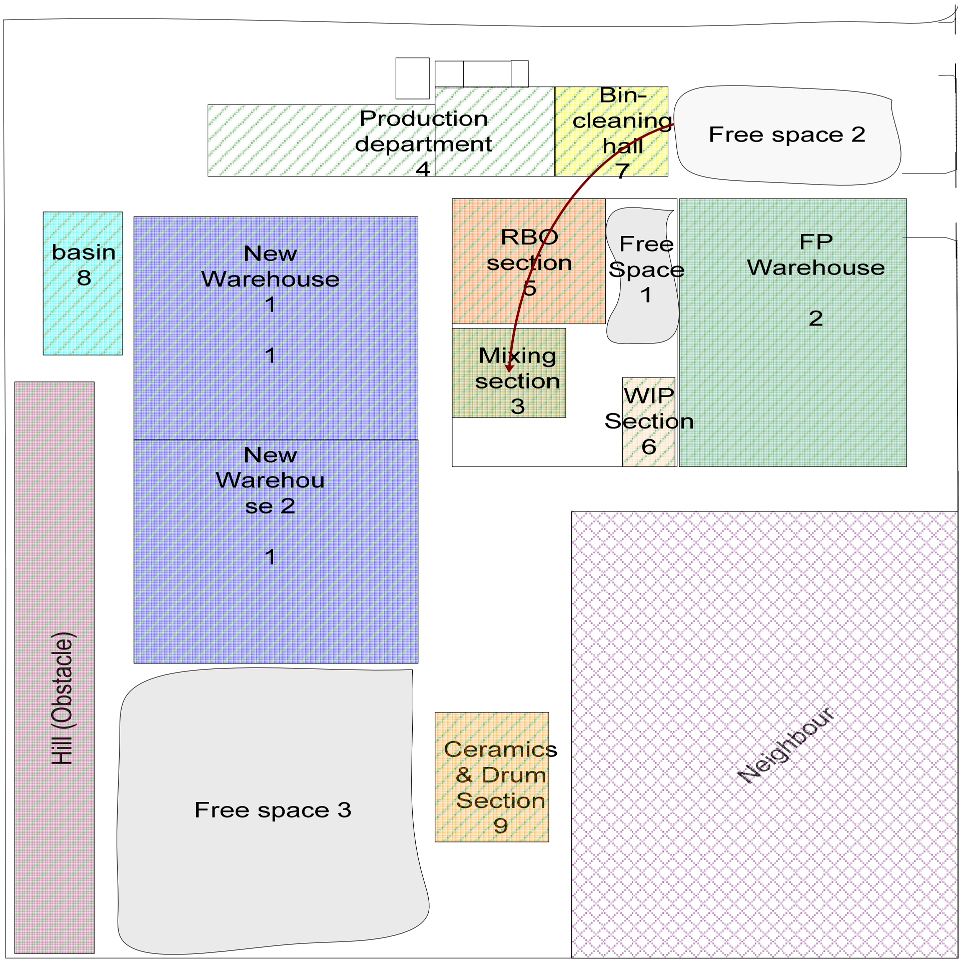


Figure 5.7: best exchange of iteration 1

Table 5.5 summarizes the exchange options for all iterations and the corresponding total transportation distance per day of each exchange option. At every iteration, the exchange option that results in the maximum reduction in the transportation distance is selected and used as initial layout for the next iteration. In iteration 2, exchange 4 (exchanging the WIP section with the Bin-cleaning section) reduces the initial layout transportation distance of iteration 2 to 27,675 meters. The layout resulted from exchanging the WIP section with the Bin-cleaning section is then used as initial layout for iteration 3.

Exchange options	Iteration						
	1	2	3	4	5	6	7
Initial layout	**35318**	**27985**	**27675**	**26035**	**25755**	**23527**	**22554**
1	39191	28658	28348	26708	25632	24610	24757
2	29852	29356	26035	26358	27324	26093	26731
3	33848	32854	32336	26541	23527	24432	23143
4	29524	27675	28123	29643	25841	24116	22582
5	42328	32369	28181	25755	26344	23527	22981
6	36290	28911	33931	26497	26245	22554	24354
7	34650	27985	28543	26075	25237	25687	
8	27985	35225	29137	28024	25095		
9	31934	28867	27395				
10	34870	29137	29737				
11	36200	29974	26515				
12	40507	28405	29664				
13	33758						

Table 5.5: Cost of alternative layouts at each iteration for all exchanges

The improvement process is then restarted with a new layout and continued until it comes to termination in iteration 7 when there are no exchanges that further reduce the estimated transportation distance. This results in the best layout of scenario 1 which is shown in Figure 5.8 (the best layout alternatives for every iteration are can be found in the Appendix 3).

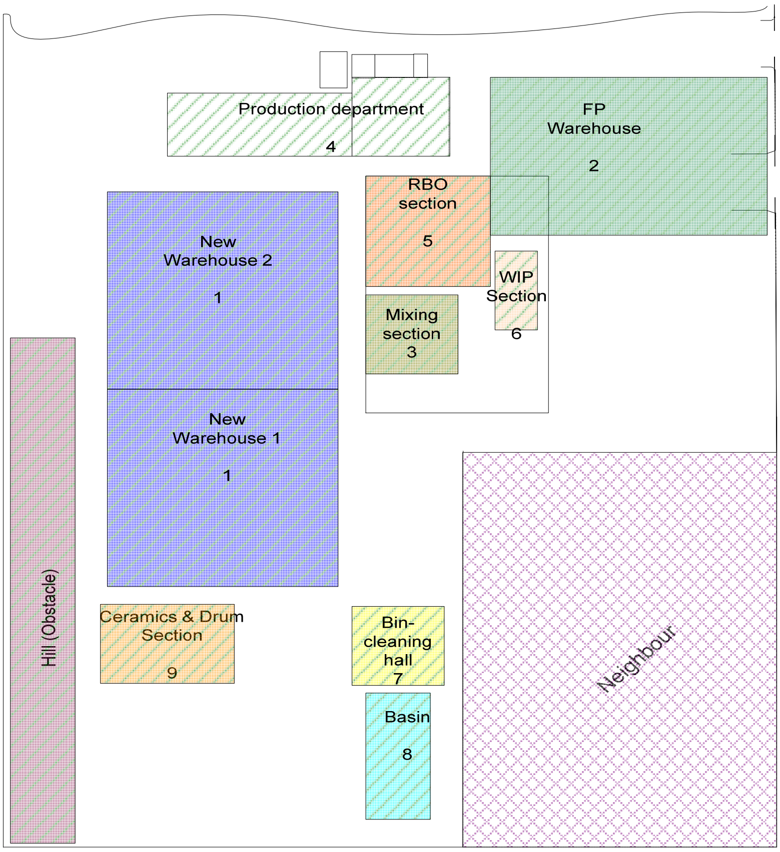


Figure 5.8: Best layout of Scenario 1

As can be seen from Figure 5.8, most of the department pairs with higher interdepartmental flow are placed next to each other. For example, the New Warehouse and the Mixing section (1&3), the Mixing section and the WIP section (3&6), the WIP section and the RBO section (6&5), the Production department and the FP-Warehouse (4&2), and the RBO section and the FP-Warehouse are placed next to each other.

The location of the FP-Warehouse is moved near to the Production department in the final layout. This is because of the high interdepartmental flow from the Production department to the warehouse. Moreover, to make use of the existing facilities and to keep of the walls of these facilities intact, the shape of the FP-Warehouse should be modified to L-shape in the final layout as shown in Figure 5.9. The final layout of Scenario 1 is displayed in Figure 5.10 with the shape of the FP-Warehouse modified.

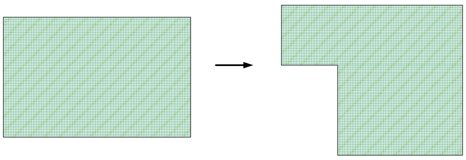


Figure 5.9: The shape of the FP-Warehouse modified

However, placing the FP-warehouse near to the Production department brings about the dislocation of the Maintenance section to other locations, and will require additional investment for the part of the FP-Warehouse that may be built near to the Production department. However, it doesn't mean that the existing FP-warehouse should be demolished and a new FP-Warehouse should be built; instead, the FP-Warehouse can be extended so that the space near the Production department can be used for storing the finished products, and the extra space (about 1160 m^2) at the rear end of the warehouse can be used for other purposes including for storing raw materials in cases of space shortages in the raw materials warehouse.

Nevertheless, the economic benefits of the extending the FP-Warehouse should be studied first before implementing it. One of the advantages of the extension is that the distance that a unit load travels from the Production department to the FP-Warehouse is reduced by about 35 meters. In Appendix 1, we calculated the cost per meter for transporting a unit load from the Production department to the FP-Warehouse to be about *€0.13*; and about 16,790 unit loads are transported from both the Production department and the RBO section to the FP-Warehouse each year. The annual saving that accrues from extending the FP-Warehouse is roughly *€76,348*. On the other hand, the cost of the extension is compared. The area to be extended is about 1160 m^2. According to the facilities manager of the company, the cost of building a new warehouse can be around €200 per m^2. Table 5.6 compares the payback periods of the extending the FP-Warehouse for warehouse types whose cost range from €200 to €400 /m^2. Accordingly, the payback periods range from 3 to 6 years. Compared to the design lifetime of the warehouses (which is more than 10 years), we conclude that extending the FP-Warehouse is economically feasible.

Warehouse cost per m2	Area to be extended (m2)	Annual Saving	Payback period (yrs)
€ 200.00	1160	€ 76,347.72	3.04
€ 250.00			3.80
€ 300.00			4.56
€ 350.00			5.32
€ 400.00			6.08

Table 5.6: Payback periods of extending the FP-Warehouse

It is also important to mention that the best layout of Scenario 1 (redrawn in Figure 5.10) satisfies the qualitative requirements and practical restrictions described in Section 3.8. The paths of the trucks (set line A), access road to the fire brigade (line set B), and the space required for the docks and maneuvering and parking areas (C) are all being fulfilled. The walls of the RM-Warehouse and the FP-Warehouse are kept intact. Besides, the departments that need investment if they are to be built new (Mixing section, and WIP-section) are located within the existing facilities (RM-Warehouse) to avoid such investments. Furthermore, there are no overlaps in the locations of the departments. The basin is also located at the far end.

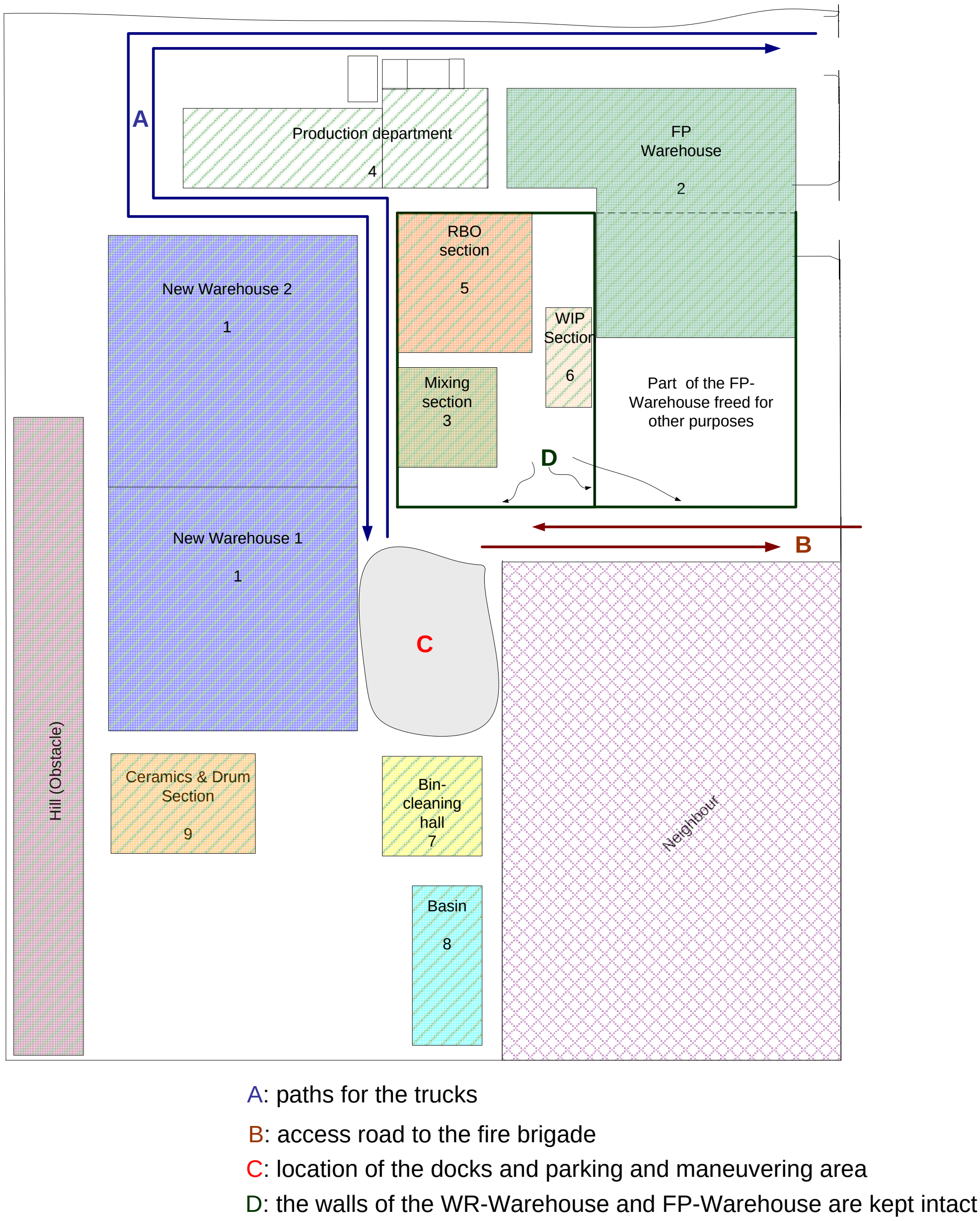


Figure 5.10: Best layout from scenario 1 with the shape of the FP-Warehouse modified

5.3 Scenario 2: the Machines are Located in the Handling department

The SLP steps for Scenario 2 are similar to the steps for Scenario 1. To avoid unnecessary repetitions, here, we shortly discuss Scenario 2 (Details are given in Appendix 2).

In Scenario 2, the machines are located together in the Handling department instead of in the New Warehouse. The New Warehouse is now used only for actual storage of the incoming materials. The change in the location of the machines brings about changes is the flow the materials that are treated in the FBO and RBOs. The flows of these materials are shown in Figure 5.11 (a) and (b). On the other hand, the materials coming out of the Handling department in this scenario are: the pre-treated materials that go to the WIP-section, the ceramics and used drums that go to the Ceramics & Drum section, and the emptied bins going to the Bin-cleaning section. The Flow of the bins is shown in Figure 5.11 (c).

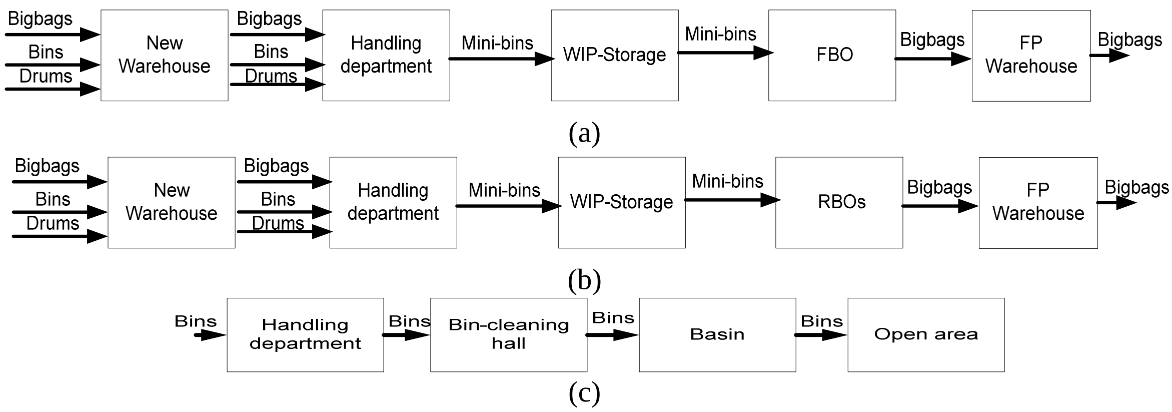


Figure 5.11: Schematic flow diagrams of materials treated in (a) FBO, (b) FBOs, and (c) the bins.

When the machines are located in the Handling department (Scenario 2), the New Warehouse is used only for actual storage of the incoming materials. The materials that are treated in the FBO and RBOs then have to pass through the Handling department for the pre-treatment. The flow of ceramics, the drums, and empty bins, therefore, originates from the Handling department. Since the New Warehouse is used only for storage purpose, we don't divide it into two halves unlike in Scenario 1. The flow of the materials in Scenario 2 are aggregated in the from-to table as in Table 5.6.

Facility name	New Warehouse	FP Warehouse	Handling department	Production department	RBO section	WIP-Storage	Bin-cleaning hall	Basin	Ceramic and Drums
New Warehouse	0	0	90	10		0	0	0	0
FP-Warehouse	0	0	0	0	0	0	0	0	0
Handling department	0	0	0	0	0	56	7	0	60
Production department	0	31	0	0	0	0	0	0	0
RBO section	0	15	0	0	0	0	0	0	0
WIP-Storage section	0	0	0	41	15	0	0	0	0
Bin-cleaning hall	0	0	0	0	0	0	0	7	0
Basin	0	0	0	0	0	0	0	0	0
Ceramic and Drums	0	0	0	0	0	0	0	0	0

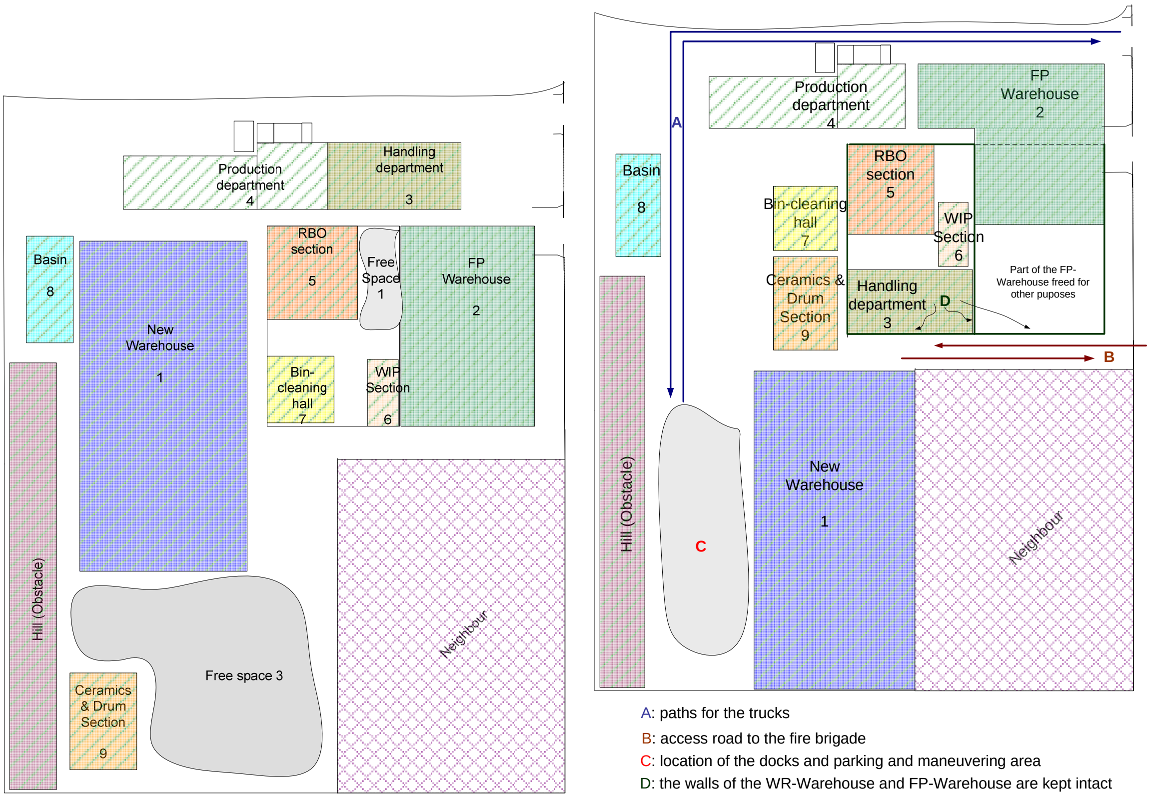
Table 5.6: Flow-to chart of the facilities in Moxba-Metrex

Having the data from Figure 5.11 and Table 5.6 as an input, we follow the SLP steps for this scenario in the same manner as Scenario 1. As we mentioned while discussing the initial layout in Scenario 1, the algorithm we are applying is path dependent that the final result may be affected by the initial layout. To reduce this effect, we start with an initial layout (displayed in Figure 5.12 (a)) with the Bin-cleaning section and the Ceramics & Drum section being located in different locations compared to that of Scenario 1.

Starting with this initial layout, we applied the improvement algorithm to develop the best layout for this scenario (i.e., when the machines are located in the Handling department). The final layout (with materials transportation distance per day = 20,857 meters) for this scenario is shown in Figure 5.12 (b). The final layout has placed department pairs with higher interdepartmental flow next to each other. For example, the New Warehouse and the Handling department (1&3), Handling department and the WIP section (3&6), the Handling department and the Ceramics & Drum section (3&9), and the Production department and the FP-Warehouse (4&2) are placed next to each other.

Similar to that of Scenario 1, the FP-Warehouse in Scenario 2 is also placed next to the Production department. Hence, the FP-Warehouse should be extended to include the area near the Production department, and to retain the existing facilities as they are, its shape should be modified to L-shape.

As can be noticed from Figure 5.14 (b), the qualitative requirements and practical restrictions are all satisfied (see the layout from Scenario 1 in Figure 5.10 for explanation).



(a) (b)

Figure 5.14: layouts of scenario 2 – (a) initial layout and (b) final layout

5.4 Conclusions

This chapter has mainly focused on developing the alternative layouts based on transportation distance of transporting materials between departments as evaluation criterion. We have considered two scenarios depending on the locations of the machines that are used for the pre-treatment processes:

1. We propose that the machines be located in the *Handling section* within the New Warehouse; and the mixers be located in the *Mixing section* within the RM-Warehouse.
2. The machines are located in their current location (i.e., the Handling department together with the mixers).

We executed the improvement algorithm to develop alternative layouts and to examine the effect of locating the machines in the New Warehouse. With modification to the shape of the FP-Warehouse, the best layouts for each scenario which are presented again in Figure 5.15.

(a) (b)

Figure 5.15: alternative layouts (a) Scenario 1 cost =22,554 (b) Scenario 2, cost = 20,857

Comparing the alternative layouts from the two scenarios, the layout from Scenario 2 (machines located in the Handling department) results in better transportation distance than that of Scenario 1 (20,857 Vs 22,554). However, this is a rough estimation of the transportation distance obtained by considering centroid-to-centroid measure, and the distance can change when we develop the detailed layout and consider the actual aisle distance measure as a distance measure. Also, there are other criteria that should be considered to choose the final layout (namely, initial investment, space utilization, and building expansions). Before we make the final selection, let's develop the detailed layouts of both alternatives. The next chapter deals with the detailed representation of the alternative layouts.

Chapter 6
Detailing the Alternative Layouts

In this chapter we develop the detailed layouts for the alternative block layouts we developed in Chapter 5 from the two scenarios. In Section 6.1 we determine the locations of the machines and facilities within each department and the locations of the input/output stations of the departments for both scenarios. Section 6.2 deals with the design of the material flow paths connecting the departments. We evaluate and compare the alternative layouts using the cost and non-cost criteria in Section 6.3. We close the chapter with conclusions.

6.1 Locations of the Machines and Pickup and Drop-off Points

In Chapter 5, we developed two alternative layouts based on the two scenarios we considered, and we determined the relative locations of the departments. The locations of these departments being not final, their shapes and locations can be adjusted within the vicinity of their relative locations and without disrupting the general layout of the departments. The adjustment may come along with locating the machines/facilities within these departments and the input/out stations of the departments. For example, the location of the Handling department (in Scenario 2) can be adjusted based on the arrangement of the machines within this department and based on the general flow of the materials from the New Warehouse to the Handling department and from Handling department to the next destinations. Based on this premise, we develop the detailed layout of the departments in the following sections.

6.1.1 Scenario 2: the Machines are Located in the Handling department

There are three departments within the RM-Warehouse: the RBO section, the WIP section, and the Handling department. Materials coming in/out of these departments should pass through the input/output doors of the RM-Warehouse. The input/output doors to the RM-Warehouse mainly depend on the layout of the machines in the Handling department. Here we take only the RM-Warehouse from Figure 5.15 (b) and determine the layout of the machines in the Handling department and the locations of the input/output doors to the RM-Warehouse. We show the possible layouts of the machines in the Handling department and the locations of the input/output doors to the RM-Warehouse in Figure 6.1.

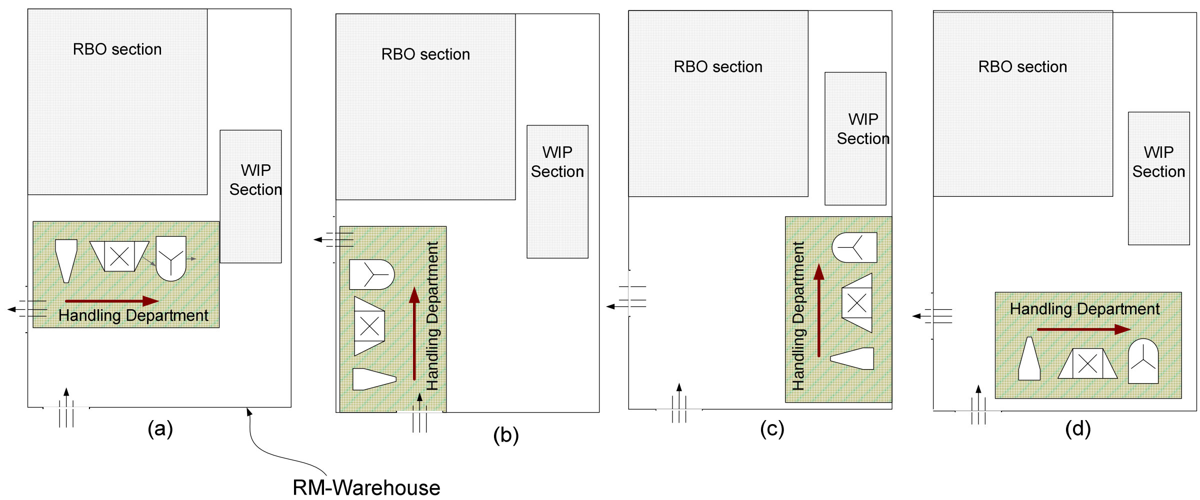


Figure 6.1: Possible layout of machines in the Handling department within the RM-Warehouse

As we mentioned earlier, the shapes and locations of the departments can be adjusted when developing the detailed layout. Accordingly, the shape and/or location of the Handling department are adjusted to comply with the arrangement of the machines within it and the input/output doors to the RM-Warehouse. The optimal arrangement of the machines should allow smooth flow of materials and minimum transportation requirements.

The pickup and drop-off points (P/D)

Every department, which materials are picked up from or delivered to, has pickup and drop-off points. The locations of these points are determined by the locations of the machines/facilities which the materials are picked from and which the materials are delivered to. In determining these points we assumed that:

1. For those departments whose locations are fixed, the locations of the pickup and drop-off points are fixed as well.
2. For the New Warehouse, the FP-Warehouse, WIP-storage, and Ceramics & Drum section, there is no fixed pickup and/or drop-off point. For those departments we use their centroids as the pickup and/or drop-off points.
3. The materials that arrive in the Handling department are filled into the banker; the bins after their contents are emptied into the banker are taken into the Bin-cleaning section, and the ceramics drums are taken into the Ceramics & Drums section. Therefore, for the materials that arrive in the Handling department, the drop-off point is the banker, but the pickup point depends on the kind of materials that need to be transported to the other departments. We assume the sieve machine as the pickup/drop-off point.
4. For the Bin-cleaning section, the drop-off point is the washing machine; and the pickup is in the separate area for inspection and labeling within the Bin-cleaning section.

Locations the input/output doors (I/O) of the departments

The input/output doors of the departments should be designed in such a way that they allow smooth flow of materials, and minimize transportation distance of materials between each pair of departments with interdepartmental flow.

The Handling department, the RBO section, and WIP-section are open sections within the RM-Warehouse; so there is no real wall separating these departments. However, the materials that come from other departments and those that go to the other departments need to pass through the doors of the RM-Warehouse. The locations of these doors are determined by the arrangement of the machines within the Handling department. We locate the input/output doors of the departments so that the forklifts passing through these doors from/to other departments will travel the shortest rectilinear distance possible. In Figure 6.1, we provide the locations of the input and output doors to the RM-Warehouse depending on the locations of the machines in the Handling department. The four alternative arrangements of the machines induce four different layouts.

Having the pickup and drop-off points (P/D) and the input/output doors (I/O) for all departments determined, we calculated the transportation distance per day by taking the rectilinear distance from the pickup point of one department to the drop-off point of the other department into account instead of the centroid-to-centroid measure. Table 6.1 shows the total transportation distances per day for the four layout options corresponding to the four layout arrangement of the machines in the Handling department. Based on this, the arrangement of the machines in Figure 6.1 (a) result in a better layout cost; and this arrangement is used for locating the input/output doors for the RM-Warehouse.

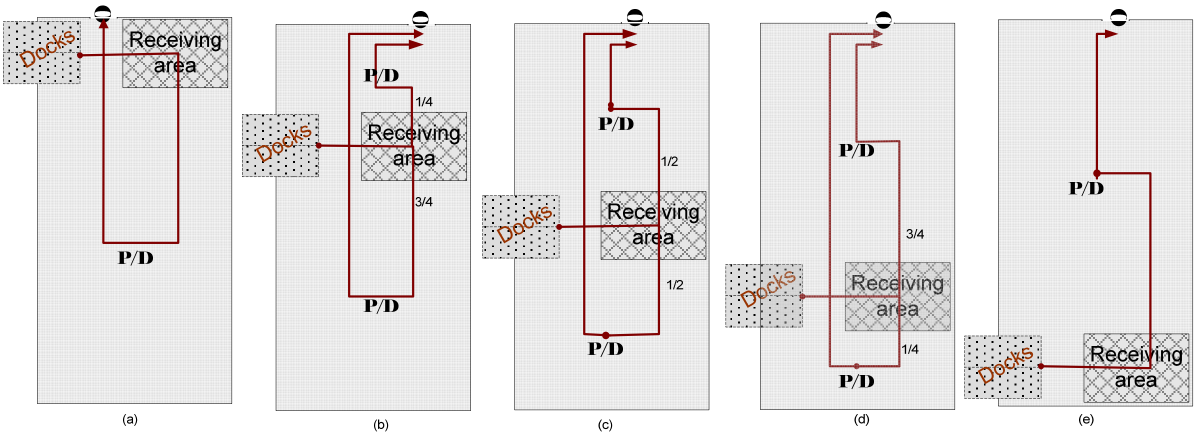
Layout option	total trnsportation distance per day
a	21222
b	21354
c	21226
d	22316

Table 6.1: Layout costs considering the four layout option in Figure 6.1.

The locations of the docks and the receiving area for the New Warehouse

The location of the docks has a big impact on the flow of the materials and, hence, on the distance that the materials should be transported within the warehouse. The location of the receiving area is directly related to the location of the docks for the incoming materials and the general flow of the materials within the warehouse. For efficient flow of the materials within the warehouse, the Receiving area should be located next to the receiving docks.

Every incoming material enters the New Warehouse through the docks, is kept in the Receiving area until it is sampled, is then stored in the storage area; finally it goes out through the output door (O). In Figure 6.2, we provide the possible location of the docks and the Receiving area. The arrowed lines in the figure represent the approximate paths that a unit load travels within the warehouse. The locations of the docks and the Receiving area divide the floor area of the warehouse in different proportion. For example, in Figure 6.2 (a), the docks and the Receiving area are located at the rear end of the warehouse, whereas, in Figure 6.2 (b), the docks and the Receiving area divide the storage floor area of the warehouse in the ratio of 1:3. This means, ¼ the incoming materials are stored in one side and ¾ of the incoming materials on the other side, and the distance that these materials are moved within the warehouse are determined accordingly. In Table 6.2, we provide the corresponding internal transportation distances within the warehouse for each location option. The location of the docks and the receiving area in option (c) result in a better internal transportation cost. Hence, we incorporate the locations of the docks and the receiving area in option (c) in the final layout.



P/D: pickup & drop-off point

O: output (exit) door

Figure 6.2: Alternative locations of the docks and the receiving area of the New Warehouse

Location option	total transportation distance of a unit load within the New Warehouse
a	9765
b	6475
c	6205
d	7035
e	7875

Table 6.2: Internal transportation distances for the alternative location shown in Figure 6.2

In Figure 6.3, we depict the detailed layout of the departments in Scenario 2 incorporating the layout of the machines in the Handling department shown in Figure 6.1(a) and the locations of the docks and the Receiving area in the New Warehouse shown in Figure 6.2(c).

Figure 6.3: Detailed layout of the departments in scenario 2

6.1.2 Scenario 1: the Machines are Located in the New Warehouse

To determine the locations of these machines in the New Warehouse, let first see the activities in the New Warehouse. The activities in the New Warehouse correspond to the processes required for the incoming materials:

1. The receiving of the incoming materials: as we discussed in Section 4.1, one of the processes that has been causing inefficiencies in the warehouse is the fact that there is no reserved receiving area for the incoming materials. In our research we observed the importance of the separate Receiving area; and we proposed that this Receiving area be made available.
2. The pre-treatment processes for the incoming materials: in Scenario 1, the pre-treatment processes are carried out in the New Warehouse; and a separate area should be reserved for locating the machines and activities required for these processes.
3. The actual storage of the materials: the major function of the warehouse is storage of the materials; and a separated area should be dedicated for this purpose as well.

Therefore, the New Warehouse should be partitioned to accommodate the three sets of activities. Of course, the spaces required by these activities are open areas within the New Warehouse; and no wall may be required for separating them.

The location of the machine in the New Warehouse

The location of these machines depends on the flow of the materials within the warehouse. Once the incoming materials are received, they are ready for sampling, sieving, and separation. For efficient flow of the materials, the facilities required for consecutive processes should be placed next to each other so that the materials will not be transported for long distances between consecutive processes. The locations of the machines depend on locations of the docks and the Receiving area.

Figure 6.4 shows the layout of the departments in Scenario 1. When we developed the alternative layouts, we assumed that the first part of the New Warehouse is used for receiving the incoming materials and for locating the machines for the pre-treatment purpose. Therefore, the docks for the New Warehouse should be located in the first part of the Warehouse.

Before positioning the docks in the warehouse, a few things have to be taken into consideration; namely:

- The locations of the docks should allow smooth flow of materials, should avoid minimize the transportation requirements
- There should be enough space for movement, maneuvering and parking of trucks (Tompkins, White et al. 2003).

Taking these considerations into account, the only possible location of the docks is circled in the Figure 6.4.

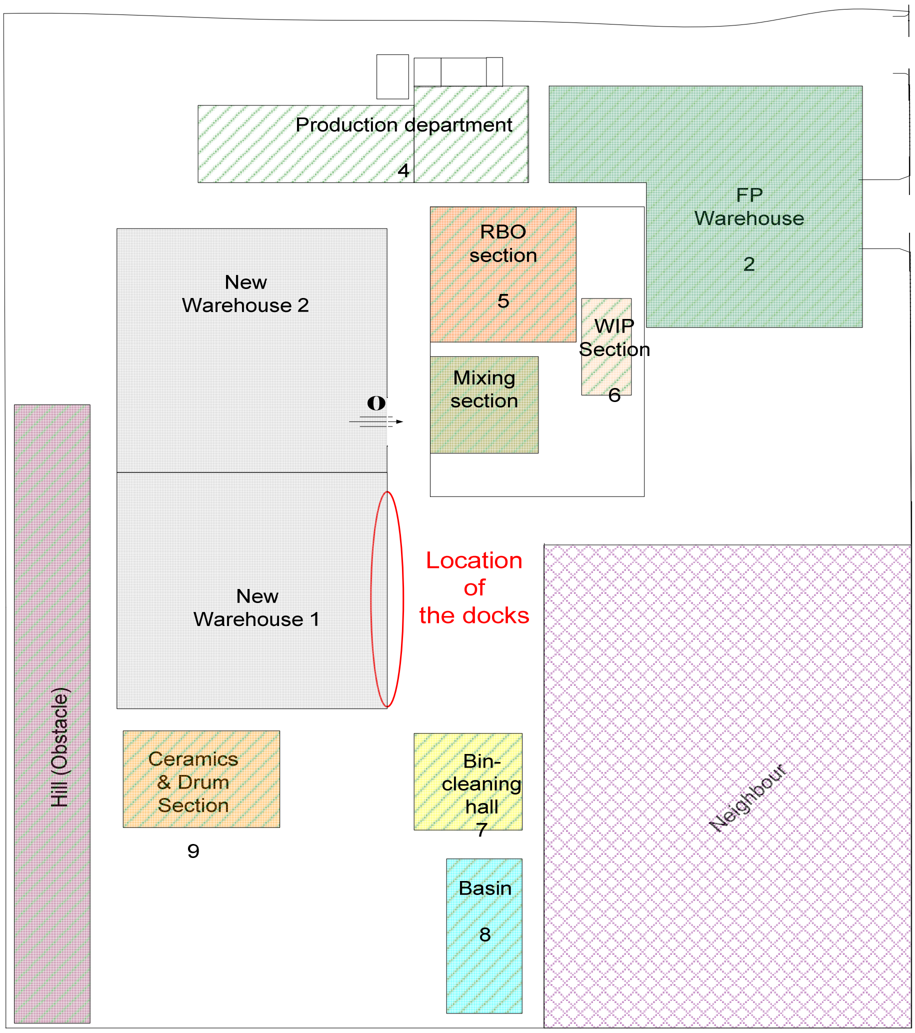


Figure 6.4: Layout of departments in scenario 1 with the possible location of the docks for the New Warehouse indicated.

The location of the docks in the warehouse has a direct impact on the location of the Receiving area and the locations of the machines used for the pre-treatment processes. Figure 6.5 shows the possible arrangement of the docks, the machines, and the Receiving area in the New Warehouse.

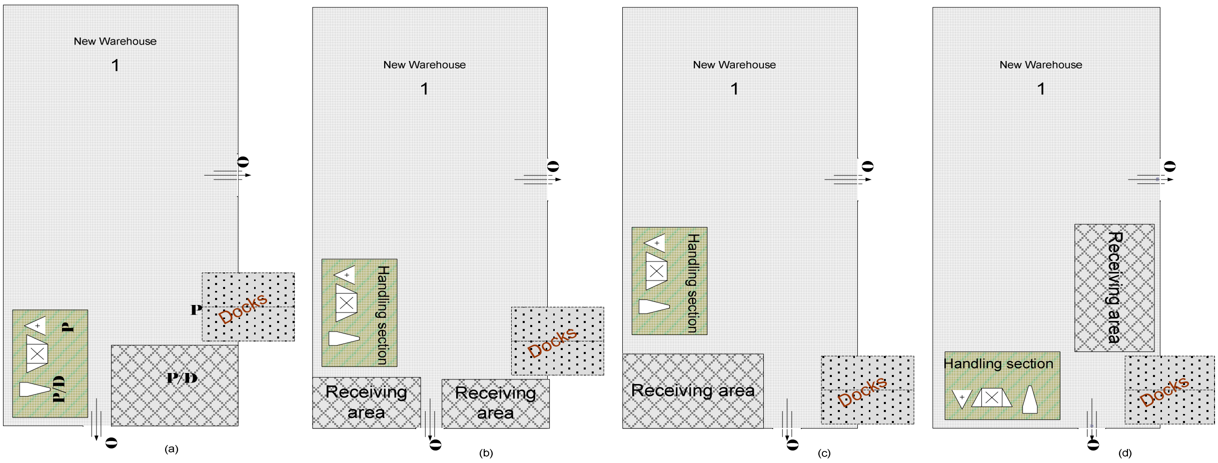


Figure 6.5: Alternative locations of the docks, the receiving area, and the Handling section

There is internal transportation involved in transporting the incoming materials from the dock to the Receiving area, from the Receiving area to the Handling section, and from the Handling section to their storage space. The transportation distance differs depending on the location of the docks, the machines and the receiving area. The internal transportation distances for the four arrangements of the machines and the Receiving area in the New Warehouse are given in Table 6.2. Accordingly, layout option show in Figure 6.5 (a) results in a better internal transportation distance.

Location option	total transportation distance of a unit load within the New Warehouse
a	8029
b	9233
c	8169
d	9492

Table 6.2: Internal transportation costs for the alternative location shown in Figure 6.4

Locations of the pickup and drop-off points and the input/output doors

In Figure 6.5, we also show the output doors for the New Warehouse for the possible arrangement of the machines and the Receiving area. The output doors for the New Warehouse are selected is such a way that the materials going out of the warehouse will be transported to the next destination with the shortest rectilinear distance possible. In Figure 6.6, we depict the detailed layout of the department incorporating Figure 6.5 (a) and the pickup and drop-off points and the input/output doors for the departments in Scenario 1.

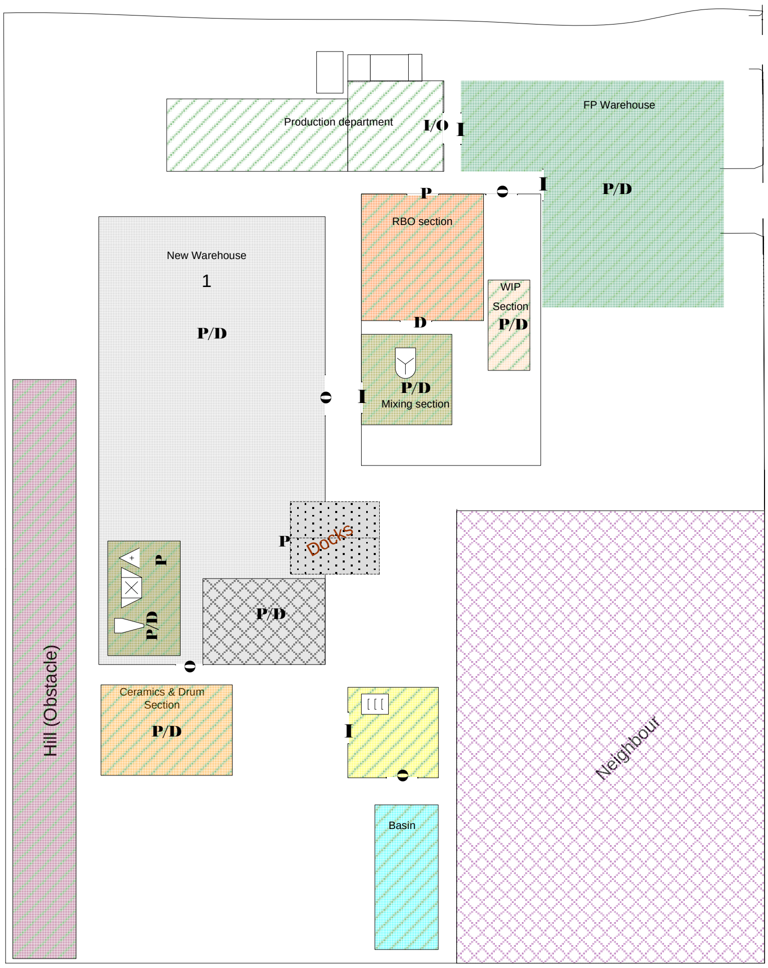


Figure 6.6: Detailed layout of the departments in scenario 1

6.2 Flow Network Design

Having the locations of the departments fixed and the input/output doors and the pickup and drop-off points for all departments located, now, we are in a position to design the materials flow networks to aid as paths for transporting materials between departments or as aisles between stations within a department.

In Section 3.5, we introduced the *shortest r-flow Network model* which we are, now, going to apply it to design the material flow paths. The model permits free and bidirectional flow and uses rectilinear distance measure. It starts by drawing horizontal and vertical lines through each station in which the intersections of each horizontal and vertical line define a grid point; it proceeds with simplifying the network by removing some of the arcs without affecting the final network; finally the least cost algorithm is applied.

We start by designing the network for the layout found in Scenario 1 (machines are located in the New Warehouse). Figure 6.7 shows the layout of the departments in Scenario 1 with horizontal and vertical lines drawn through all the station of each department. The intersections of the horizontal and vertical lines define grid points.

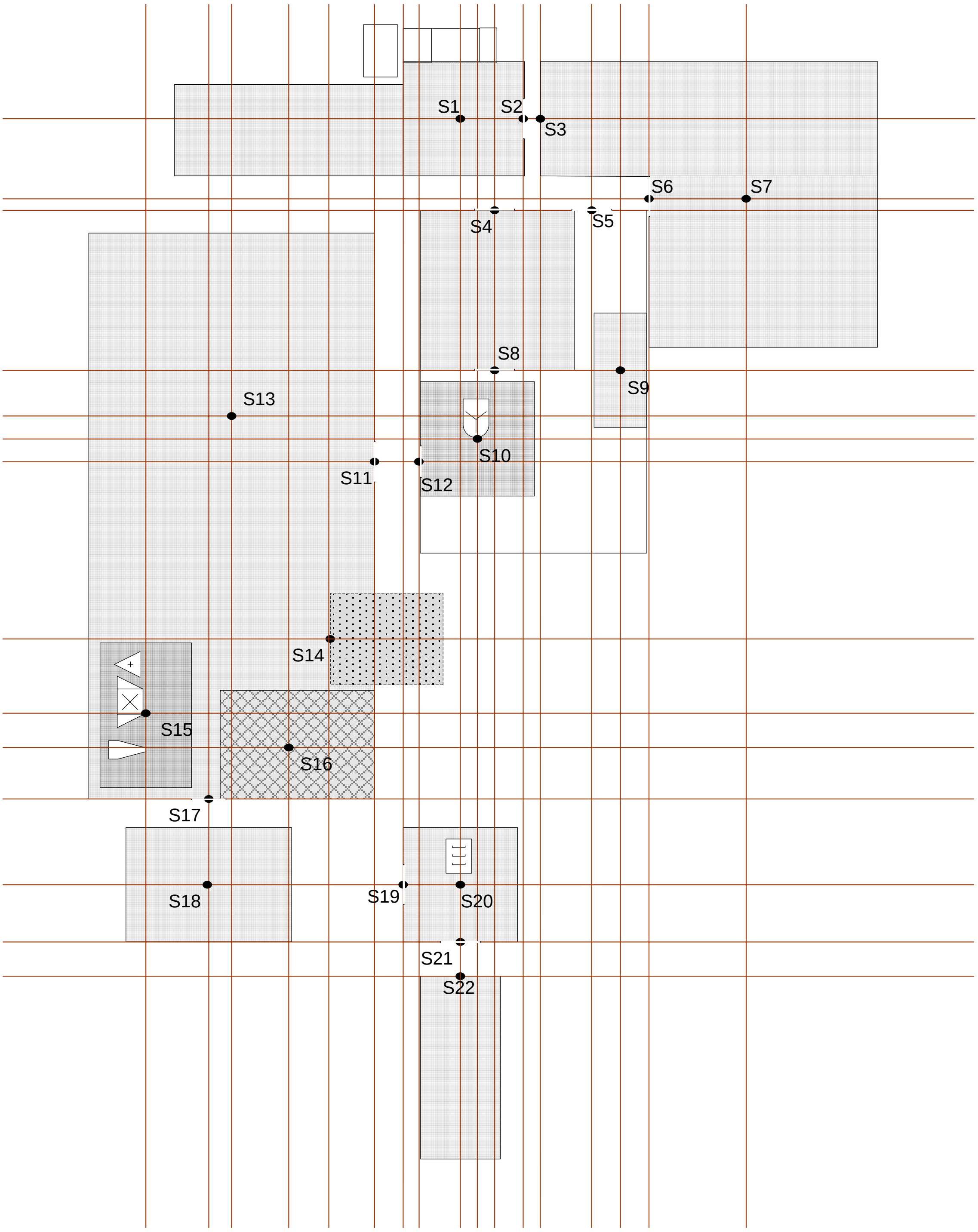


Figure 6.7: Station locations and grid graph for the departments in Scenario 1

The objective of the flow network design is to design minimum rectilinear distance paths for the materials flowing between departments. In Chapter 5, we classified the materials into five groups depending on the processes they require and, hence, the way they flow. These are:

1. the materials that are treated in the FBO which passes through the stations designated by f_1: S15 → S17→ S16 → S14 → S12 → S13→ S11 → S10 → S8 →S2 → S1 → S2 → S3 →S4→ S6
2. those treated in the RBOs which pass through the stations designated by f_2: S15 → S17 → S16 → S14 → S12 → S13 → S11 →S10 → S9 → S7 →S5 → S6
3. those treated in the RTO which pass through the stations defined by f_3: S15 → S17 → S14 → S12 → S13 → S8 → S2 → S1 → S2 → S3 →S4 → S6

4. the bins which pass through the stations defined by
   f_4: S16 → S18 → S20 → S21 → S22 → S23
5. the ceramics and drums which pass through the stations designated by
   f_5: S16 → S18 → S19

Therefore, the stations that are included in the path flow of a group of materials need to be connected. Some of the arcs connecting two stations lie within the departments that additional investment on paths may not be required; for example, the arcs between the paths (S14, S16) and (S15, S13) lie within the New Warehouse and the arc between the path (S9, S5) lies within the RM-Warehouse. On the other hand, other arcs lie outsides of departments that if these arcs are included in the final network, additional investment is required; for example arcs between the paths (S17, S19) and (S11, S12).

Some of the arcs in the grid graph shown in Figure 6.7 can be removed without affecting the value of the final solution. One way to remove such arcs is by picking an arc and asking the question: given a feasible solution to the network design which uses this arc, can an alternate feasible solution be found of equal or lesser value which does not use the arc? If yes, the arc can then be removed. On the other hand, all the arcs in a straight line segment joining two stations and the arcs that make up a unique path between two stations are included in the final solution. Figure 6.8 shows the reduced grid graph with some of the others removed and with some of the arcs (marked in thick dark) included in the final solution.

Having the grid graph simplified, we now apply the *least cost algorithm* to design the remaining network. The algorithm is a dynamic programming based method to find the shortest rectilinear path between two stations in the grid graph. For a flow *f*, a rectangular sub-graph defined by R (*f*) consists of precisely those arcs which may be used by *f* when some rectilinear path is taken. For example, for the grid graph in Figure 6.8, if *f* = (S15, S17), then R (*f*) will be the sub-graph induced by the nodes {13, 14, 17, 18, 21, 22}.

The nodes corresponding to the two stations (the origin and destination) lie on the opposite corners of this rectangular sub-graph. The arcs connecting the two nodes can be included in more than one rectangular sub-graph. Thus the number of rectangular sub-graphs which can potentially use an arc *a* can be easily determined. This number is called the *potential* of arc *a*, and is denoted by P_a. P_a is the number of rectangular sub-graphs *R (f)* which contain arc *a*. If an arc is included in path flow of more than one material, then the fixed cost of the path is smaller because the fixed cost is shared by more than one flow.

The fixed cost of an arc is, then, the length of the arc divided by the P_a. For instance, taking arc (11,12) in Figure 6.8, the arc is included in the rectangular sub-graphs of (S17, S16) and (S16, S18); hence, the potential of arc (11,12) is 2, and therefore the fixed cost of the arc is 6 (=12/2, 12 being the length of the arc). To this end, we have provided the fixed cost of all the arcs in Figure 6.9.

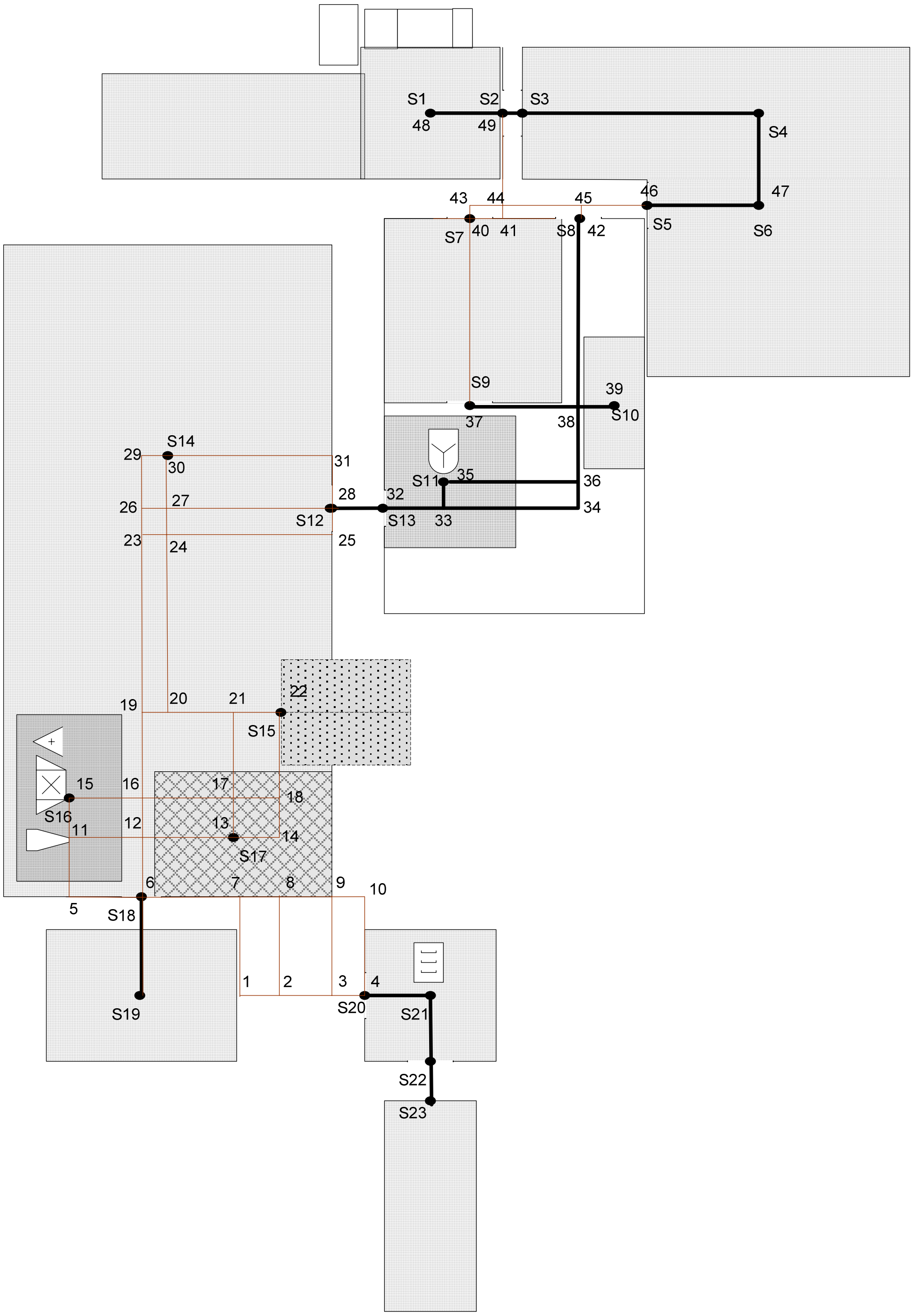


Figure 6.8: the grid graph with some of the arcs removed and with the dark lines included in the final solution

The fixed cost of a path is the sum of the fixed costs of the arcs in the path. Once an arc is included in the final solution, its cost is set to zero so that any other path of a flow can include this arc without incurring additional cost. Hence, the weights of the arcs marked in dark thick lines are all set to zero.

The material flow for each group of materials, denoted by f_1, f_2, f_3, f_4, and f_5, has to pass through the stations described above. For example, f_5 has to pass through stations S15→S17→S18. Hence, the shortest path of f_5 is the shortest paths connecting S15 with S17 and S17 with S18.

We now design the path of f_1 = (S15, S17, S16, S14, S12, S13, S11, S10, S8, S2, S1, S2, S3, S4, S6). The path f_1 is the sum of the paths that connect the stations in that flow. We start by connecting stations S15 with S17, and then S17 with S16, we then proceed until we get all stations connected.

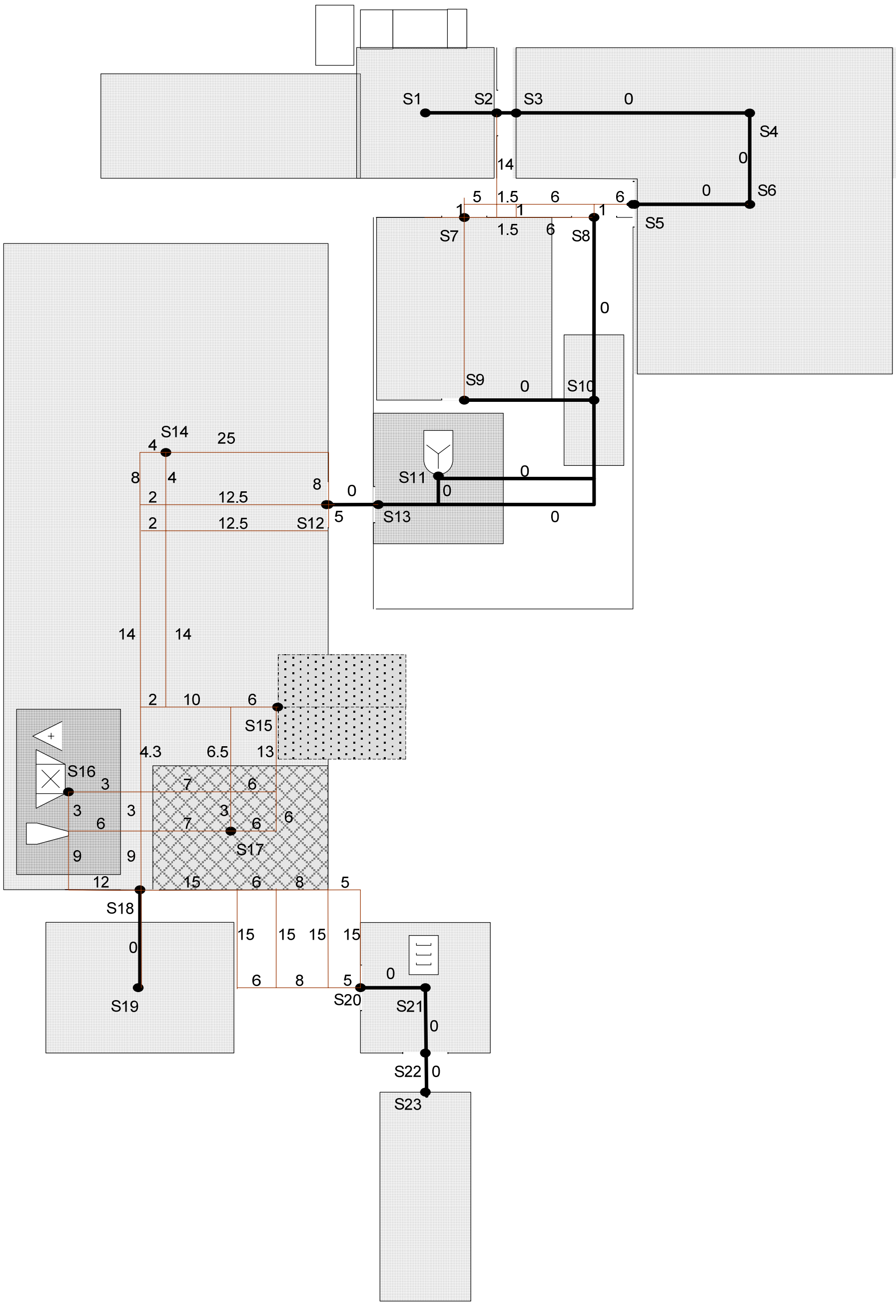


Figure 6.9: the grid graph with the weights of the arcs included

In Table 6.3, we summarize the alterative paths that connect two stations that are included in the flow network of the materials defined by f_1. For example, stations S17 and S16 can be connected by the alternative paths connecting the nodes (13, 17, 16, 15), (13, 12, 16, 15), or (13, 12, 11, 15). The costs of the alternative paths are calculated by adding the costs of the arcs included in the paths; the path with minimum cost is then selected to be included in the final solution. If in case two paths have equal cost, we arbitrarily select one; for instance, path (13, 17, 16, 15) and (13, 12, 16, 15) have equal costs of 13, but we randomly selected the later one. The selected paths for each pairs of stations are highlighted in table.

The selected paths for connecting the stations are, then, included in the final solution and marked in thick dark line. Also, the weight of those paths are set to zero so that when we design the paths for the flow of the other materials, the marked paths can be included without incurring additional cost. In Figure 6.10, we upgrade Figure 6.9 by including the paths that are selected for the network flow materials defined by f_1.

Stations to be connected	Altenative paths	cost of alternative paths
S15 ---> S17	**22-->21-->17-->13**	15,5
	22-->18-->17-->13	25
	22-->18-->14-->13	22
S17 ---> S16	13-->17-->16-->15	13
	13-->12-->16-->15	13
	13-->12-->11-->15	16
S16 ---> S14	15-->16-->19-->23-->26-->29-->30	35,3
	15-->16-->19-->23-->26-->27-->30	29,3
	15-->16-->19-->23-->24-->27-->30	29,3
	15-->16-->19-->20-->24-->27-->30	29,3
S14 ---> S12	30-->31-->28	33
	30-->27-->28	16,5
S12 ---> S13	**31-->32**	0
S13 ---> S11	**32-->33-->35**	0
S11 ---> S10	**35-->36-->38-->39**	0
S10 ---> S8	**39-->38-->42**	0
S8 ---> S2	**42-->45-->44-->49**	14
	42-->41-->44-->49	14
S2 ---> S1	49-->48	0
S1 --> S2-->S3-->S4-->S6	S1 --> S2-->S3-->S4-->S6	0

Table 6.3: alternative paths connecting two stations included in the path of f_1 and their corresponding costs

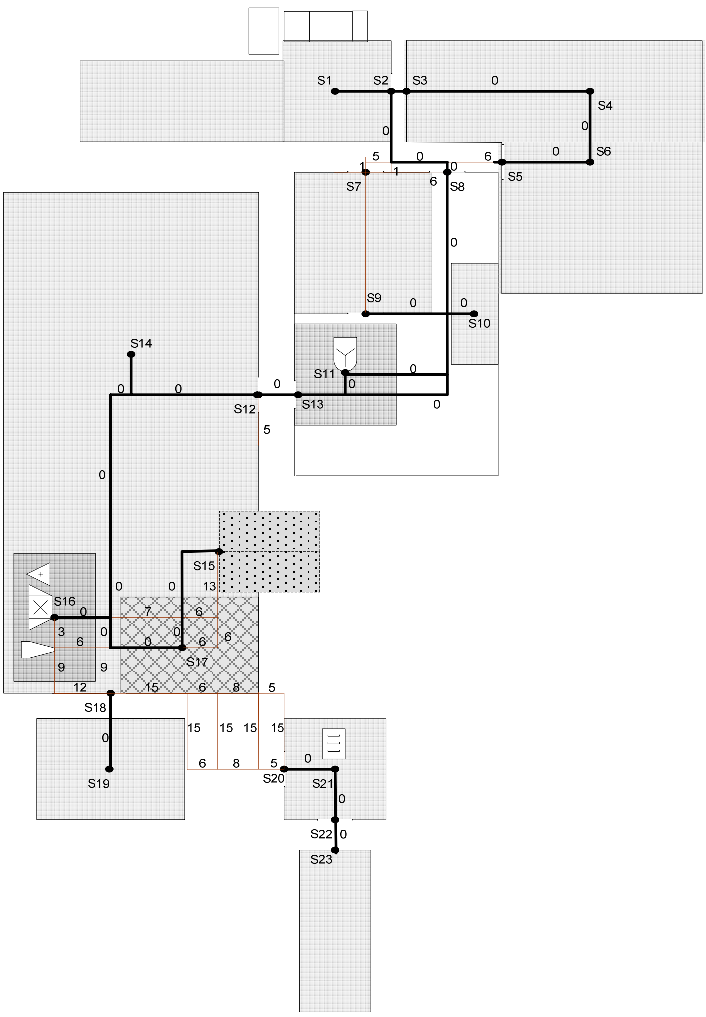


Figure 6.10: The grid graph with the arcs included in the path of f_1 connected.

Having the material flow network in Figure 6.10 as an input, we design the flow path of the other materials. Table 6.4 shows the flow paths of the materials defined by f_2. As can be seen from the table, the stations included in f_2 are already connected except stations S7 and S5.

Stations to be connected	Altenative paths	cost of alternative paths
S15 ---> S17	22-->21-->17-->13	0
S17 ---> S16	13-->12-->16-->15	0
S16 ---> S14	15-->16-->19-->23-->26-->27-->30	0
S14 ---> S12	30-->27-->28	0
S12 ---> S13	31-->32	0
S13 ---> S11	32-->33-->35	0
S11 ---> S10	35-->36-->38-->39	0
S10 ---> S9	38-->37	0
S9 ---> S7	37-->39	0
S7 ---> S5	40-->41-->42--45-->46	17
	40-->41-->44--45-->46	12
	40-->43-->44--45-->46	12
S5 ---> S6	46--->47	0

Table 6.4: alternative paths connecting two stations included in the path of f_2 and their corresponding costs

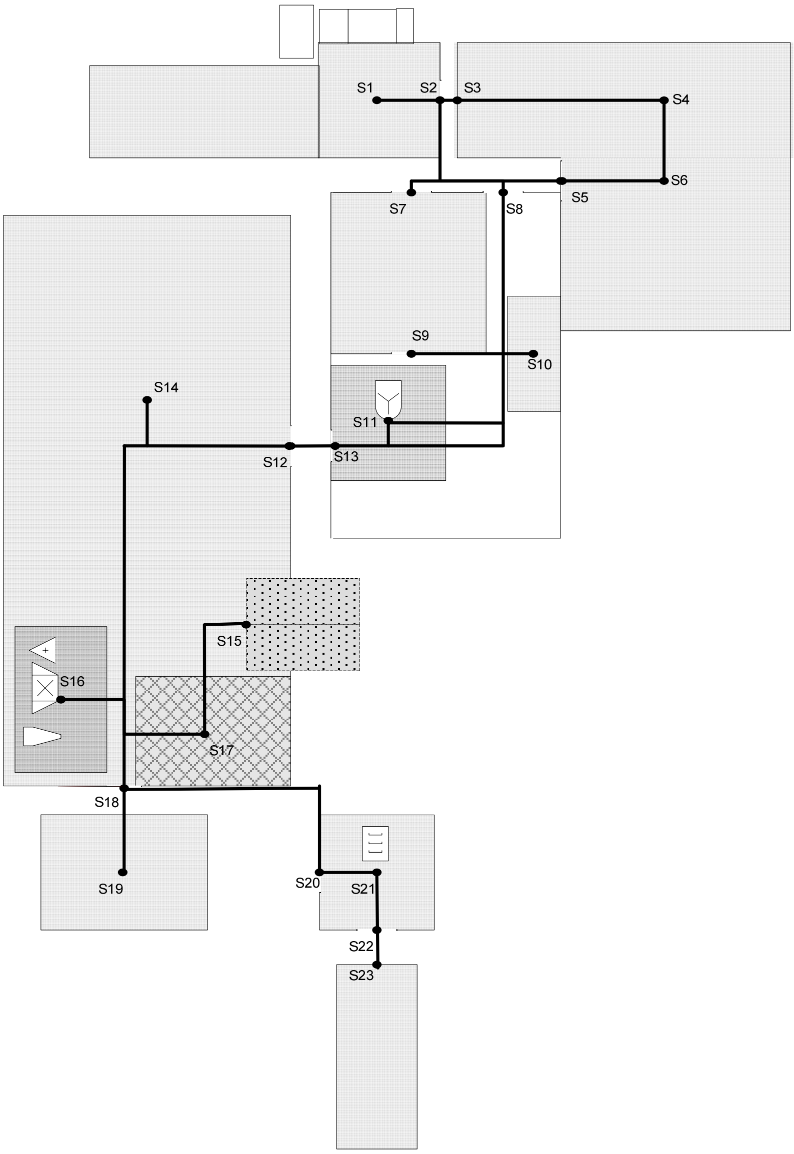


Figure 6.11: The layout of the department in Scenario 1 and their material flow paths

We have designed the flow paths of the other materials defined by f_3, f_4, and f_5 in similar manner following the procedure we applied for f_1 and f_2. Figure 6.11 shows the final flow network connecting all departments.

As we mentioned above, most of the stations reside within the departments, and the infrastructures (like asphalts) for the paths connecting these stations are already there. Therefore, these paths in the network represent the main aisles within these departments.

As can be noticed from Figure 6.11, the stations are connected by rectilinear paths. This is so because we have used rectilinear distance measure; and we have assumed that the departments have rectangular shape. The rectangular shape of the departments restricts the flow paths to pass through the centers of their stations or through their rectangular contours. However, this doesn't mean that these rectilinear paths should be strictly followed; in fact, these paths can be amended in actual implementation.

We have also applied the *shortest r-flow Network model* to design the materials flow paths of the department in Scenario 2 following the same procedure as we did when we design the flow paths of the departments in Scenario 1. To avoid redundancies, we provide, in Figure 6.12, only the final layout and the flow path of network of the departments; we give the details in Appendix 4.

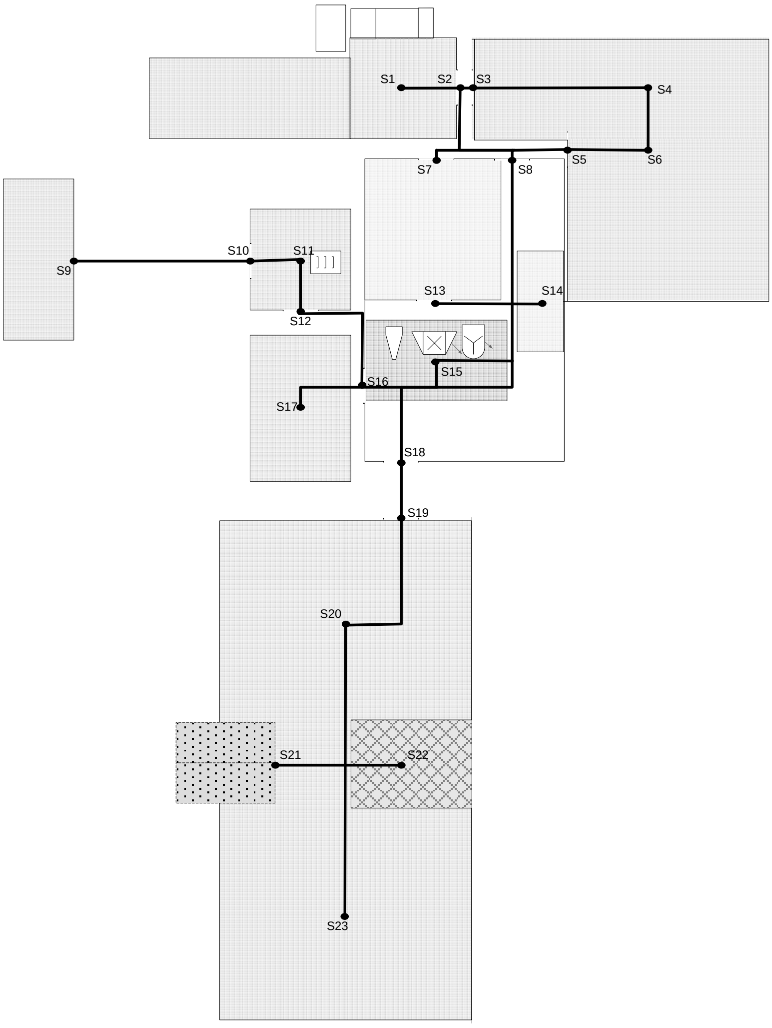


Figure 6.12: The layout of the department in Scenario 2 and their material flow paths

6.3 Evaluation of the Alternative Layouts

In Section 3.6, we mentioned the criteria for evaluating alternative layouts. Even though many cost and non-cost factors should be considered for evaluating alternative layouts, the transportation (handling) cost is the main cost criterion commonly used. So far, we used the total transportation distance among departments as a surrogate layout cost to develop the alternative layouts. Based on the transportation distance as a criterion, we have developed two alternative detailed layouts. Now, we are in a position to give final evaluation of the two layout alternatives based the other cost and non-cost criteria.

1. The transportation costs

   In Chapter 5, since we didn't know the actual pickup and drop-off stations for all departments, we calculated the transportation distances between two departments taking the approximate centroid-to-centroid distance measure. However, now, having the pickup and drop-off points determined, we calculated the actual aisle distance from the pickup point of one department to the drop-off point of the other department.

   The materials transportation distances per day of the layout resulted from Scenario 1 (shown in Figure 6.11) taking the actual aisle distance is **27,886** meters; whereas, that of the layout resulted from Scenario 2 (shown in Figure 6.12) is **27,968** meters.

   However, one of the advantages of Scenario 1(the machines are located in the New Warehouse) is that it virtually eliminates the handling and transportation efforts accompanying sampling. In Section 4.2.1, we estimated the reduction in transportation distance from this to be 2,400 meters. This means that the layout in Scenario 2 results in additional materials transportation distance of 2,400 meters due to the fact that sampling is done separately in this scenario which increases the total transportation distance per day to **30,368** meters.

   We also compare the layout costs of both scenarios with the cost of the existing layout. In Chapter 2, we estimated that the materials transportation distance of the existing layout to be 30,360 meters. In Appendix 1, we calculated the cost per unit distance (meter) for transporting a unit load from the Production department to the FP-Warehouse to be about €0.13. Assuming the cost of materials from/to other departments is the same, Table 6.5 shows the transportation cost component of the cost of production of a unit load (i.e., big bag).

Layout options	Transortation distance per day (∑∑*fij.dij*)	*Tranportation cost per meter (Cij)*	∑∑Cij.(fij.dij)	Big bags produced each day	Internal transporation cost of a big bag of finished product
Existing layout	30360	€ 0.13	3946.8	31	€ 127.3
Scenario 1	27886	€ 0.13	3625.18	46	€ 78.8
Scenario 2	30368	€ 0.13	3947.84	46	€ 85.8

Table 6.5: Transportation cost comparison of the existing and the proposed layouts

- According to the flow data from 2009, in the existing situation, about 31 big bags are produced every day. In the new situation, with the introduction of the RBOs, the big bags produced each day are about 46. We assume that the flow data will remain unchanged over the coming years. Comparing the existing layout and the layout in Scenario 1, we observe that in the existing layout the forklifts travel for about 30,360 meters to produce 31 big bags of finished materials, whereas in Scenario 1, the forklifts travel for 27,886 meters to produce 46 big bags of finished materials. When we compare them in terms of the transportation cost, the internal transportation cost of producing a big bag of finished product in the existing layout is about €127, whereas that of the layout in Scenario 1 is about €79 which results in internal transportation cost saving of €48 per big bag of finished materials. About 16,790 big bags of materials being produced every year, this layout results in annual cost reduction of about €805,920.

2. Initial investment costs

   The modifications in the layout of the departments may be accompanied with a requirement for additional investments. Some of the new departments (the New Warehouse and the Bin-cleaning hall) require constructing buildings. Moreover, we have proposed to expand the FP-Warehouse to use the area near the Production department. These activities require additional investment. However, these investment requirements are equally applied to both the scenarios we have considered.

On the other hand, in Scenario 1, the sieving and separation of the materials is carried out in the New Warehouse, whereas mixing is done in the Mixing section. This means that the materials coming out the sieve machine (in the New Warehouse) have to be kept in a ‘special’ kind of packaging containers until they are taken to the Mixers (in the Mixing section). This obviously requires additional investment for making the packaging containers available. Hence, the layout in Scenario 2 has initial investment cost advantage. The costs of the packaging materials depend on the kind of packing required.

3. Space utilization and building expansion

Modern industrial plants are constantly undergoing changes, and space may be reserved for future expansions or layout changes, and hence 100% space utilization is not always desirable. In fact, in the layouts we consider, the floor area available is much larger than the total area required by all departments; hence, the space utilization is much less than 100%. However, important considerations about space utilization are the concentration of the available free spaces and their locations. The available free space should be concentrated within a specific area so that it can be integrated for use by a new activity. If the available free space is divided into small parts, each part can be wasted. Moreover, the free space should be located in the area where it can be easily accessible for further expansion.

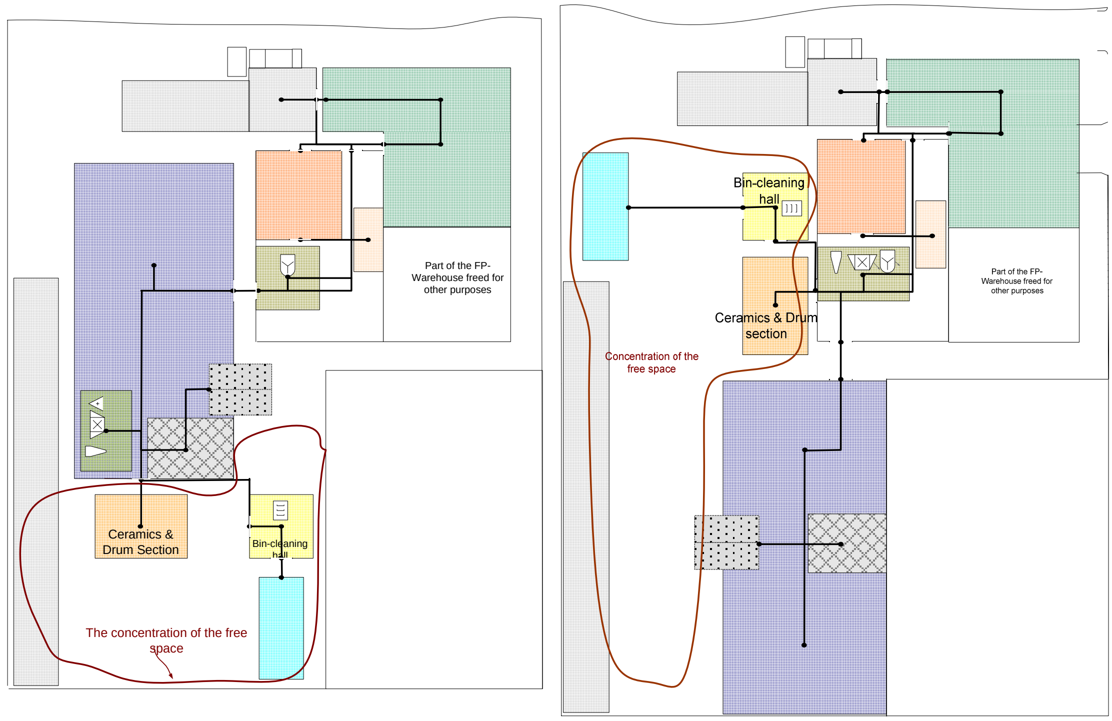
Figure 6.13 shows the layouts of the departments from both scenarios with their free spaces shown circled. The Ceramics & Drum section is an open area, and the Bin-cleaning hall is a cheap building. So, if the space used to locate these two departments is required for expansion or for locating other more important new facilities, they can be easily freed and made available for use; hence we consider the area used for locating these departments as a free space that might be used for potential expansion.

In the layouts in both scenarios, the available free spaces are fairly concentrated in specific locations. However, the two layouts differ in the location of the available free spaces. In the layout of Scenario 2 in Figure 6.13 (b), the free space is located at the center adjoining almost all the departments. This has an advantage in the sense that if expansion is required by any of the departments, the expansion can be carried out easily with less disruption to the other departments. Moreover, a need may arise that a new facility be build near to the existing departments; and with the layout in Figure 6.13(a), the modification can easily be accommodated.

On the other hand, in the layout of Scenario 1 in Figure 6.13 (a), the free space is located at the rear end next to the New Warehouse which is far away from the production facilities. In industrial plants, most of changes arise from changes in production processes or from introducing of additional processes; the free space available should be able to absorb these changes with minimum disruption. To this end, the free space available in this layout cannot be made available for expansions and changes in the production processes without disrupting the overall layout.

4. Other considerations

In addition to the criteria mentioned above, the developed alternative layouts should also be evaluated in terms of the other criteria described in Section 3.6.2, and in terms of the fulfillment of the qualitative requirements and practical restrictions we mentioned in Section 3.8. These qualitative requirements and practical limitations are addressed while we execute the algorithm and, hence, the layouts of the departments from both scenarios fulfill these qualitative requirements and practical restrictions.



(a) Scenario 1 (b) Scenario 2

Figure 6.13: the detailed layouts for both scenarios with their free spaces circled in red.

6.4 Conclusions

In this chapter, we developed the detailed layout of the alternative layouts for the two scenarios we considered by determining the locations of the machines, the pickup and drop-off points for each department, and the docks for the New Warehouse. We also designed the materials flow paths connecting pairs of departments for the two layout alternatives. We then calculated the transportation costs per day taking the actual distance of the designed flow paths.

The layouts from the two scenarios result in a better layout cost compared with the existing layout. Moreover, the final layout of Scenario 1 (the machines are located in the New Warehouse) results in a better transportation cost per a big bag of finished materials compared to that of Scenario 2 (**€78.8** vs. **€85.8**). On the other hand, layout in Scenario 1 requires additional investment in the packaging containers. Moreover, the layout in Scenario 2 (the machines are located in the Handling department) results in a better space utilization with a free space that can be potentially used for future expansion. Table 6.6 summarizes the comparison of the layouts from the two scenarios based on the criteria considered.

Evaluation criterion	Layout option Scenario 1	Layout option Scenario 2
Transportation cost	+	-
Initial investment cost	-	+
Space utilization and Building expansion	-	+
Qualitative requirements & practrical restrictions	+	+

Table 6.6: comparison of the layouts from both scenarios based on the evaluation criteria considered

By and large, the choice between the two alternatives relies on what the company is striving for. We have discussed the two alternatives with the problem owners. Their main objective is to minimize the operating (transportation) cost; they are less concerned with the space utilization and building expansions and the investments on the packaging materials. Therefore, we recommend that the layout from Scenario 1 (which is shown in Figure 6.14) be implemented.

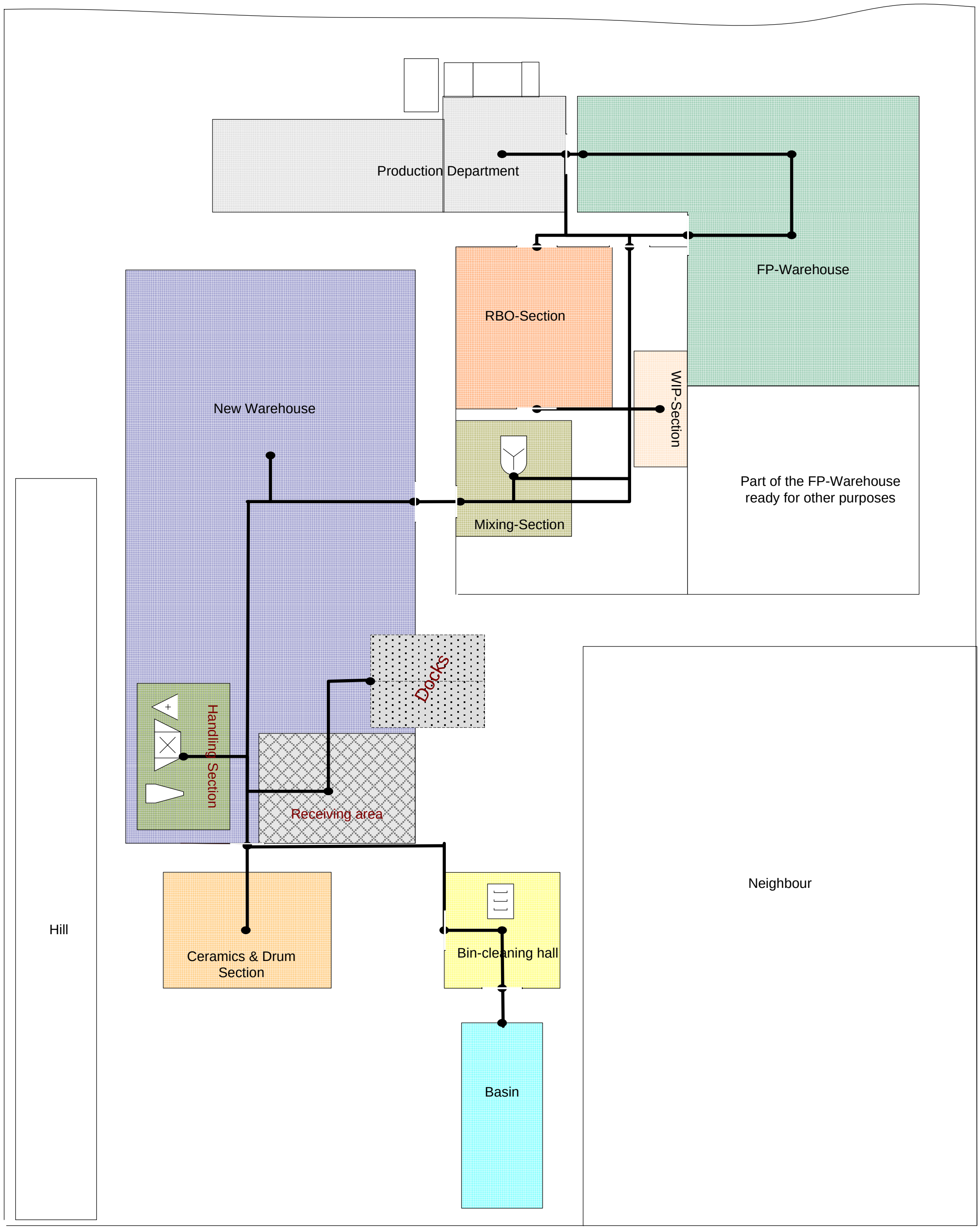


Figure 6.14: final layout recommended for implementation.

Chapter 7
Recommendations for Implementation

In this chapter, we give recommendations on how the proposed solution should be implemented.

Implementing the new plan can be considered as a project. Undertaking a project requires considerable amount of resources (money, time, personnel, etc). Since a project is composed of various independent activities, carrying out those activities simultaneously might not be possible either for technical reasons (example, the start of an activity may depend on the completion of another activity) or because several activities may compete for the same resources (example, a person or machinery may be required by several activities) that the available resources may not allow performing those activities at the same time. Therefore, implementing the project should be well planned, organized, and managed.

Moreover, since implementing the new plan will affect the existing production facilities in one way or another, its implementation should be carried out with minimum disruption of the production process. The new plan includes building of new facilities such as the New Warehouse and the Bin-cleaning hall, installing the RBOs, and moving of some facilities to other locations. Clearly, some of these activities depend on other activities; and for efficient implementation, proper implementation procedure should be devised and adhered to.

We have followed the solution implementation steps (Joseph and Robert 1992) to plan the implementation of our proposed solution. The plan includes identifying the activities comprising the project, determining the sequences on which these activities should be carried out, determining their resource requirements, and assigning responsibilities to each activity. We now apply the implementation procedure step-by-step.

1. Specify the activities in the plan: to effectively plan and execute the proposed solution, it is helpful to visualize it as a project having an overall goal with several objectives. Each objective will have a number of discrete, separately identifiable activities. The activities in our case are:

    1. Building the New Warehouse
    2. Freeing the RM-Warehouse
    3. Installing the RBOs
    4. Freeing the space in the Wet section for the maintenance section
    5. Moving the Handling department to the RM-Warehouse
    6. Moving the maintenance section to the proposed location
    7. Building the Bin-cleaning hall
    8. Moving the washing machine to the Bin-cleaning hall
    9. Constructing the material flow paths connecting the departments
    10. Locating the Ceramics & Drum section
    11. Moving the big containers to the Ceramics & Drum section
    12. Locating the WIP-section
    13. Extending the FP-Warehouse

2. Sequencing the activities in the plan: this step determines the sequence in which these activities will have been done. The sequence is determined by examining each activity and determining

which other activities must be completed before this activity can begin. Through this analysis, a sequence in which several activities that can be done simultaneously will emerge.

Performing most of the activities mentioned above depends on the construction of the New Warehouse and on moving the Handling department to the RM-Warehouse. Moving the Handling department to the RM-Warehouse happens only if the space in the RM-Warehouse is freed; and for the space in the RM-Warehouse to be freed, the New Warehouse has to be constructed first and the raw materials have to be stored there. Meanwhile, building the Bin-cleaning hall can be done simultaneously while constructing the New Warehouse. But, this depends on the resource available; for example, the same people may be involved in the both activities that doing both activities in parallel may not be possible.

The sequence for the other activities can be found in similar manner. For example, extending the FP-Warehouse can only happen when the Handling department and Maintenance section are moved, and the latter happen after the space in the Wet section have been freed. The precedence diagram in Figure 7.1 summarizes the sequence on which the activities can be carried out.

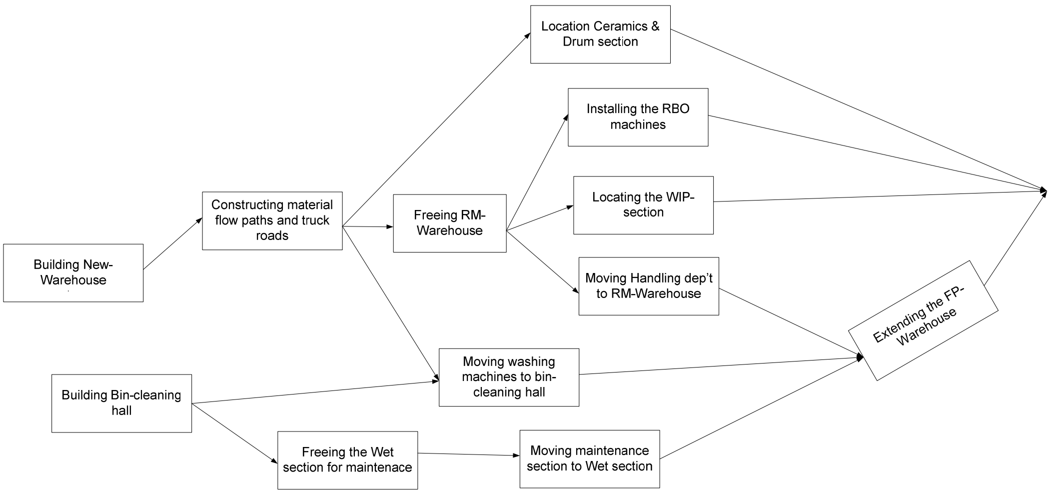


Figure 7.1: Precedence diagram of the activities for implementing the proposed solution

3. Managing the implementation: once the activities are identifying and their sequence is determined, the next step is to estimate the start and completion time of each activity taking availabilities of the required resources for that activity into account. Resources should then be assigned for each activity so that it will be carried out within the stipulated time frame.

   One important resource in the implementation of the plan is the personnel aspect. First, all the personnel likely to be affected by the new layout should have been informed of the objective of the layout, and what would mean to them in terms of their responsibilities. Implementation should start with the formation of project teams and should follow with the scheduling and assignment of responsibilities to the activities in the plan. The implementation should be managed by preparing simple forms that define exactly what is to be done, by when, and by whom.

Chapter 8
Conclusions and Recommendations

This research has focused on identifying the inefficiencies related to the logistic processes, developing the layout of the departments in the new plan, and designing the material flow paths connecting the departments so that the handling and transportation efforts are minimized. In this chapter, we discuss the overall conclusions and recommendations of the research.

8.1 Conclusions

1. The inefficiencies related to the logistic processes arise from the following areas:

   - Unavailability of facilities related to the storage and handling of materials. Since there is no separate area reserved for the receiving of the incoming materials, these materials have been directly stored in random locations, and the random allocation in turn has made the handlings and relocation during the retrieval of materials to be high. Also, because there is no temporary storage for the Work-in-processes, the mixed materials have been transported for long distances to the Warehouses for temporary storage.

   - Inefficient locations of existing facilities. The sieving and separation of the incoming materials are being done in the Handling department, but this has been causing long distance transportation of ceramics and other materials that don’t take part in the treatment processes. Furthermore, the facilities required for cleaning, washing, and inspection of the empty bins are currently located in different places, and this has created unnecessary long distance movements of the bins.

1. The inefficiencies in the logistic processes can be improved from two areas:

   - Introducing separate areas for the receiving of the incoming materials and for temporary storage of the work-in-processes. The Receiving area for the incoming materials gives the workers to identify the types of the incoming materials and to decide where, in the warehouse, these materials should be located instead of random allocations. Also, having the WIP section for the temporary storage of the work-in-processes reduces the handling and transportation efforts required to transport these materials back to the warehouses for the temporary storage.

   - Locating the facilities that are required for the consecutive processes in single department. By combining the sampling, sieving, and separation of the incoming materials in the New Warehouse, the handling and transportation efforts if sampling were to be done separately can be eliminated. Also, locating all the facilities required for the cleaning, washing, and inspection of the bins in Bin-cleaning hall reduces the transportation and handling efforts needed for transporting the bins among the cleaning and washing facilities.

2. Comparing the transportation cost for the existing layout and for the layouts the departments for the two scenarios, we concluded that:

   - The layout of the departments in Scenario 1 results in a transportation cost €79 for producing a big bag finished materials which shows a €7 reduction compared to the layout of the departments in Scenario 2. This is so because if the machines are located in the New Warehouse, sampling can be combined with sieving, and the handling and transporting efforts required for sampling can be eliminated. About 16,790 big bags of materials being produced every year, this layout results in annual cost reduction of about €117,530 compared to that of the layout in Scenario 2.

- The layout of the departments in Scenario 1 also improves the current transportation cost of producing a big bag of finished materials from €127 to €79 which shows about €48 reduction per big bag of finished materials. About 16,790 big bags of materials being produced every year, this layout results in annual cost reduction of about €805,920. The improvement is attributed to the improvement in the logistic processes, combining the sampling process with the sieving and separation processes, and extending the FP-Warehouse to use the space next to the Production department.

- Extending the FP-Warehouse to make use of the space near the Production department reduces the distance that a big bag of finished material travels from the Production department to the FP-Warehouse by 35 meters. These results in an annual cost saving of €76,348 compared to the existing location of the FP-Warehouse.

8.2 Recommendations

Based on the results of our research, we would like to give the following recommendations.

1. Since the layout of the departments in Scenario 1 results in a significant improvement in the transportation cost (a saving of €48 per big bag of finished materials), we recommend Moxba-Metrex for its implementation. We recommend extending the FP-Warehouse to make use of the space next to the Production department. We also recommend that the sieving and the separation of the incoming materials be carried out in the New Warehouse.

2. The reduction in the transportation cost partly comes from the improvements in the logistic processes. We therefore recommend that:

   - The Receiving area (for the temporary storage of incoming materials) and the WIP-section (for temporary storage of work-in-progresses) be made available.

   - The sieving and separation of the incoming materials should be done in the New Warehouse, and samples be taken during the sieving process.

   - The facilities required for the cleaning, washing, and inspection of the bins be located at the Bin-cleaning hall.

Recommendations for further research:

4. We believe that the handling and transportation during storage allocation and retrieval process in the warehouse and the space utilization of the warehouses can be improved by applying appropriate storage and retrieval systems. Also, since the transportation and handling costs don't depend on the size of the packaging material, having bigger packaging containers will reduce the handling and transportation costs. However, since this was not the main objective of this research, we didn't deal in depth with the storage and retrieval systems. Therefore, further study should be done to improve the storage and retrieval systems of the materials and to optimize the sizes of the packaging containers.

5. In our research, although we didn't discuss it in depth, we observed that there is capacity imbalance in the production capacities. The throughput of the FBO is much less than the throughput of the Mixers – the materials that are treated in the FBO a week (seven days) can be mixed in three days. This means that the resources in the Handling department are underutilized. Since the main component of the production cost is the cost of the fixed resources (machines, materials handling equipments), by increasing the utilization of these resources, the production cost can further be reduced. Moreover, the imbalance in capacity has caused materials to stay in the warehouse for longer times which ties up the floor area in the warehouses. Therefore, further study should be conducted on improving the capacities of the facilities in the Production department.

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Appendix 1
Transportation and Handling Cost Calculations

This section calculates the approximate cost of transporting materials from the Production department to the FP-Warehouse. Heragu (Heragu 1997) provides the following formula for determine the cost to move a unit load between facilities, Let:

f_{ij} number of trips required to transport material from facility *i* to facility *j*
d_{ij} distance (in meter) from facility *i* to facility *j*, for a given layout
LULT average loading and unloading time (in minutes) per move
S average speed (in meter per minute) of material handling equipment (e.g., forklift)
C investment or leasing cost for the material handling equipment
OP labor plus non-labor (fuel, power, and maintenance) operating costs per minute
T_{ij} time (in minute) to transport material from facility *i* to facility *j* per trip
MHC_{ij} total material handling cost to transport material from facility *i* to facility *j*
MHR_{ij} material-handling cost per unit distance per trip to transport material from facility *i* to *j*

$$T_{ij} = LULT + \frac{d_{ij}}{S}$$

$$MHC_{ij} = C + T_{ij} f_{ij} OP$$

$$MHR_{ij} = \frac{MHC_{ij}}{f_{ij} d_{ij}}$$

Using the above formulates and the following parameters, we calculate the approximate cost of transporting a unit load per meter. Table 1 displays the annual leasing cost of the forklifts; for our calculations, we take the average of these costs.

Leasing cost of a forklift		
Mark	**Type**	**leasing cost per year**
Yale	GLP40LJ	€ 77,000.00
yale	GLP40LJ	€ 97,000.00
Yale	GLP40LJ	€ 78,000.00
yale	GLP40LJ	€ 78,000.00
Yale	GLP50MJ	€ 84,000.00
manitou	150 AET 2	€ 88,390.00
Yale	GLP30VX	€ 46,000.00
	C(average)	€ 78,341.43

Table 1: Leasing cost of forklifts

Table 2 shows the variable costs which include the monthly cost of fuel for the forklifts and monthly salaries of the operators. Maintenance for the forklifts is done for free by the company the forklifts are leased from; hence we don't include the maintenance costs in the cost calculations. We assume that the Production department operates 24 hours a day, 7 days a week, and 52 weeks a year with uptime of 85%. We also assume that standard working hours of an operator is 8 hours per day. Accordingly, average operating cost of a forklift per minute is *€ 0.24.*

Lobour and non-labour cost	
average fuel cost for a forklifts per month	€ 402.71
average salary for an operator per month	€ 2,600.00
average operating cost per month	€ 8,202.71
average operating cost of a forklift per minute	**€ 0.24**

Table 2: Average operating cost of a forklift

In Table 3, we show the cost calculations for transporting materials from the Production department to FP-Warehouse. The new location of the FP-Warehouse reduces the expected distance that a unit load travels from Production department to the FP-Warehouse from 92 to 56 meters, which results in reduction of 35 meters. We take the flow data from the Production department to the FP-Warehouse from the flow data of 2009 for the finished materials that are produced in the FBO and RTO. We also include the estimated flow of finished materials produced in the RBOs. We assume the flow data remains unchanged in the coming years. Accordingly, the transportation cost per meter is *€ 0.13.*

Data	value			
flow (per year) from production to FP-warehouse (f_ij)	16790			
Expected distance a unit load travels, in meters (d_ij)	91.48	<-- existing	56.48	<-- new
average loading and unluading time, in minutes (LULT)	0.67			
Average transporting time from the production dep't to the FP-Warehouse (minutes)	2			
average leasing cost for a forklift per year , C	€ 78,341.43			
labor and non-labor cost to operate a forklift per minute (OP)	€ 0.24			
time to transport a unit load for the production dept to the FP-W (T)	2.67			
annual cost of transporting unit loads from production to FP-Warehouse (MHC_ij)	€ 199,547.32			
transportation cost per meter(MHR_ij)	€ 0.13			

Table 3: Transportation cost per meter calculation using the above formulas

Appendix 2
Layout of Departments in Scenario 2

5.2 Scenario 2: Machines are located in the Handling department

The SLP steps for Scenario 2 are shortly discussed in this section.

5.2.1 Analyzing the input data

Step 1: Input data

In scenario 2, the machines are located together in the Handling department instead of in the New Warehouse. The New Warehouse is now used only for actual storage of the incoming materials. The change in the location of the machines brings about changes is the flow the materials that are treated in the FBO and RBOs. The flows of these materials are shown in Figure 5.9 (a) and (b). On the other hand, the materials coming out of the Handling department in this scenario are: the pre-treated materials that go to the WIP-section, the ceramics and used drums that go to the Ceramics & Drum section, and the emptied bins going to the Bin-cleaning section. The Flow of the bins is shown in Figure 5.9 (c).

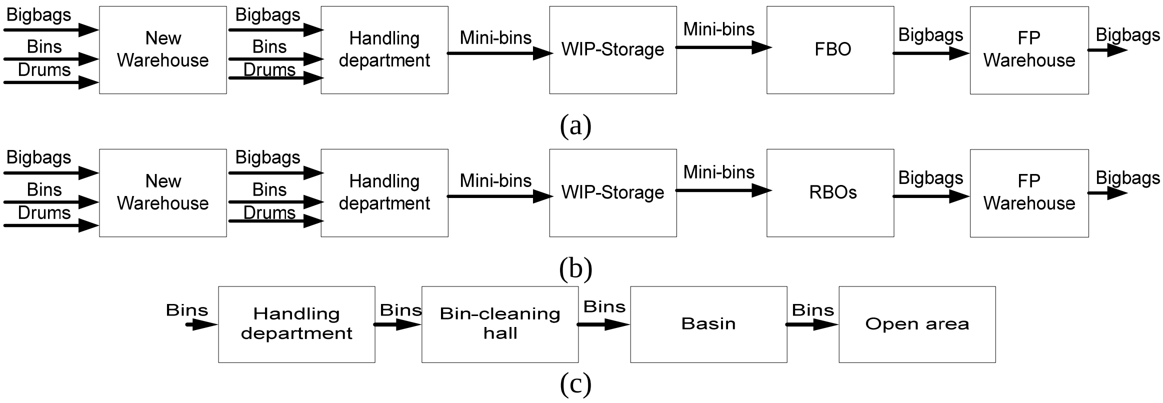

Figure 5.9: Schematic flow diagrams of materials treated in (a) FBO, (b) FBOs, and (c) the bins.

Step 2: Flow of materials analysis.

When the machines are located in the Handling department (Scenario 2), New Warehouse is used only for actual storage of the incoming materials. The materials that are going to be treated in the FBO and RBOs then have to pass through the Handling department for the pre-treatment. The flow of ceramics, the drums, and empty bins, therefore, originates from the Handling department. Since the New Warehouse is used only for storage purpose, we don't divide it into two halves unlike in the first scenario. The flow of the materials in this scenario are aggregated in the From/To table as in Table 5.6.

Facility name	New Warehouse	FP Warehouse	Handling department	Production department	RBO section	WIP-Storage	Bin-cleaning hall	Basin	Ceramic and Drums
New Warehouse	0	0	90	10		0	0	0	0
FP-Warehouse	0	0	0	0	0	0	0	0	0
Handling department	0	0	0	0	0	56	7	0	60
Production department	0	31	0	0	0	0	0	0	0
RBO section	0	15	0	0	0	0	0	0	0
WIP-Storage section	0	0	0	41	15	0	0	0	0
Bin-cleaning hall	0	0	0	0	0	0	0	7	0
Basin	0	0	0	0	0	0	0	0	0
Ceramic and Drums	0	0	0	0	0	0	0	0	0

Table 5.6: Flow-to chart of the facilities in Moxba-Metrex

Step 4: Relationship diagram

Following the changes in the flow of the materials, and the hence From/To table, the relation diagram for scenario 2 is modified and presented in Figure 5.10.

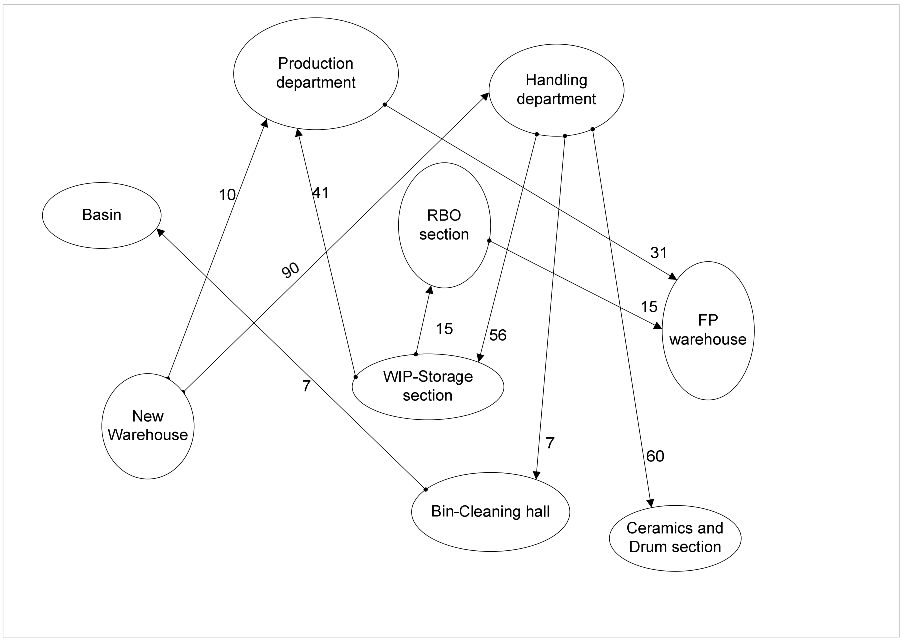

Figure 5.10: the relationship diagram

Step 5&6: The space requirements/available space

The only department whose area requirement changes in this scenario is the Handling department. Since all the machines used for the pre-treatment purpose are located altogether in the Handling department, the area for this department increase to 800 m^2. On the other hand, there is no a separate Mixing section in this scenario. The floor area requirements for all departments are summarized in Table 5.7.

Facility name	Length	Width	Area required
New Warehouse	100	50	5000
FP-Warehouse	60	40	2400
Handling deparment	40	20	800
Production department	61	26	1586
RBO section	27	28	756
WIP-Storage section	20	10	200
Bin-cleaning hall	20	20	400
Basin	30	14	420
Ceramic & Drums section	30	20	600

Table 5.7: Facility area requirements

Step 7: Space relationship diagram

The space relationship diagram for this scenario is modified as in Figure 5.11 to comply with the changes in the previous steps.

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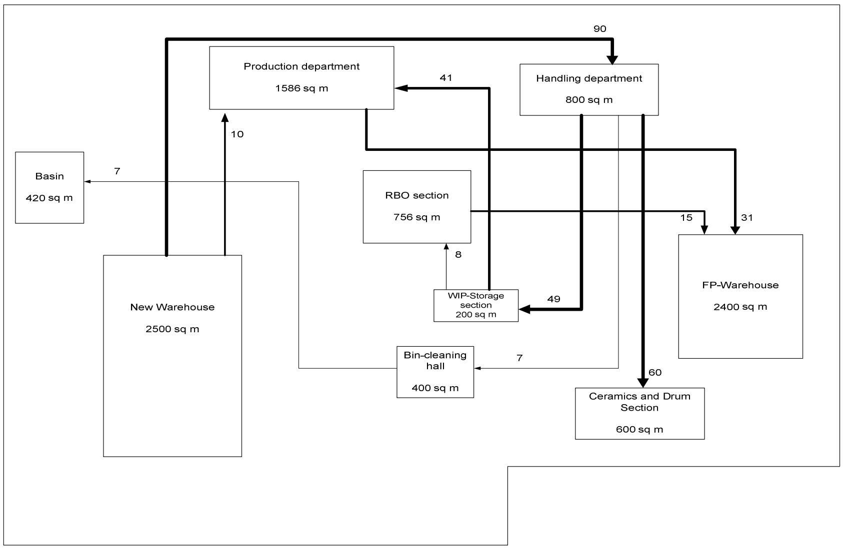


Figure 5.11: Space relationship diagram

Step 8&9 practical limitations and modification considerations

The practical limitations and assumptions made in scenario 1 apply to this scenario as well.

5. 2.2 Search for alternative layouts

Step 8&9 Developing alternative layouts

Executing the algorithm for this scenario begins with the initial layout shown in Figure 5.12. As we described while discussing the initial layout in scenario 1, the algorithm we are applying is path dependent that the final result may be affected by the initial layout. To reduce this effect, we start with an initial layout with the Bin-cleaning section and the Ceramics & Drum section being located in different location compared to that of scenario 1 as shown in Figure 5.12.

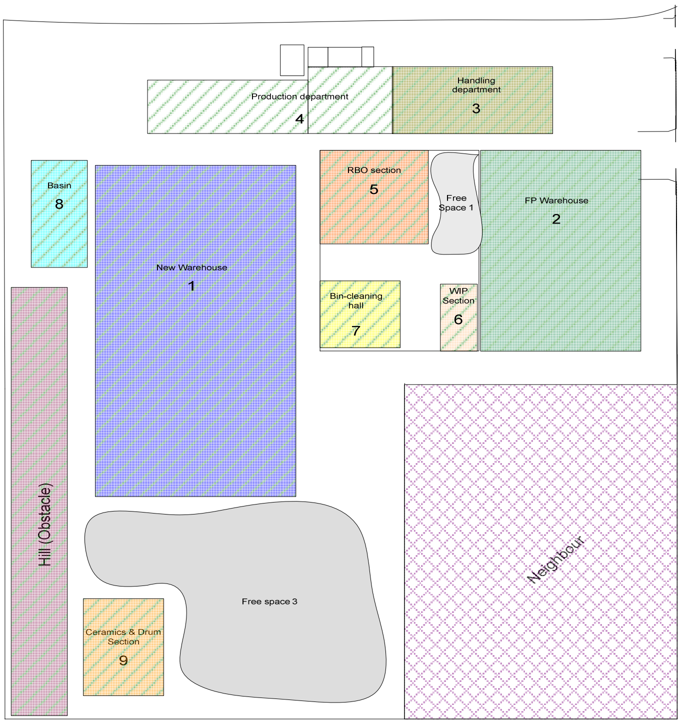


Figure 5.12: Initial layout of scenario 2

Starting with the initial layout in the first iteration, we exchanged the locations of the departments or moved a department to the available free spaces. Table 5.8 summarizes the costs of alternative layouts formed as a result of the exchanges. We start with initial layout transportation cost of 42,076 meters. We then proceed with exchanging the locations of the departments in search of a better layout. At the first iteration, exchange 3 has the maximum reduction in the layout cost and is saved as a 'best layout so far' (MIN). This results from exchanging the location of the Handling department with that of the Bin-cleaning section as shown in Figure 5.13. The layout found in exchange 3 of iteration 1 is then used as initial layout for the second iteration. The exchange procedure proceeds in similar manner until it comes to termination in iteration 5 when layout cost reduction is not attainable anymore; which results in the best layout for scenario 2 shown in Figure 5.14 (a).

Exchange options	Iteration						
	1	2	3	4	5	6	7
Initial layout	**42076**	**27583**	**27219**	**24019**	**22639**	**22065**	**20857**
1	42396	**27219**	28485	25285	23905	23905	22123
2	29837	28165	27615	24415	24345	23625	22417
3	**27583**	29401	27639	24439	23059	**20857**	21277
4	42076	28003	26645	23445	**22065**	22485	25057
5	35444	27459	27065	23865	22485	26145	
6	38156	31023	29919	26719	26719	26265	
7	45976	28005	25839	**22639**	26839		
8	42986	27533	27039	26839			
9	42083	27687	**24019**				
10	38896						

Table 5.8: results of scenario 2

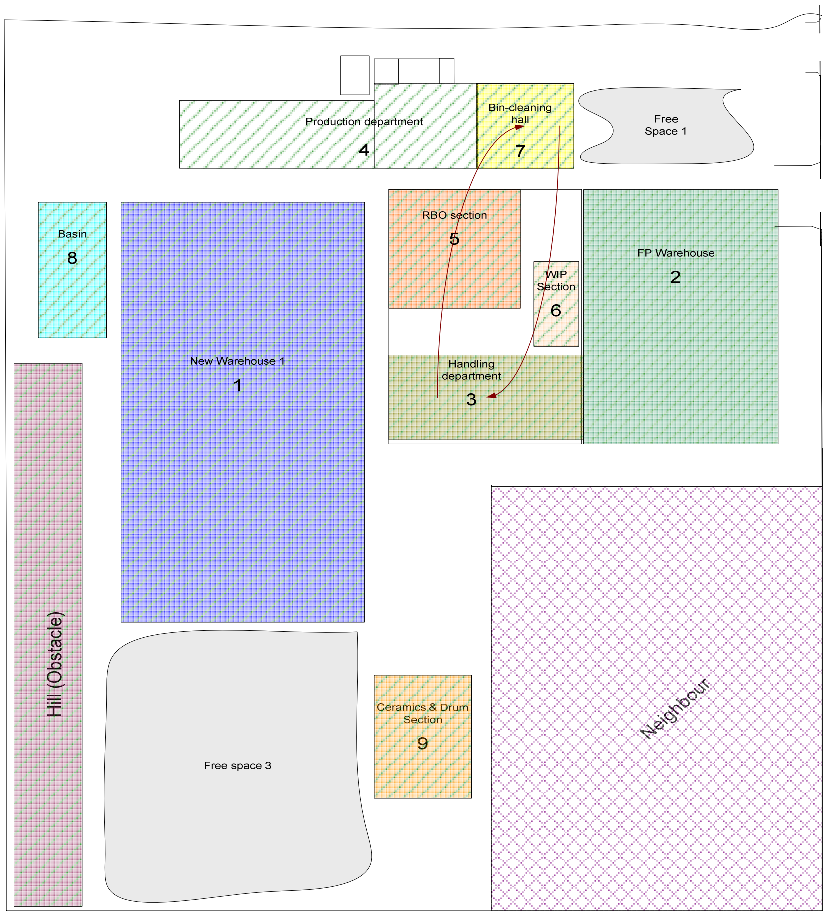


Figure 5.13: Best exchange of iteration 1

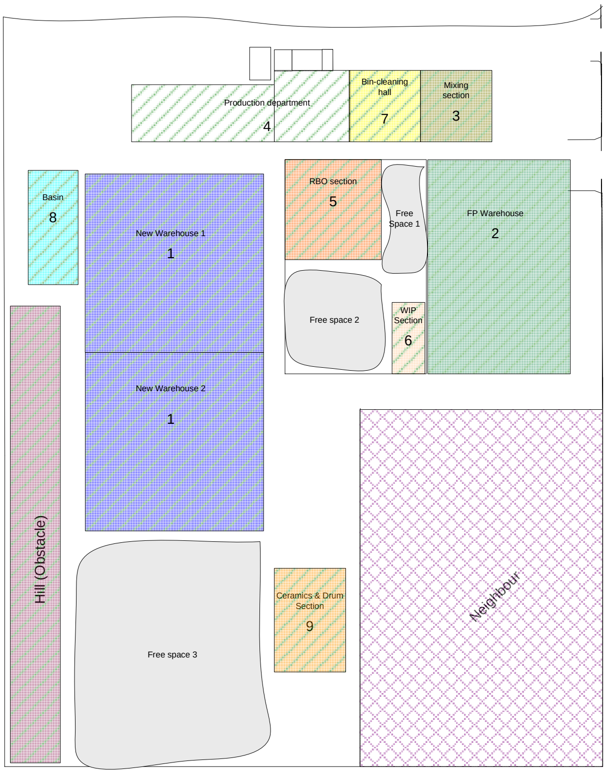
(a) (b)

Figure 5.14: best layout from scenario 2

The layout in Figure 5.14 (a) has placed department pairs with higher interdepartmental flow next to each other. For example, the New Warehouse and the Handling department (1&3), Handling department and the WIP section (3&6), the Handling department and the Ceramics & Drum section (3&9), the Production department and the FP-Warehouse (4&2), and the RBO section and the FP-Warehouse are placed next to each other.

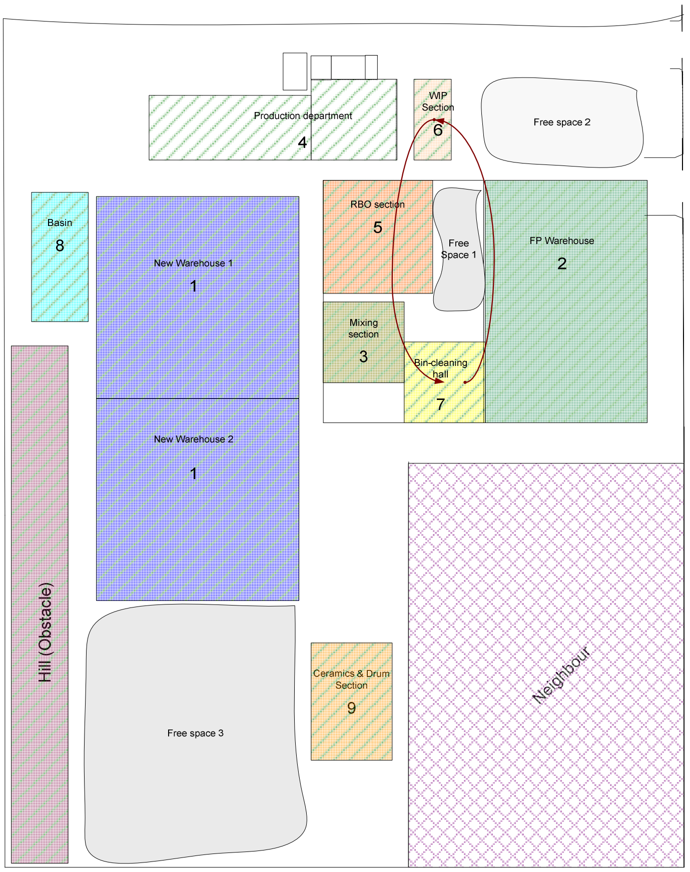
Similar to that of scenario 1, the FP-Warehouse in scenario 2 is also placed next to the Production department. Hence, the FP-Warehouse should be extended to include the area near the Production department, and to retain the existing facilities as they are, its shape should be modified to L-shape.

Appendix 3
Layouts for Every Iteration in Scenario 1 and Scenario 2

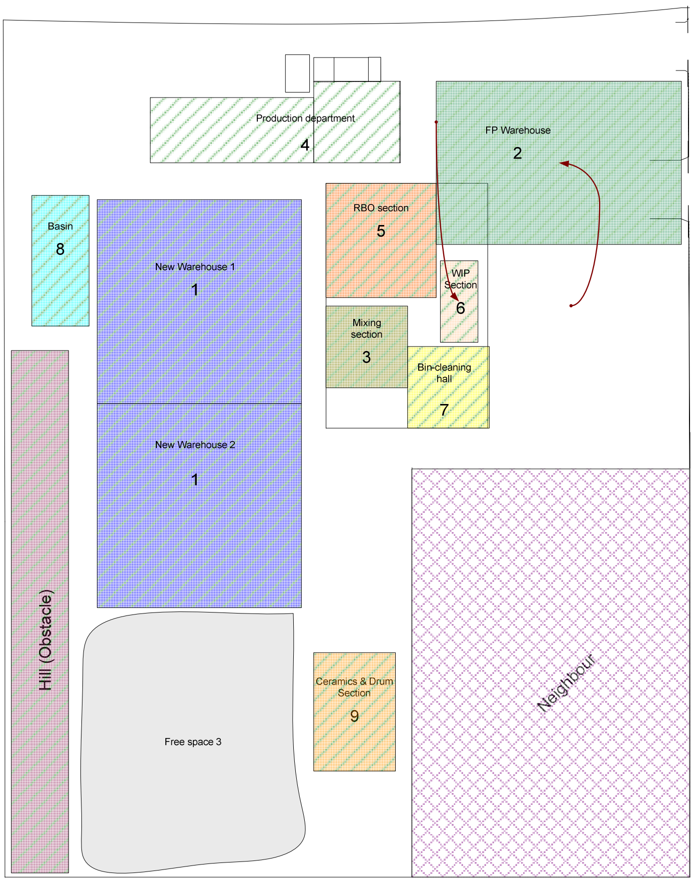


Initial layout: layout transportation distance = 36,570

Best exchange of iteration 1: layout transportation distance = 28,265



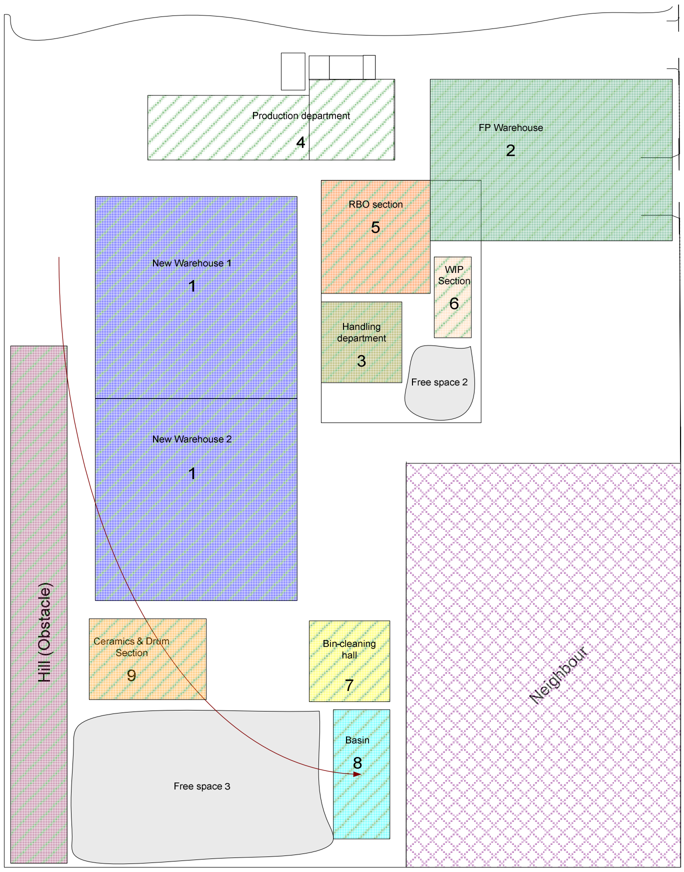
Best exchange of iteration 2: layout transportation distance = 28,251



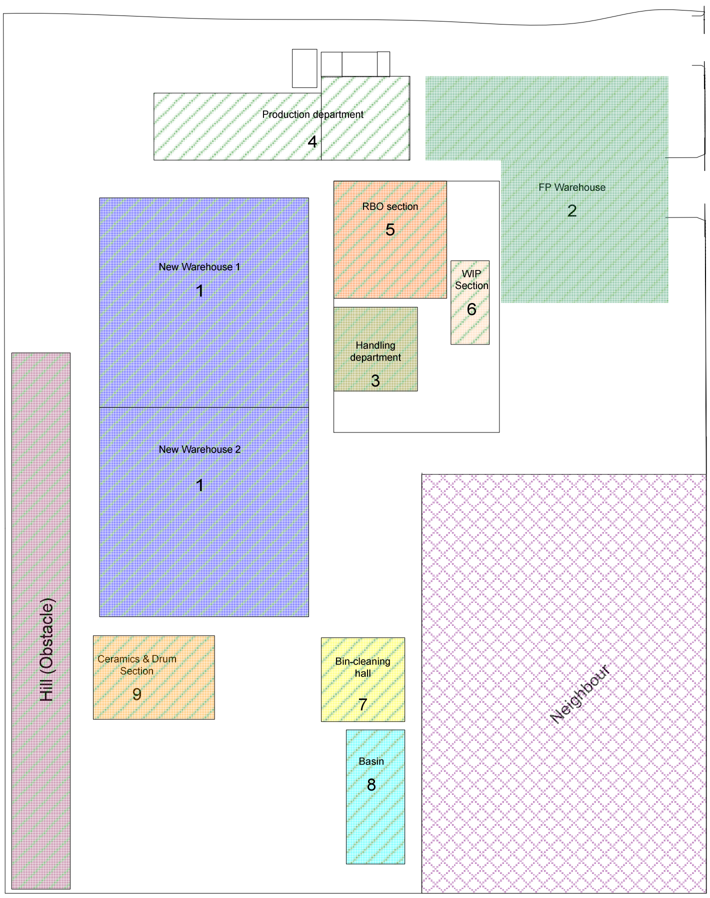
Best exchange of iteration 3: layout transportation distance = 26,283

Best exchange of iteration 4: layout transportation distance = 26,003

Best exchange of iteration 5: layout transportation distance = 24,375



Best exchange of iteration 6: layout transportation distance = 24,280

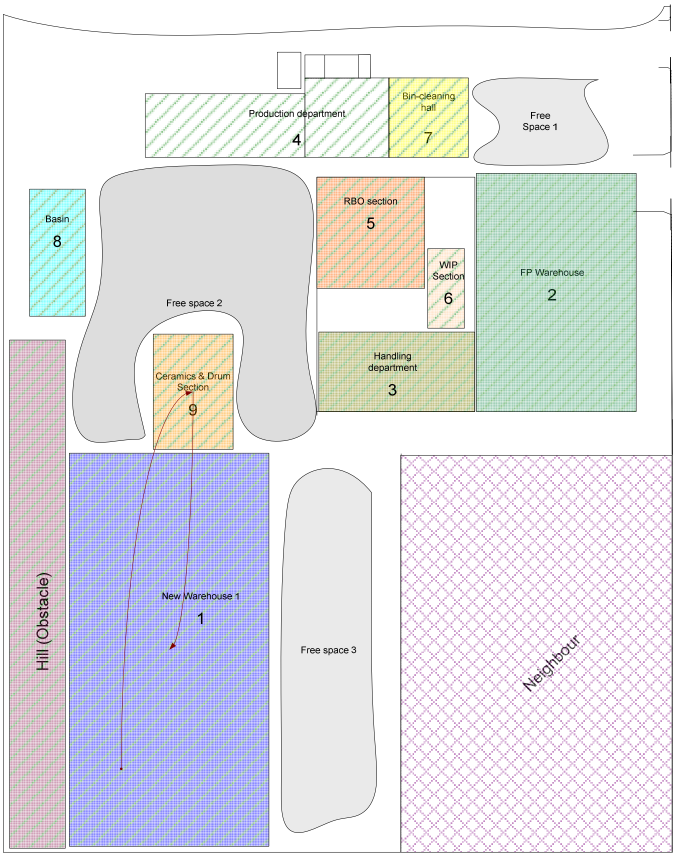


Iteration 6 with FP-Warehouse modified

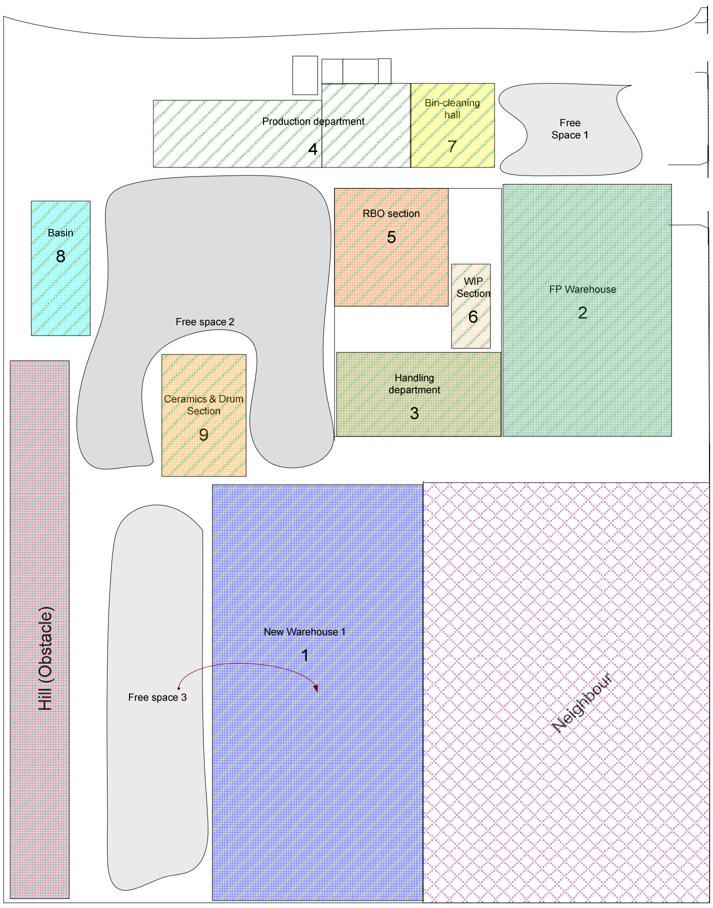
Scenario 2 Iteration results

Initial layout: layout transportation distance = 42,076

Best exchange of iteration 1: layout transportation distance = 27,583



Best exchange of iteration 2: layout transportation distance = 27,219

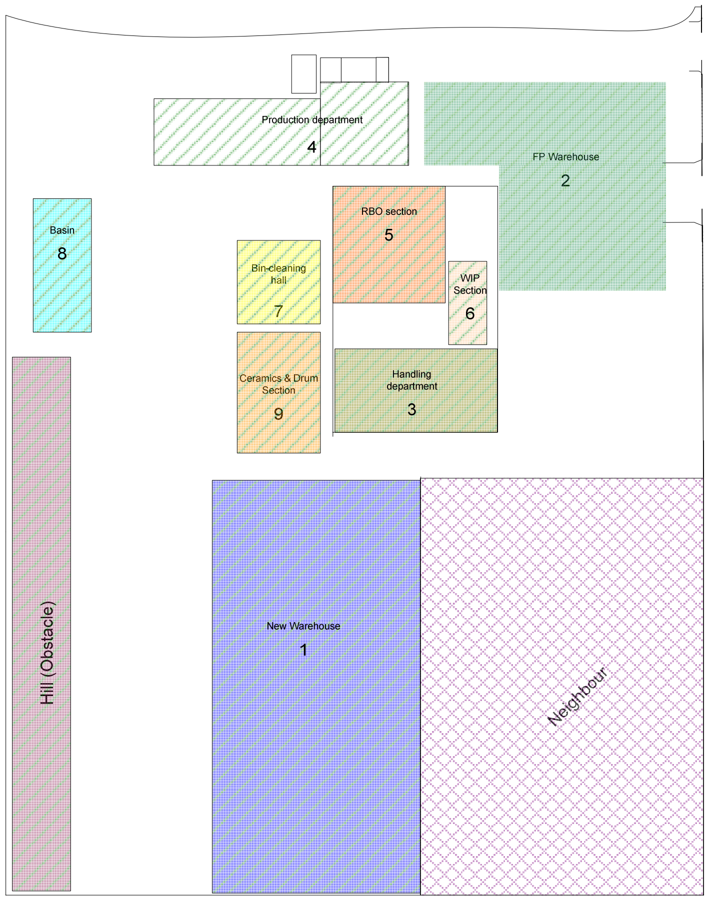


Best exchange of iteration 3: layout transportation distance = 24,019

Best exchange of iteration 4: layout transportation distance = 22,639

Best exchange of iteration 5: layout transportation distance = 22,065

Best exchange of iteration 6: layout transportation distance = 20,857



Iteration 6_FPW modified

Appendix 4
Material Flow Paths of Departments in Scenario 2

Depending on the processes they require and the layouts of the departments in Scenario 2, the flow of the materials are defined as follows:

1. the materials that are treated in the FBO which passes through the stations designated by
   f_1: S21→ S22→(S23 or S20)→S19→S18→S15→S14→S8→S2→S1→S2→S3→S4→S6
2. those treated in the RBOs which pass through the stations designated by
   f_2: S21→ S22 →(S23 or S20)→S19→S18→S15→S14→S13→S7→S5→S6
3. those treated in the RTO which pass through the stations defined by
   f_3: S21→ S22 →(S23 or S20)→S19→S18→S8→S2→S1→S2→S3→S4→S6
4. the bins which pass through the stations defined by
   f_4: S15→S16→S12→S11→S10→S9
5. the ceramics and drums which pass through the stations designated by
   f_5: S15→S16→S17

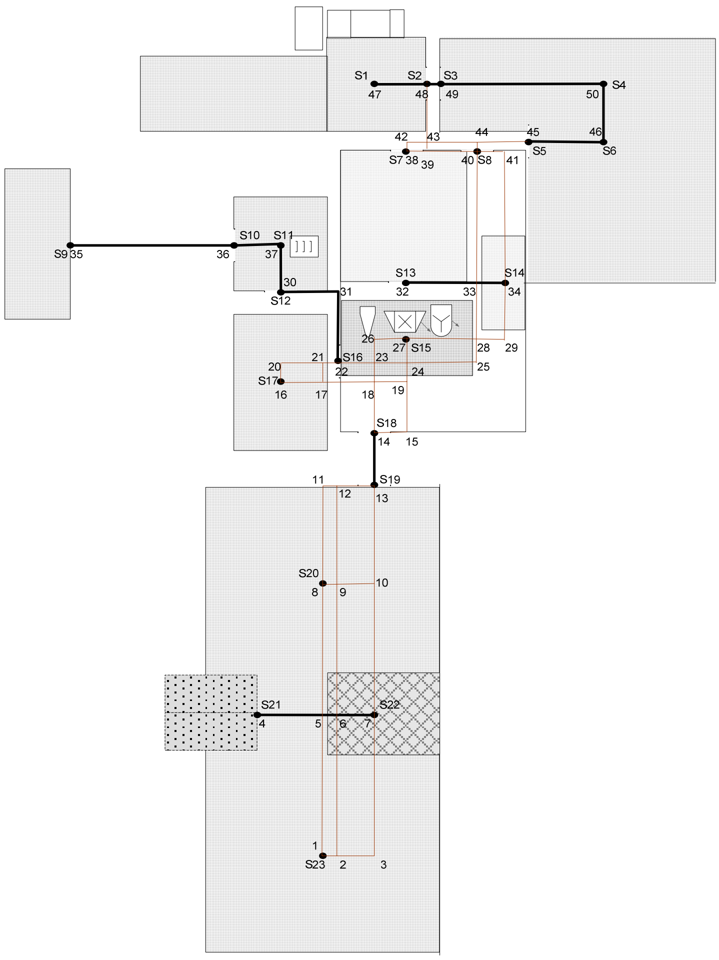


Figure 1: the grid graph with some of the arcs removed and with the dark lines included in the final solution

Starting with the grid graph in Figure 1, we applied the *shortest r-flow Network Model* to design the material flow paths in Scenario 2. We start with designing the flow of the materials whose flow is designated by f_1. The selected paths are highlighted in the Table 1. The paths for the other flows are also shown in Table 2 through Table 4. The Final flow path network is shown in Figure 2.

Stations to be connected	Altenative paths	cost of alternative
S21 ---> S22	4-->5-->6-->7	0
S22 ---> S23	7-->6-->5-->1	16
	7-->6-->2-->1	17.5
	7-->3-->2-->1	21.5
S22 ---> S20	7-->6-->5-->8	14
	7-->6-->9-->8	15
	7-->10-->9-->8	18
S20 ---> S19	8-->9-->10-->13	15
	8-->9-->12-->13	16
	8-->11-->12-->13	16.5
S23 ---> S19	1-->2-->3--7-->10-->13	46.5
	1-->2-->6-->9-->10-->13	45.5
	1-->2-->6-->9-->12-->13	46.5
	1-->5-->8-->9-->10-->13	45
	1-->5-->8-->11-->12-->13	46.5
S19 ---> S18	13-->14	0
S18 ---> S15	14-->15-->19-->24-->27	23.5
	14-->18-->19-->24-->27	20
	14-->18-->23-->24-->27	20
	14-->18-->23-->26-->27	20
S15 ---> S14	27-->28-->29-->34	31
	27-->28-->33-->34	26
S14 ---> S8	34-->33-->40	30
	34-->41-->40	33
S8 ---> S2	40-->39-->43-->48	17
	40-->43-->43-->48	17
S2 ---> S1	48-->49	0
S1 --> S2-->S3-->S4-->S6	S1 --> S2-->S3-->S4-->S6	0

Table 1: alternative paths connecting two stations included in the path of f_1 and their corresponding costs

Stations to be connected	Altenative paths	cost of alternative
S21 ---> S22	S21 ---> S22	0
S22 ---> S23	S22 ---> S23	0
S22 ---> S20	S22 ---> S20	0
S20 ---> S19	S20 ---> S19	0
S23 ---> S19	S23 ---> S19	0
S19 ---> S18	S19 ---> S18	0
S18 ---> S15	S18 ---> S15	0
S15 ---> S14	S15 ---> S14	0
S14 ---> S13	S14 ---> S13	0
S13 ---> S7	S13 ---> S7	0
S7 ---> S5	38-->42-->43-->44-->45	11
	38-->39-->43-->44-->45	11
	38-->39-->40-->44-->45	14
S5 ---> S6	S5 ---> S6	0

Table 2: alternative paths connecting two stations included in the path of f_2 and their corresponding costs

Stations to be connected	Altenative paths	cost of alternative
S21 ---> S22	S21 ---> S22	0
S22 ---> S23	S22 ---> S23	0
S22 ---> S20	S22 ---> S20	0
S20 ---> S19	S20 ---> S19	0
S23 ---> S19	S23 ---> S19	0
S19 ---> S18	S19 ---> S18	0
S18 ---> S8	S18-->23-->24-->25-->28	19
S8 ---> S2	S8 ---> S2	0
S2 ---> S1	S2 ---> S1	0
S1 --> S2-->S3-->S4-->S6	S1 --> S2-->S3-->S4-->S6	0

Table 3: alternative paths connecting two stations included in the path of f_2 and their corresponding costs

Stations to be connected	Altenative paths	cost of alternative
S15 ---> S16	27-->26-->23-->22	11.5
	27-->24-->23-->22	5.5
S16 ---> S17	22-->21-->20-->16	16
	22-->21-->17-->16	16

Table 4: alternative paths connecting two stations included in the path of f_2 and their corresponding costs

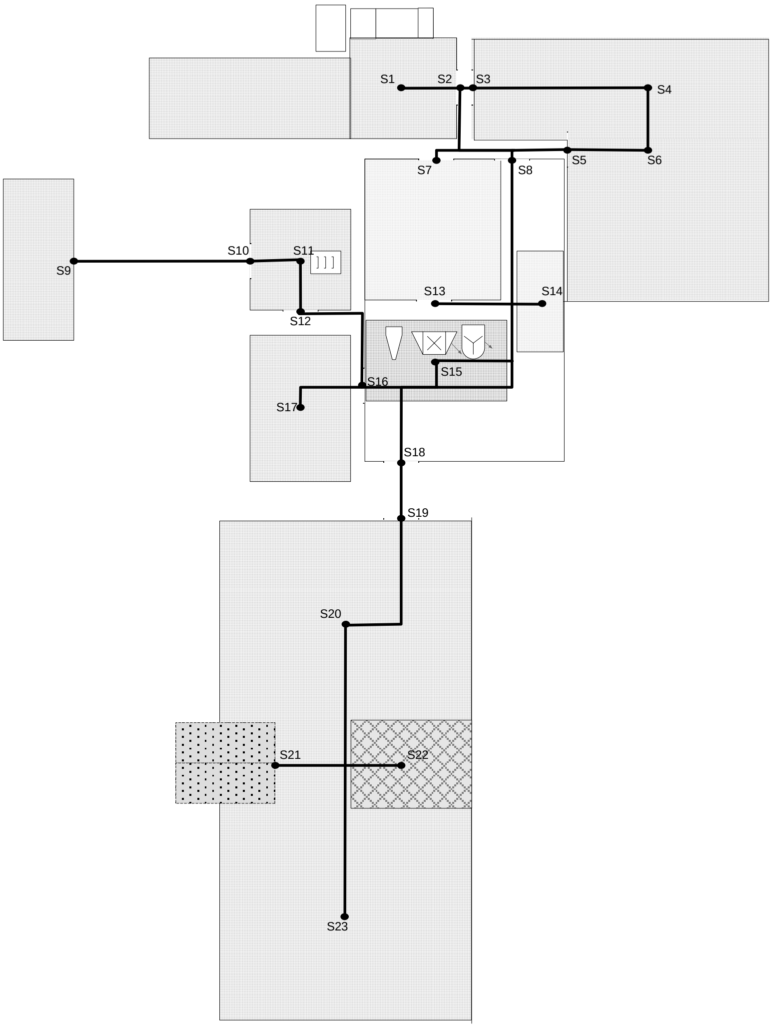


Figure 2: The layout of the department in Scenario 2 and their material flow paths

Appendix 5
Facilities in the Mixing section

Facilities	Length	Width	Height
Mixer B	7,5	3	4,5
Mixer A	7,5	4,5	4,5
Screwconveyer B	11	0,6	0,7
Screwconveyer A	10	0,6	0,7
Bunker	3,1	2,1	4

Table 1: Dimensions of the machines in the Mixing-section

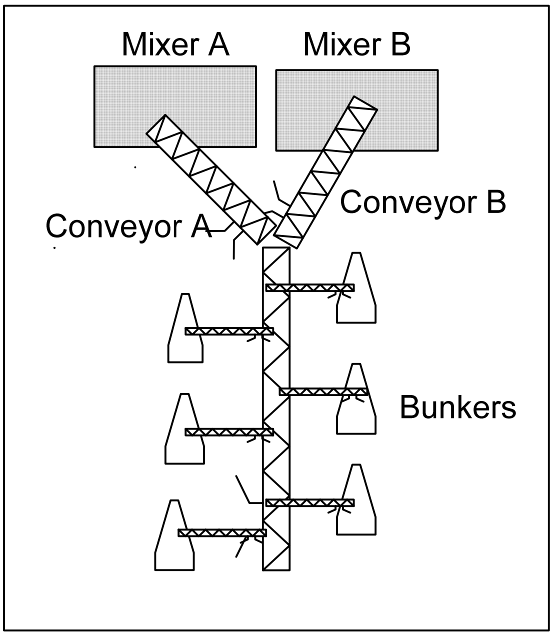


Figure 1: Arrangement of the facilities in the Mixing-section