IMPROVEMENT OF FACILITY LAYOUT USING SYSTEMATIC LAYOUT PLANNING: A CASE STUDY OF NUMERICAL MACHINING COMPLEX LIMITED

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DECLARATION

This thesis is my original work and has not been presented in any university/institution for a degree or for consideration of any certification.

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APPROVAL

We confirm that the work reported in this thesis was carried out by the candidate under our supervision as the University Supervisors.

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DEDICATION

This thesis is dedicated to my beloved family; my mum, dad, sisters, and wife. They have been a great source of motivation and have offered support and encouragement at every stage.

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ABSTRACT

The facilities layout problem is an integral part of facilities planning that aims to systematically arrange and locate all production units within a facility with an objective of improving the production operations of a company. Numerical Machining Complex is planning to improve the production of its manufacturing operations in its machining and fabrication workshop. It seeks to enhance the performance of the existing workshop in terms of efficiency, productivity, and space utilization. It endeavours to adopt a layout strategy that is flexible and able to accommodate its future production needs with a desire of having a well designed and improved layout that maximizes the production capacity of all its facilities. The main purpose of this research is, therefore, to develop an improved model using Systematic Layout Planning procedure to enable Numerical Machining Complex to create and effectively evaluate facility layouts. To achieve this initiative, existing traditional layout procedures were discussed and gaps identified. A model was then developed, consisting of six phases used sequentially to design, improve and evaluate facility layouts. Data on the company's production processes was collected, flow analysis conducted, and three alternative layouts generated. The developed alternative layouts were evaluated, and compared with the existing layout. A suitable layout alternative was finally selected. The flow analysis developed relationships between activities across the workstations and identified the key areas of improvement in the existing layout. The suggested improvements aided in the development of new layouts. Based on a multi-criteria decision analysis of the developed alternatives, layout 1 was selected. The selected layout has lower rearrangement costs and a better priority score, though it slightly increases material handling costs by 3 per cent. It improves the safety of the existing layout of the company, offers flexibility, improves the flow of materials and people, and utilizes space efficiently. The developed model includes rearrangement costs which are not included in the Systematic Layout Planning model. In practice, the model helps Numerical Machining Complex to develop new layouts and the author recommended that the company should use it to study the process flow of materials and people, consider the generated layouts and implement the preferred one. They should also eliminate all the machines that have broken down in the workshop for improved flow.

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LIST OF ABBREVIATIONS

AfDB - Africa Development Bank

CNC- Computer Numerically Controlled

FLP - Facility Layout Problem

GHM- Gear Hobbing Machine

GNP- Gross National Product

GT- Group Technology

HMC- Horizontal Milling Centre

MCDM- Multi-Criteria Decision Making

NMC - Numerical Machining Complex

PEM - Pairwise Exchange Method

SLP- Systematic Layout Planning

TMC- Turning Machine Centre

UMC- Universal Machine Centre

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Today, there is a rapid change in corporate environments and manufacturing facilities are going through periods of expansion and decline due to ever-changing strategic goals. Many companies are fast switching from one product line to another and discontinuing the existing production lines. To keep up with the pace, the facility layout, a key element of facilities planning, has to be adaptable to changes (Chen, 2013). A facilities layout strategy emerges from the overall strategic plan of a firm and its success is dependent on having an efficient production system, therefore, it is essential that the product design, the process selection, and the schedule design be mutually flexible and supportive (Tompkins, 2010).

More often, companies forget to consider strategic planning for their facilities. Instead, they focus on other factors such as maintenance, quality assurance, and marketing. In the recent times, facilities planning has become more and more important and researchers have proposed several new layout design strategies to improve the performance of manufacturing systems. The facility designers select these layouts based on the degree of uncertainty in the production mix, the volume data for future needs and revision of layout costs (Maryam Hamedi, 2012). Facilities planning has thus gone from simple planning or no plan at all to complex mathematical modeling solutions (Tompkins, 2003).

The facilities layout problem (FLP) is an integral part of facilities design and it aims to locate all the production units within a facility. Traditionally, FLP features two approaches; qualitative or quantitative (Sahin, 2010). The qualitative approach aims to maximize closeness rating scores between work centres or departments based on a closeness function derived from a relationship chart while the quantitative approach aims to minimize the total material handling costs between departments based on a distance function (Jia Zhenyuan, 2011). According to Keragu, (1999), a facility designer attempts either to maximize the adjacency measure, minimize the total cost of material handling or optimize a combination of the two. Therefore, FLP can be formulated differently but it is usually considered as an optimization problem (Poormostafa, 2011).

A crucial element during the FLP design process is the design of an effective material handling system. Material handling decisions have a significant impact on the effectiveness of a facility layout. In this regard, the layout design and the handling system should be considered simultaneously (Tompkins, 2010). Many researchers try to address material handling cost reduction as an important aspect because it is estimated that material handling cost contributes to 20-50% of the manufacturing cost of a product. Furthermore, it is generally agreed that effective facilities planning can reduce these costs by at least 10 to 30% (Tompkins, 2003). When the location of the workstations or machines changes, a reduction in material handling cost can be achieved by minimizing the distance traveled by the material handling equipment between the facilities.

From literature, there are many approaches aimed at creating facility layouts. Many of these approaches are advanced algorithmic techniques such as genetic algorithm technique (Resende, 2015), and ant colony optimization algorithm (Chen, 2013). Algorithm approaches usually involve only quantitative input data and they are complex, thus requiring advanced training in mathematical models (Chien, 2004). However, procedural approaches, such as Systematic Layout Planning(SLP), can be used to link both qualitative and quantitative factors together in the facility design process (Apple, 1977). Furthermore, according to Sharp, (1999), much research effort has been on the facility layout design process and there is a lack of solutions in the evaluation stage.

According to Tompkins, (2010), there is an organized systematic approach to the facility layout problem which applies the traditional engineering design process. This approach can be used to either design a new layout or improve an existing one. Developing a new layout involves constructing one from 'scatch' while improving a layout involves generating alternatives based on an existing layout. There are various traditional layout design procedures, such as Systematic Layout Planning(SLP), Reeds Layout procedure, Apples's Layout Procedure, among others. Even though a majority of the existing literature focuses more on designing a new layout, more work still involves improving the layout of existing facilities (Tompkins, 2003). The Pairwise Exchange Method (PEM) technique can be used for evaluating alternative facility layouts generated from the improvement type category. This technique seeks to minimize the total cost of transporting materials between workstations. It uses a distance matrix and is based on a rectilinear distance from the centroid of one workstation to the centroid of another workstation.

Evaluation of facility layout alternatives is a difficult affair as multiple objectives, both qualitative and quantitative, are usually involved (Taho Yang, 2000), and considering that these objectives are subjective in nature, their optimization can, therefore, be used to bridge the gap between theory and practice. According to Keragu, (1999), any alteration of an existing layout introduces two types of costs: downtime costs incurred due to the loss in production time and the cost of physically moving equipment from their existing location to the new location. The benefits of the new layout should be greater than the costs of rearrangement of an existing layout.

1.2 Company Background

Numerical Machining Complex (NMC) Limited is an ISO 9001:2008 certified engineering firm incorporated under the Companies Act as a Liability Limited Company. It is located in Nairobi, Workshop Road, Industrial Area, and it was established in 1994 by the Kenya government to take over the functions of Nyayo Motor Corporation Limited, a state corporation established in 1990 to manufacture motor vehicles and vehicle spare parts. NMC currently engages in the design and manufacture of industrial and automotive parts. It offers automotive spare parts such as brake discs; railway spare parts including brake blocks, and bolster liners; industrial replacement parts including shafts and sprockets.

The company also resells design and manufacturing software such as AutoCAD - drafting, detailing and conceptual design software. In addition, it offers Computer Numerically Controlled (CNC) machining, heat treatment, foundry, fabrication, and training services.

1.3 Problem Environment

In the recent past, there have been rapid changes in production techniques and equipment and many more changes are expected in the future. Very few companies will be able to retain their old facilities or layouts without severely damaging their competitive position in the marketplace (Tompkins, 2003). Numerical Machining Complex Limited (NMC) is one such company. During the early period, NMC operated as a research institution with conducting research being its primary objective. In essence of time, the research mission changed and the company began operating commercially to supply local firms with manufactured spare parts. The change of mission over time was occasioned by several factors; key among them the need to have an industrial powerhouse that would drive the country's industrialization agenda towards the realization of Vision 2030.

This change of strategy by NMC over time did not occasion an immediate significant change in the layout strategy of the company despite its importance on the overall efficiency and productivity of its manufacturing processes. The company continues to purchase new machines and equipment to support its operations, all geared towards the realization of the new objectives. The criteria for the physical placement of the new equipment has never been defined, rather, they are placed in the nearest available space. This random placement of equipment across the workshop has affected the relationship between activities by changing material flow patterns of the manufacturing processes thereby altering the original layout. According to Keragu, (1999), a manufacturer should alter the layout whenever the situation warrants. This is despite it being impossible to define stable material flow patterns between workstations over a long planning horizon in a dynamic environment.

Figure 1.1: Turning Machine that has broken down laying at the workshop

The layout of the workshop floor of the company is process-oriented and it has more than twenty machines arranged across for conducting various machining operations. These machines are designed as workstations and they perform various milling activities ranging from facing, turning, slotting, drilling, boring and gear-hobbing, among others. They mainly include, among others; universal milling machines, horizontal milling machines, turning machines and gear hobbing machines. These machines are computer numerically controlled.

Also included are a turn mill, a CNC lathe machine, surface grinders, a band saw and conventional lathe machines.

Among the afore-mentioned machines, there are two turning machines and one horizontal milling machine that have been non-operational for more than 10 years. These machines have exhausted all maintenance and repair strategies and are considered by the company as irreparable. As such, they do not benefit NMC yet they continue to occupy space in the workshop and affect the flow of materials. It's also important to highlight that there are many assorted parts and machines in the workshop which have never been used before for any machining operations. They include crankshaft grinders, two smaller conventional lathe machines, and a conventional shaping machine.

Figure 1.2: Assorted parts and machines in the workshop

The production department is responsible for the planning and execution of all machining operations in the workshop. NMC produces different products for different customers. Each product is customized according to the specification of the customer. Ordinarily, a customer can either present a detailed design of an intended product for production or present a product for repair or for heat treatment. Alternatively, NMC can design the product according to the needs of the customer and then manufacture it. The production department assigns each job to the different machines based on the process design of the intended product.

The workshop has a heat treatment section where products that require heat treatment are processed. It is important to mention that any workpiece that gets into the workshop for machining can originate either from a customer, foundry section (casting) or from a raw piece of metal cut by the band saw. There are four types of material handling equipment that are used at the workshop. They include two bridge cranes, one forklift, two trolleys, one hydraulic fork trolley, and four wheelbarrows. They are used to transport materials across different workstations.

Furthermore, there are some machines, such as the band saw, that have been placed along the gangways of the workshop thereby posing safety risks. In summary, its crucial for business executives to understand the importance of effective facilities planning and to effectively plan for change in the design of existing products, the processing sequences for existing products, quantities of production and associated schedules and the structure of organization and management philosophies. These variables affect the facility layout and as such, it should be flexible to accommodate them (Adil Baykasoglu, 2006). It is important to appreciate that facilities planning is a dynamic and continuous process that should adapt to changes and as such, it needs to be viewed from a life-cycle perspective (Tompkins, 2010).

Figure 1.3: Bandsaw and the light fabrication section being located along the gangway in the workshop

Based on the above facts, this research uses Systematic Layout Planning (SLP) as a procedural tool for layout improvement. An improved model was created to help NMC improve the flow of materials and people, and improve efficiency and productivity. The existing layout was evaluated through flow analysis. Alternative layouts were then generated and compared with the existing layout. Rearrangement costs were considered and a multi-objective layout assessment criteria developed to aid in the selection of the most suitable alternative layout. The assessment used was the multi-criteria decision making (MCDM) technique that utilized both the economic and non-economic factors in determining the most suitable alternative.

1.4 Problem Statement

Numerical Machining Complex is planning to enhance production of its manufacturing operations by expanding the number of machines operating in the facility. They are looking to improve the performance of the existing workshop in terms of efficiency by improving on the flow of materials, people and information; increasing productivity by reducing backtracking, and utilizing space by eliminating non-effective machines. They seek to adopt a layout strategy that is flexible, able to accommodate their future production needs and one that can adapt to productivity improvement in the flow of people and materials. The proposed layout should be able to quickly respond to changes in demand, production volume, and product mix.

1.5 Research Objectives

1.5.1 Main Objective

The main objective of this research is to develop an improved model using Systematic Layout Planning to enable Numerical Machining Complex to create and effectively evaluate facility layouts.

1.5.2 Specific Objectives

The specific objectives of this research are to;

1. Evaluate the current facility layout by analysing the flow of materials across workstations.

2. Determine the relationships between various activities across the workstations.

3. Develop improved facility layout alternatives for consideration.
4. Evaluate the developed layout alternatives and select the most suitable one.

1.6 Scope of the Study

NMC has divided its manufacturing operations into two main sections, namely; Machining and Fabrication Section and the Foundry Section. This thesis is going to limit its scope to the former. The purpose of this work is to improve the facilities design of the shop floor which has a process-oriented layout.

1.7 Significance of the Study

Facilities' planning is an important subject that has a great impact on the overall effectiveness and profitability of a company. A company can benefit from today's changing working environment if it employs effective facilities planning and production management. According to Tompkins, (2003), approximately 8% of the gross national product (GNP) has been spent annually on new facilities in the United States and it is suggested that over 250 billion will be spent annually in the United States alone on facilities that will require planning or replanning. This size of investment in new facilities each year makes the field of facilities planning important.

Despite the importance of effective facilities planning, companies have not really made use of the existing literature to their advantage. According to research done by Williamson, (1996), companies plan their layouts based on personal views as they are unaware of the facility layout work published by the academic sector, and even if they knew, they often do not use the models as they are complicated and require advanced personnel in the design process (Chien, 2004). It is, therefore, relevant to get a simple, easy to follow and inclusive procedure that shall aid companies to design and evaluate facility layouts.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

In this chapter, an overview of the facilities planning process, which is the base for conducting this research, was discussed. Included in this part are facilities planning, types of layouts, layout procedures, material handling, and multi-criteria decision-making. Deductions from the literature were presented too.

2.2 Facilities Planning

The facilities planning subject continues to be a popular topic among researchers for many years now. It is one of the most popular published areas in the academic field. According to Tompkins, (2003), facilities' planning seeks to determine how an activity's tangible fixed assets best support achieving the activity's objective and in a manufacturing context, it involves determining how a manufacturing facility best supports production. Basically, the main objective of facilities planning is to utilize a company's available resources in the most effective way in order to maximize the return on investment on all capital.

Facilities' planning is divided into two main components; facilities location and facilities design. The former seeks to place the facility with respect to customer, suppliers and other interfacing facilities. The latter seeks to determine how the design components of a facility support achieving the facility's objectives. Facilities design is then separated into three components namely; facility systems design, layout design and handling systems design (Tompkins, 2003).

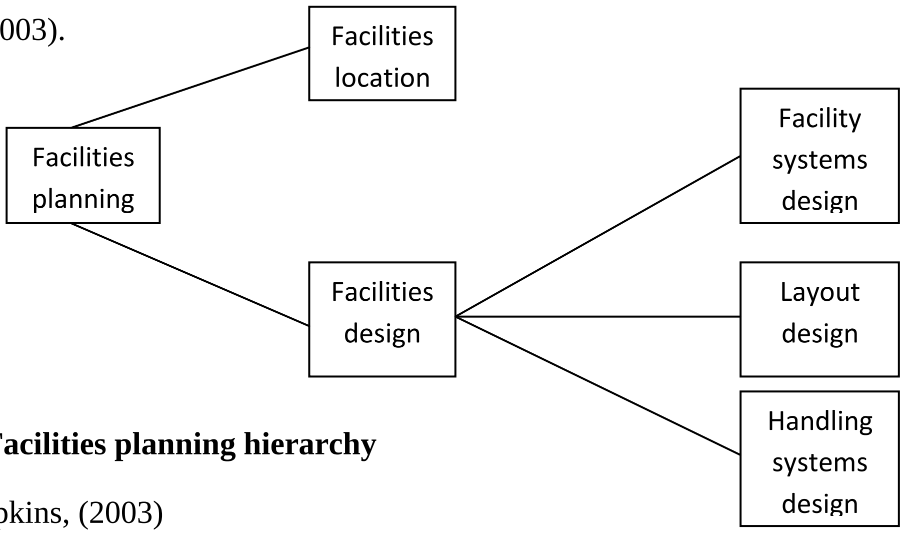


Figure 2.1: Facilities planning hierarchy

Source: Tompkins, (2003)

The facility systems consist of the structural systems, the enclosure systems, the lighting/electrical/communication systems and sanitation systems, that is, power, gas, light, heat, ventilation, air conditioning and water piping. The layout consists of all the equipment, machinery, and furnishings within the facility. The handling system consists of the mechanisms needed to satisfy the required facility interactions.

Facilities' planning is a strategic matter that is affected by the overall business strategy of a firm, thus manufacturing strategies must be integrated with other elements of overall business strategy in order to achieve high productivity (Tompkins, 2003). The concepts, techniques, and technologies used in the manufacturing system result from the product, process and schedule design used by facility designers in the facilities planning process. There is a relationship between product, process and schedule design and facilities planning. Product design involves determining which products are to be produced and the detailed design of individual products. Process design involves determining how the products are to be produced and schedule design involves determining how much to produce and when to produce. Therefore, the facilities planner is dependent on the timely and accurate input from product, process and schedule designers in order to carry out his task effectively (Tompkins, 2010)

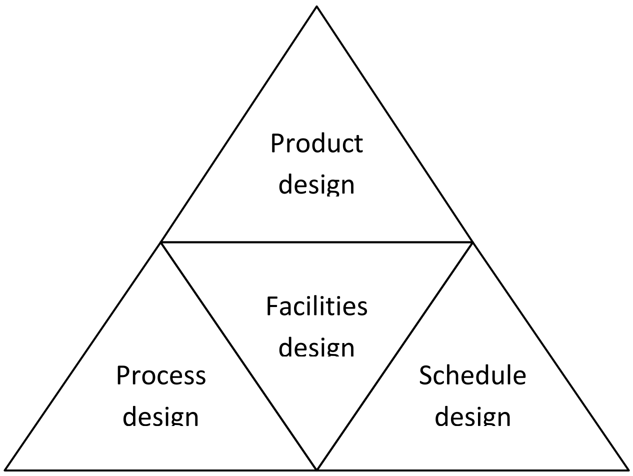


Figure 2.2: Relationship between product, process and schedule design and facilities planning

Source: Tompkins, (2010)

Facilities' planning is a dynamic process. It continues to change over time due to the development of new methods and techniques in the production process as a result of changes in technology. In this regard, it is a continuous improvement process that should be viewed from a lifecycle perspective (Tompkins, 2003).

2.2.1 Objectives of Facilities Layout Planning

The purpose of any layout strategy is to facilitate the flow of materials, information, and people between areas. This is achieved by specifying the arrangement of processes, related equipment, and work areas, including storage and customer service areas. The general objective of the facility layout problem is to develop an economic layout that meets the requirements of product design and volume, process equipment and capacity, quality of work life and building and site constraints.

According to Tompkins, (2003), some of the typical facilities design objectives are to;

1. Support the vision of the organization through improved material handling, material control, and good housekeeping.
2. Minimize capital investment.
3. Effectively utilize people, equipment, space, and energy.
4. Be adaptable and promote ease of maintenance.
5. Provide for employee safety and job satisfaction.

It is critical to note that in real-world cases, a facility designer interface with conflicting objectives more often (Jaafari, 2009). Hence it is important to evaluate carefully the performance of each generated alternative, using each of the appropriate criteria (Tompkins, 2003).

2.2.2 Principles of Facility Layout

According to N.Suresh, (2008), there are seven key principles of facility layout

1. The principle of integration: A good layout integrates manpower, materials, machines and all the supporting services in order to effectively utilize resources.
2. The principle of minimum distance: This involves arranging facilities with an aim of minimizing the distance of travel of both materials and workers.
3. The principle of cubic space utilization: A good layout utilizes all the available space in the most effective way.
4. The principle of flow: A good layout optimizes the flow of materials, information, and people without backtracking.

5. The principle of maximum flexibility: A good layout can be altered without much cost and time depending on the future requirements.
6. The principle of safety, security, and satisfaction: A good layout should give due consideration to the safety of the workers and safeguard the plant and machinery against any harm.
7. The principle of minimum handling: A good layout should reduce material handling to the minimum.

2.2.3 Classification of Facilities Layout

Traditionally, there are four types of layouts that are considered appropriate for a manufacturing facility:

1. Process Layout
2. Product Layout
3. Fixed Position Layout
4. Group technology Layout/Cellular Layout

2.2.3.1 Process Layout

This type of layout is recommended for batch production and it's primarily found in job shops or firms producing customized and low volume products that require different processing requirements and sequence of operations. It is a configuration in which operations of a similar nature or function are grouped together (Santos, 2014). Process layouts are often referred to as functional layouts as their purpose is to process products involving a variety of processing requirements. A good example is a machine shop. A machine shop has separate departments with general purpose machines grouped together by their functions e.g. grinding, milling, drilling, and lathes. It is, therefore, important to note that facilities that are configured according to their individual functions have a process layout. This type of layout offers a firm adequate flexibility to handle a variety of routes and process requirements.

A diagram of the process layout is shown in figure 2.3

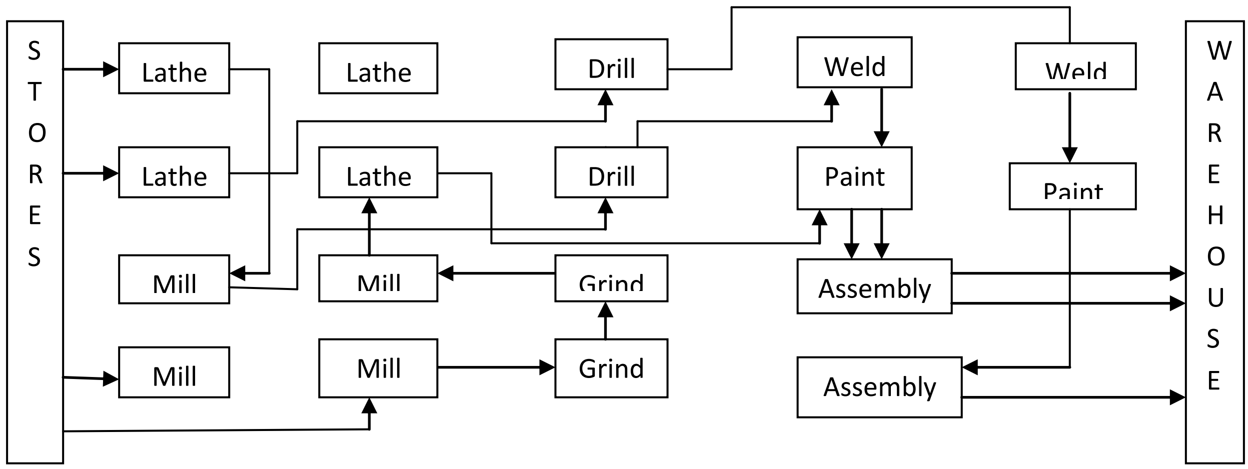


Figure 2.3: Process layout

Source: Tompkins, (2003)

Advantages of Process Layout

1. Flexibility; A manufacturing firm is able to produce a wide variety of processing requirements.
2. System protection; since there are multiple machines, a failure in one of them does not stop production of the rest.
3. Cost; Most times, it is less costly to purchase and maintain general purpose equipment as compared to specialized equipment.
4. Easier supervision; There is easy supervision of tasks as workers for each department become highly knowledgeable about their functions.

Disadvantages of Process Layout

1. Backtracking and long movements may occur in the handling of materials thus leading to inefficiency
2. The equipment utilization rates are often low as machine usage is dependent upon a variety of output requirements.
3. There are often complications of production planning and control because of the constantly changing schedules and routings.
4. There are comparatively large amounts of in-process inventory as space and capital are tied up by work in process.
5. There is low productivity as each job requires different setup time and operator training.

2.2.3.2 Product Layout

This type of layout is found in a repetitive assembly and continuous flow industry referred to as a flow shop. A flow shop produces highly standardized and high-volume products that require the use of standardized and repetitive processes. Here, production resources are arranged sequentially based on the routings of the products. This sequential arrangement allows the entire process to be laid down in a straight line and at times such a process may be dedicated to the single production of one product. Such flow enables utilization of labour and equipment as they are subdivided smoothly across the whole operation. This arrangement also minimizes material movement across the production facility (N.Suresh, 2008).

This layout is based by allocating a machine close to the next one in line and in the correct sequence to manufacture the product, and since there is the high volume of production, the machines on the line can be automated, with very little manual labour.

A diagram of product layout is shown in figure 2.4

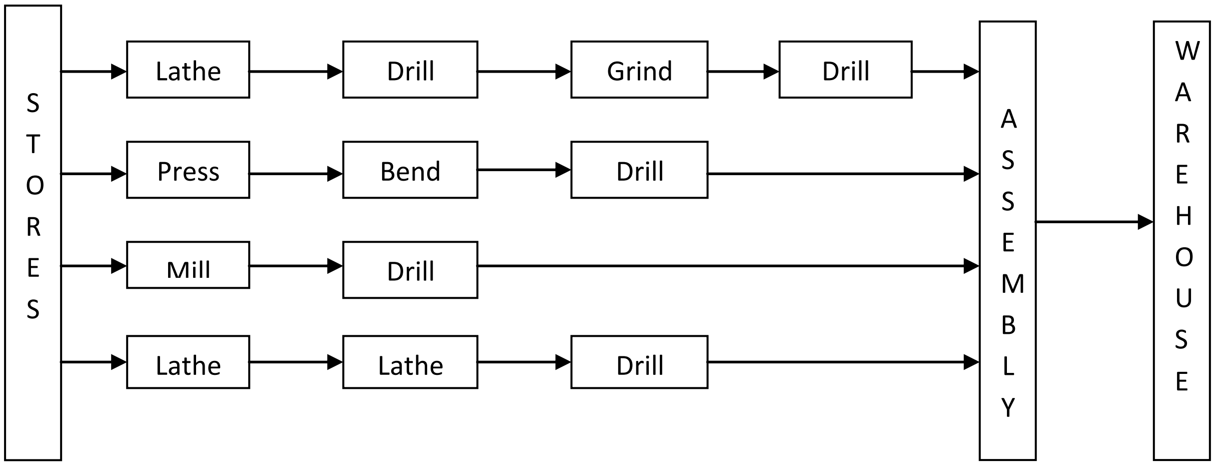


Figure 2.4: Product layout

Source: Tompkins, (2003)

Advantages of Product Layout

1. Product layouts can manufacture a large volume of products in a short time.
2. The high volume of production makes the unit cost low and the labour specialization reduces training time and costs.
3. There is a high degree of equipment and labour utilization.
4. Production planning and control is possible.
5. Material handling is reduced because of the reduction of distance in machine location

Disadvantages of Product Layout

1. There is the lack of process flexibility as the production system is designed to suit certain products.
2. A breakdown in one of the machines along the line may lead to stoppage of the whole line thus affecting operations.
3. It requires high investment in terms of capital on equipment.
4. The system is repetitive and as such it causes human fatigue on the workers.

2.2.3.3 Fixed Position Layout

This type of layout is appropriate for a product that is too large or bulky to move. Here, the product being worked on remains stationary and workers, equipment and materials are moved to it. Fixed positions layouts are used in the construction large projects such as buildings, power plants and dams, shipbuilding and production of large aircraft and space mission rockets (N.Suresh, 2008).

A diagram of a fixed position layout is shown in figure 2.5

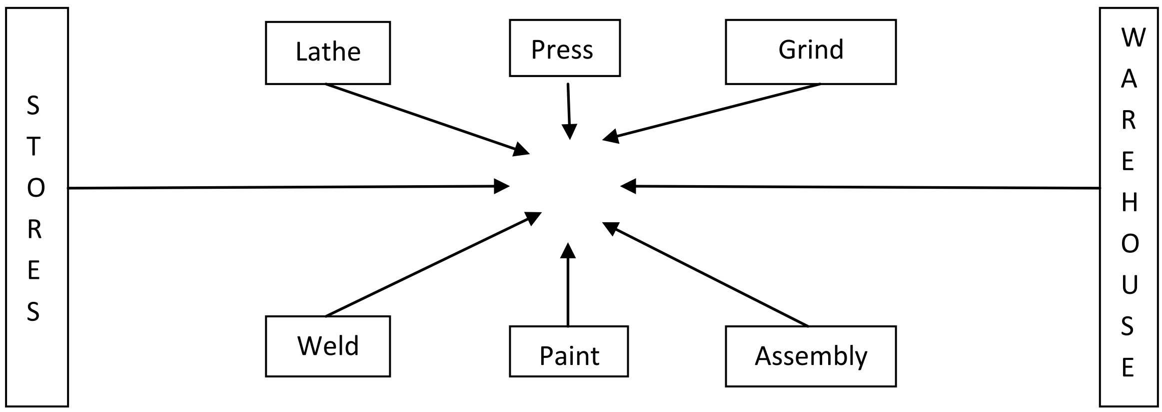


Figure 2.5: Fixed position layout

Source: Tompkins, (2003)

Advantages of Fixed Position Layout

1. It is flexible and it can accommodate multiple changes in product design, product volume, and product mix.
2. There is reduced movement of materials.
3. There is a continuity of operations and responsibility from teams in the different sections thus eliminating problems of re-planning.

Disadvantages of Fixed Position Layout

1. Increased movement of equipment and materials is expensive.
2. Duplication of equipment may occur.
3. The work area may be crowded making storage space unavailable.
4. General supervision is normally required.
5. Skilled personnel may be required to work on different operations.

2.2.3.4 Group Technology Layout/Cellular Layout

A group layout combines both the advantages of product and process layouts. Here, machines are grouped according to the process requirements for a set of similar items or part families that require similar processing. These groups are referred to as cells. These processes are grouped into cells using a concept known as group technology (GT). GT involves the identification, analysis, and comparisons of parts with similar design features and similar process characteristics. This technique is normally used for companies that manufacture a variety of parts in small batches to enable them to take advantage and economics of flow line layout (N.Suresh, 2008). If there are *m*-machines and *n*-components, in a group layout, the *m*-machines and *n*-components will be divided into a distinct number of machine-component cells (group) such that all the components assigned to a cell are processed within that cell itself. Here, the objective is to minimize the movements between cells (N.Suresh, 2008).

The main objective of a group technology layout is to minimize the sum of the cost of transportation and the cost of equipment.

Advantages of Group Technology Layout

1. Reduced work in process and work movement.
2. There are reduced paperwork and overall production time.
3. There is effective machine utilization and productivity.
4. There is reduced material handling and machine set up time is low.
5. This layout arrangement supports the use of general-purpose equipment.

Disadvantages of Group Technology Layout

1. This system layout requires general supervision.
2. There is reduced shop flexibility.
3. It requires skilled employees compared to the product layout.
4. It requires a balanced material flow between the process and product layout, otherwise, storage for work in process is required.

A diagram of group technology layout is shown in figure 2.6

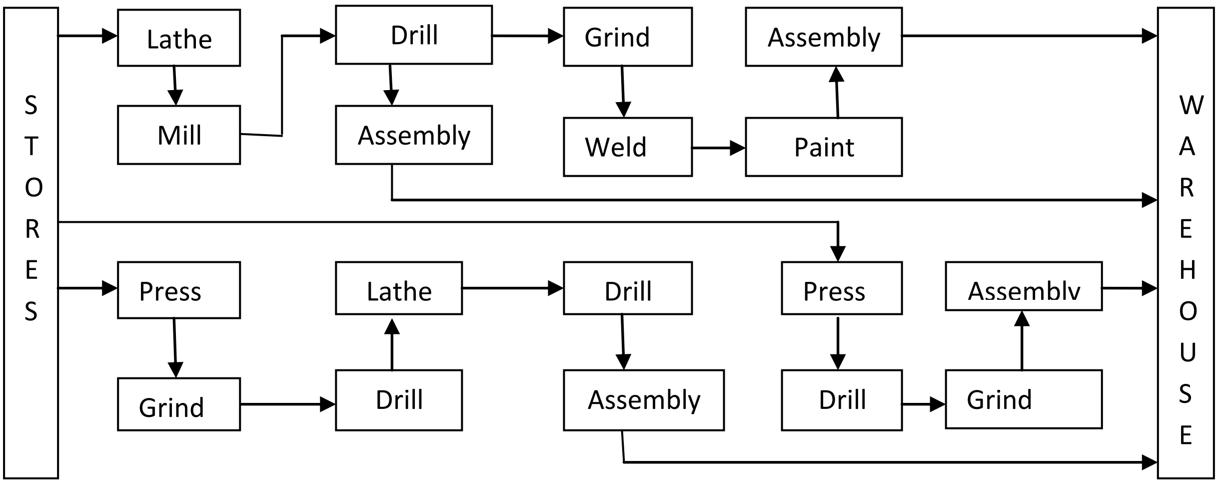


Figure 2.6: Group Technology Layout

Source: Tompkins, (2003).

The relationship between the different types of layouts to volume and product variety is shown in figure 2.7

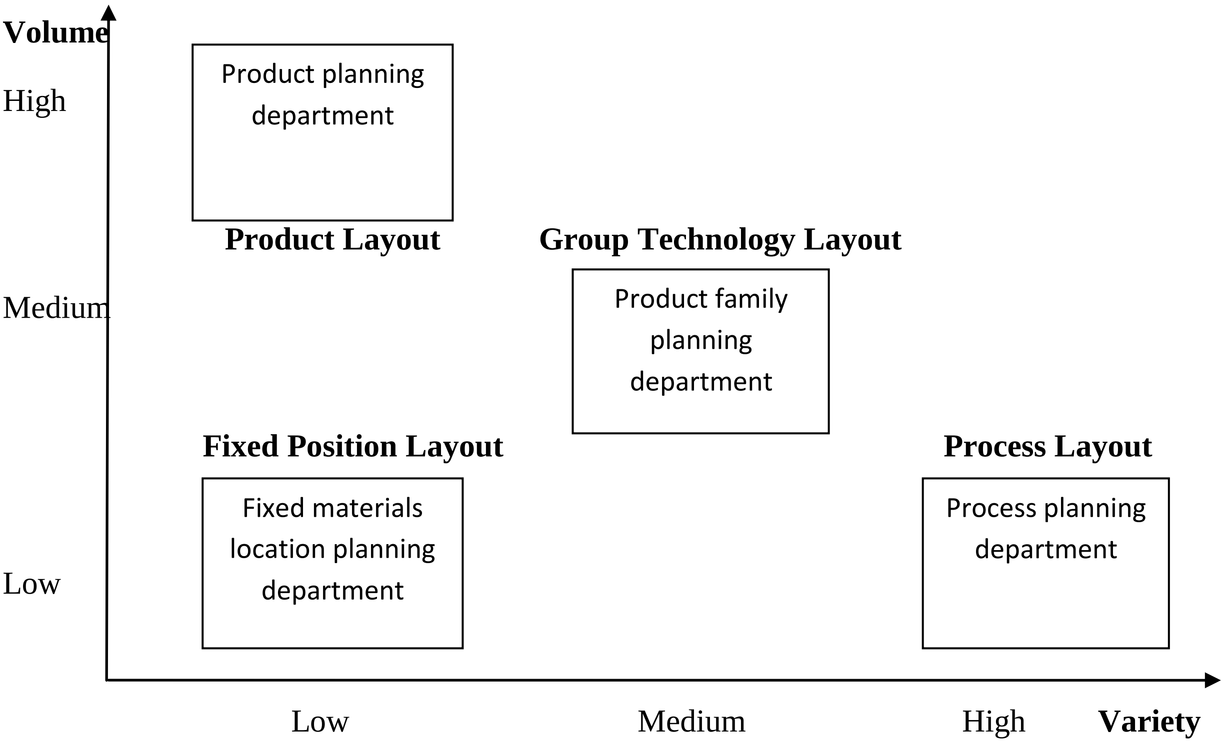


Figure 2.7: Types of layouts based on volume-variety

Source: Tompkins, (2010)

2.3 Facilities Planning Process

Although a facility is planned only once, it is often re-planned so as to synchronize it with the ever-changing objectives. This, therefore, makes facilities' planning a continuous improvement process that should be viewed from a life-cycle perspective. (Tompkins, 2010).

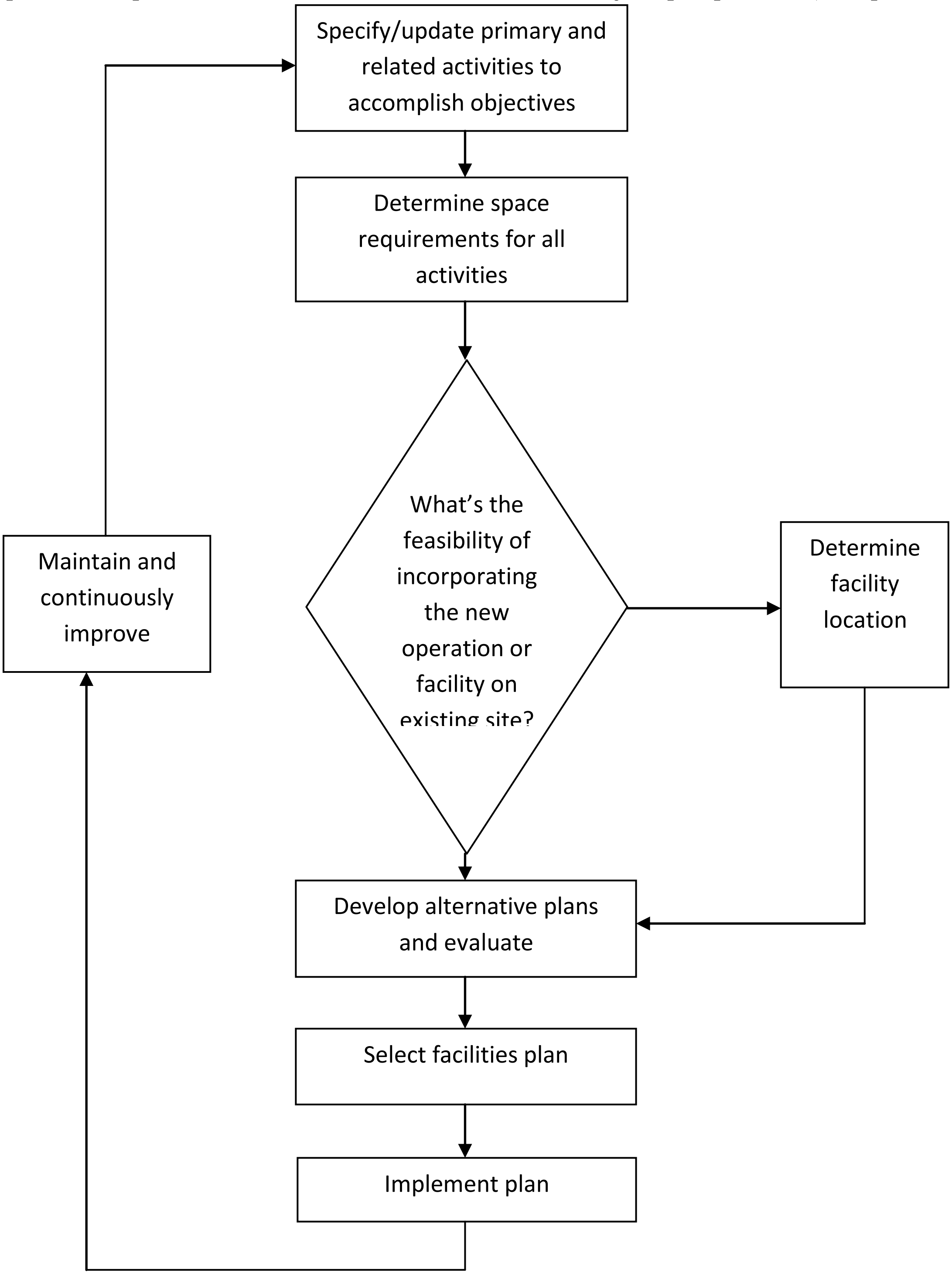


Figure 2.8: Continuous improvement facilities planning cycle

Source : Tompkins, (2010)

According to Tompkins, (2003), facilities planning can be approached using an organized and systematic approach that applies the engineering design process. Such application would result in the following six steps:

1. Define the problem. In this step, the objective of the facility should be specified to include what is to be produced, how much, when and how and all support activities should also be identified.

2. Analyze the problem. After identification of the key activities, interrelationships among them should be determined. Space requirements of the activities should also be determined.

3. Generate alternative designs. In this step, alternative facility plans should be generated from the relationship diagramming of the activities.

4. Evaluate the alternatives. This step aims to rank the generated facility plans using stated evaluation criteria.

5. Select a facility plan**.** The information generated in step 4 should help someone to select an effective facility plan.

6. Implement the selected plan. After selecting a suitable facility plan, a plan for installation, debugging and maintenance should be developed so as to implement the plan.

2.4 Layout Procedures

There are a variety of procedures that can be used to develop the layout of a facility. According to Tompkins, (2010), these procedures can be used either to construct a new layout or improve an existing one. The following procedures were reviewed by Tompkins, (1984, 2003) and they will be discussed in this research.

2.4.1 Immer's Basic Layout Planning Steps

This approach is one of the earliest in the subject of layout planning. It was developed by Immer in 1950 and it entails the basic steps in the analysis of a layout. In his own words, he stated "This analysis should be composed of three simple steps, which can be applied to any type of layout problem."

The three steps are:

1. Put the problem on paper.

2. Show lines of flow.

3. Convert flow lines to machine lines.

This approach by Immer does not make any provisions for the planning and construction of a new layout. It lays more emphasis on an existing layout that needs improvement. Furthermore, this approach would be best suited for a product type of layout rather than a process type configuration since the listed steps do not consider the limitations of a process type configuration such as backtracking.

2.4.2 Nadler's Ideal Systems Approach

This is an approach that was developed by Nadler in 1961 to design work systems. It is also useful in facilities planning to design layouts. This approach is more of a philosophy rather than a procedure and it follows the sequence below:

1. *Aim* for the "theoretical ideal system."

2. *Conceptualize* the "ultimate ideal system."

3. *Design* the "technologically workable ideal system."

4. *Install* the "recommended system."

As shown in figure 2.9, in this ideal systems approach, a facility designer starts at the top with a "theoretically best" and all the way down to his "recommended practical design." Nadler wanted to change the way of thinking of a facility designer from "what has been" to "what can be."

In practice, this is a philosophy and its theoretical view can only be used by a facility designer based on individual needs of the facilities being developed. It lacks concrete steps of designing a layout and it's the reason facility designers do not use it in practice to either design new layouts or improve existing ones.

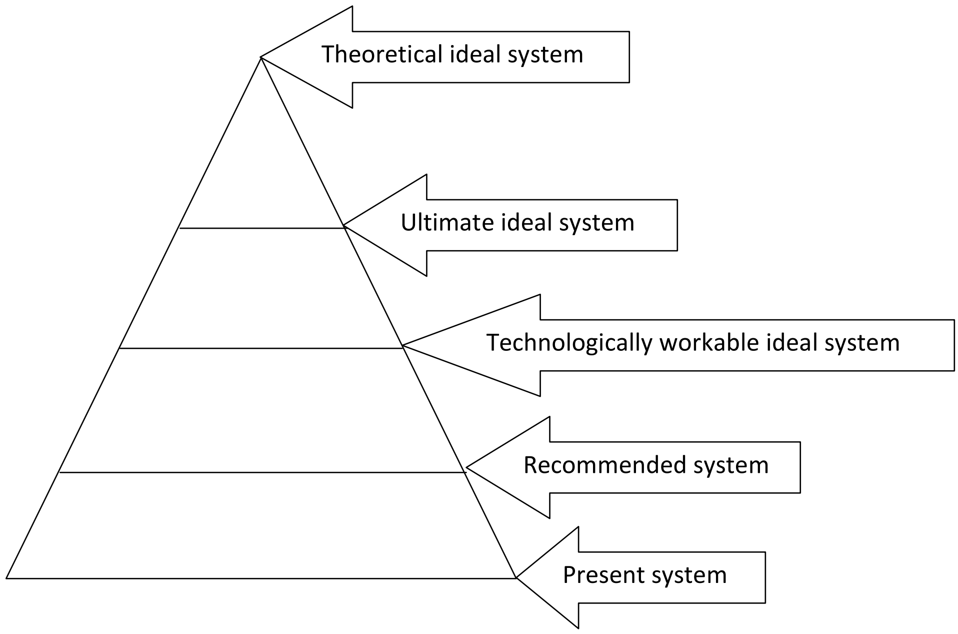


Figure 2.9: The hierarchical ideal systems approach

2.4.3 Apple's Plant Layout Procedure

Apple proposed a detailed sequence of 20 steps of constructing a plant layout. Apple noted that the steps do not necessarily have to be performed in the given sequence since the design of any facility layout is different. The steps are as follows:

1. Procure the basic data.
2. Analyze the basic data.
3. Design the productive process.
4. Plan the material flow pattern.
5. Consider the general material handling plan.
6. Calculate equipment requirements.
7. Plan individual workstations.
8. Select specific material handling equipment.
9. Coordinate groups of related operations.
10. Design activity interrelationships.
11. Determine storage requirements.
12. Plan service and auxiliary activities.
13. Determine space requirements.

14. Allocate activities to total space.

15. Consider building types.

16. Construct master layout.

17. Evaluate, adjust and check the layout with the appropriate persons.

18. Obtain approvals.

19. Install the layout.

20. Follow up on implementation of the layout.

Although Apple's Layout Procedure is recognized as a traditional layout design procedure which can be used in designing new facility layouts, it is rarely used by facility designers. It is not a procedural approach, just as Apple had envisaged and this makes it difficult for facility designers to use it in practice, especially in improving existing layouts and since these steps are not necessarily performed in sequence, there is a lot of jumping around between them and this causes backtracking. This backtracking costs resources and decreases the effectiveness of the layouts being developed. When these factors, among others, are put into consideration by facility designers, Apple's Layout Procedure becomes ineffective in improving existing facility layouts.

2.4.4 Reed's Plant Layout Procedure

According to Tompkins (2003), Reed recommended ten steps, which he described to as a "systematic plan of attack", to be used in planning and preparing a facility layout. The steps are listed below:

1. Analyze the product or products to be produced.

2. Determine the process required to manufacture the product.

3. Prepare layout planning charts.

4. Determine workstations.

5. Analyze storage area requirements.

6. Establish minimum aisle widths.

7. Establish office requirements.

8. Consider personnel facilities and services.

9. Survey plant services.

10. Provide for future expansion.

Reed considered the third step, the layout planning chart, to be the most important in the layout process. The chart integrated the following factors:

1. The flow process, including operations, transportations, storage and inspections.

2. Standard times for each operation.

3. Machine selection and balance.

4. Manpower selection and balance.

5. Material handling requirements.

Reed's "systematic plan of attack", although recognized as a traditional layout design procedure, poses certain challenges to modern facility designers. To begin with, this procedure is not suitable for the improvement of existing facility layouts. In the modern manufacturing environment, the flow of materials is an important aspect when it comes to layout development and improvement. Flow is not a consideration in Reed's procedure, thereby making it unattractive to facility designers. Secondly, Reed laid more emphasis on the layout planning charts. In practice, most manufacturing firms do not either store or misreport this data. They are mostly concerned with producing goods for their customers without having to incur more costs by developing the charts. The effect is that there is no valid data to solve a layout design problem

2.4.5 Systematic Layout Planning Procedure

Systematic layout planning (SLP) is a procedural layout design approach developed by Muther in 1961. It's a proven powerful tool in facility layout design and it has been widely used by researchers for academic and practical purposes and it uses the activity relationship chart as its foundation (Tompkins, 2003). An activity relationship chart results from the analysis of the different activities and how they relate to each other. It is performed based on the input data and an understanding of the roles and relationships between activities. The input data also helps generate a material flow analysis chart normally referred to as a From-to-Chart. From the analysis of the material flow of chart and activity relationship chart, a relationship diagram is developed (Tompkins, 2010). The next step involves determining the amount of space to be assigned to each activity and after the space assignments have been made, space templates are made for each department in order to obtain the space relationship diagram.

The next step involves developing and evaluating a number of layout alternatives based on modification considerations and practical limitations, and finally, the preferred alternative is recommended. The SLP procedure is illustrated in figure 2.9

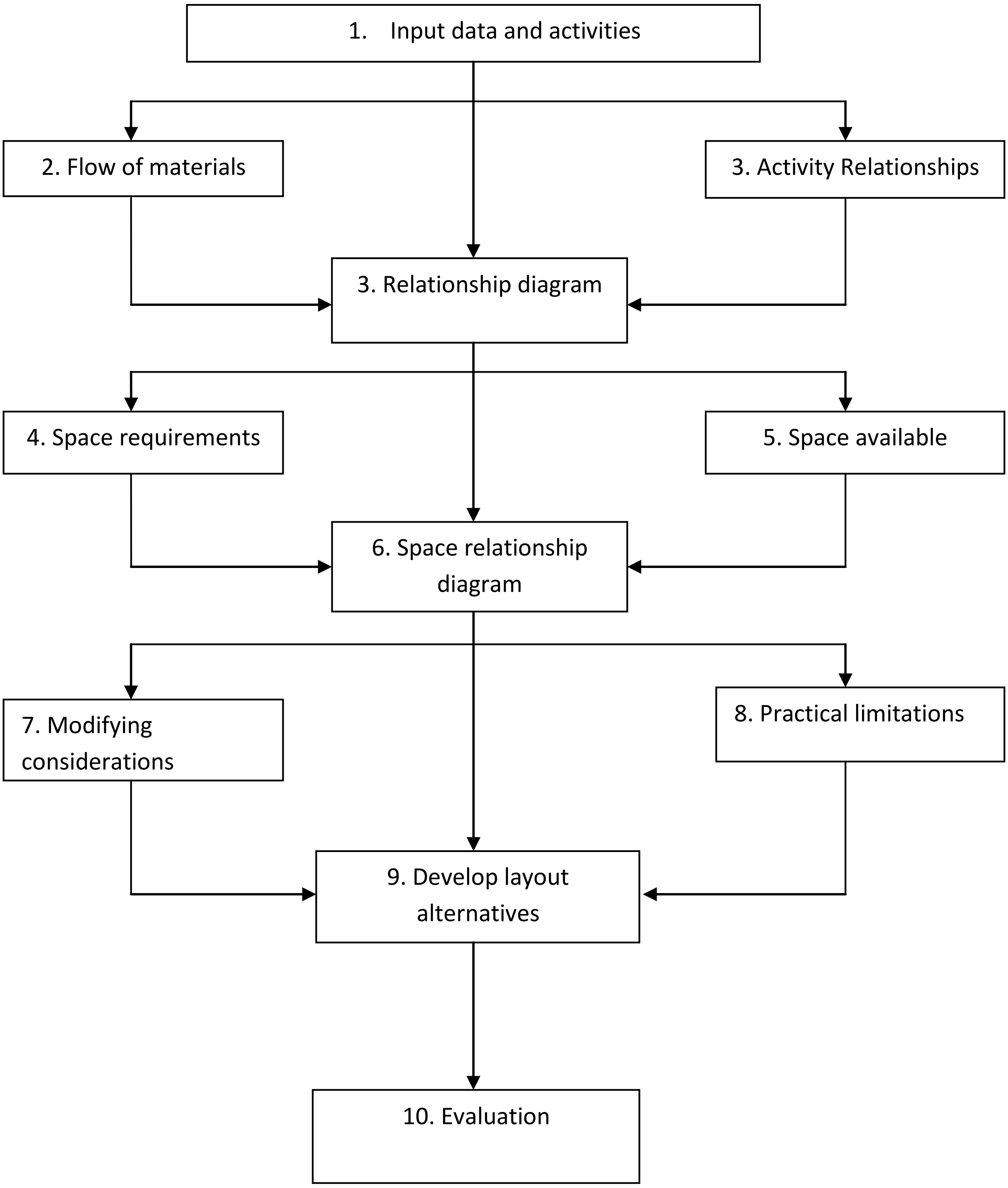


Figure 2.10: Systematic layout planning (SLP) procedure

Source: Tompkins, (2010)

The steps in the systematic layout planning are discussed in detail as follows;

Step 1: Input Data and Activities

This is the first step of the facility design process. Here, all the data on all activities is collected. The data collected is on process movement and material handling movement. This information is found in the daily operations and it can be obtained from stored data of manufactured products. It is critical to find data on all transports between work areas. The process design of the products aid in collecting all the relevant data

Step 2: Flow of Materials Analysis

The process flow of a product is the path that the product takes while moving through the production process. Material flow analysis is important as it helps a facility designer to design an effective material handling plan. Flow analysis tries to minimize the distance travelled, cross traffic, backtracking, and production cost. Flow analysis can be classified into three key areas, namely, flow within workstations, flow within departments and flow between departments (Tompkins, 2003). After the path of each activity is identified and analysis is done, a from-to-chart is formed. This chart represents all the flow volumes between activities across the workstations. An example of a from-to-chart is shown in figure 2.10.

From \ To	Stores	Milling	Turning	Press	Plate	Assembly	Warehouse
Stores		12	6	9	1	4	
Milling					7	2	
Turning		3			4		
Press					3	1	1
Plate		3	1			4	3
Assembly		1					7
Warehouse							

Figure 2.11: From-to-chart

Source: Tompkins, (2003)

Step 3: Activity Relationship Chart

An activity relationship chart shows how activities relate to each other in the process design. A closeness rating is assigned depending on the importance the relationship between the activities. According to Muther, (1974), an activity relationship chart is the best way to integrate all supporting activities of any process that is being investigated. The closeness rating system is normally assigned as follows;

A – Absolutely necessary relationship. This rating is characterized by features involving high volume flow, expensive product movement, fragile product movement, shared equipment and high-cost employees.

E – Especially important relationship. It is characterized by; high to moderate volume flow, costly product movement, and employees working together more often.

I – Important relationship. It is characterized by; moderate flow volumes and moderate expensive product movement.

O – Ordinary relationship. It is characterized by low product movement

U – Unimportant relationship. There is limited contact between activities and the relationship between these activities should not be considered.

X – Not desirable. These relationships are incompatible and as such, unnecessary.
An example of a relationship chart is illustrated in figure 2.11. Source: Tompkins, (2003)

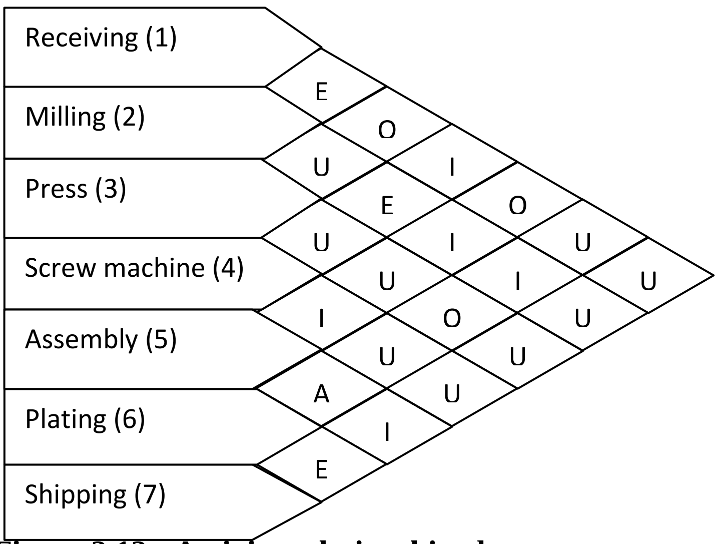
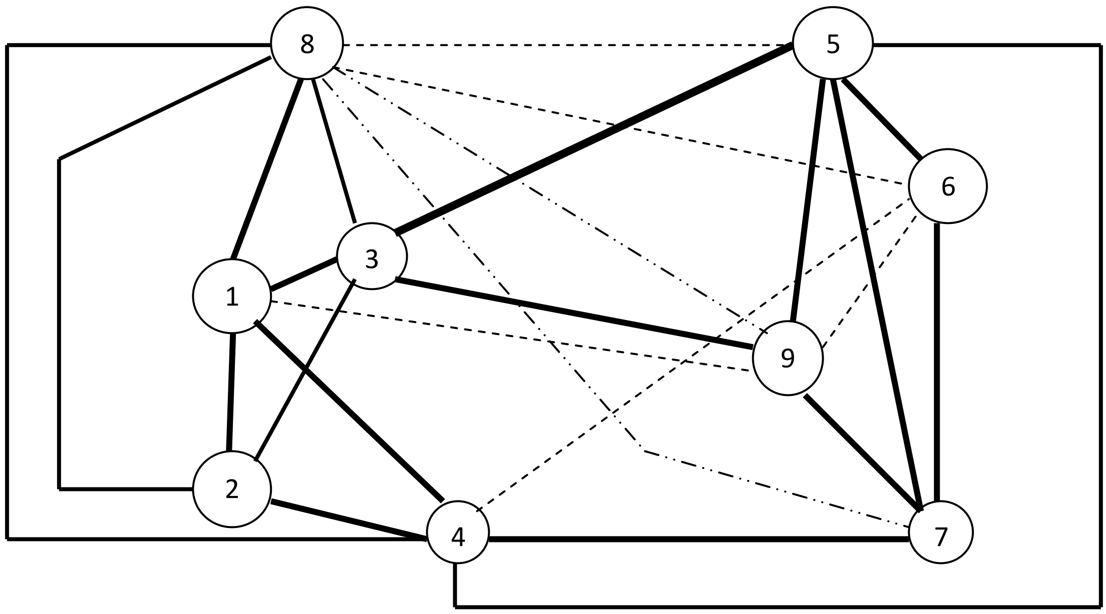


Figure 2.12: Activity relationship chart

Step 4: Relationship Diagram

A relationship diagram indicates the relationship and between work centres and it helps in positioning the work centres spatially. Those work centres having the highest closeness relationships are placed close to each other. In this case, a work centre is a pair of activities. We normally begin with those work centres belonging to class A, then class E, I, O, and so on. The relationship is extended until all these classifications are captured. Relationship lines are normally drawn to represent the closeness rating. Figure 2.12 shows an activity relationship diagram with explanations on the relationship lines used.



Line	Closeness ratio
	A- Absolutely necessary
	E-Especially important
	I-Important
	O-Ordinary

Figure 2.13: Relationship diagram

Source: Tompkins, (2010)

Step 5: Space Requirements

Space requirement, according to Tompkins, (2010), is an important aspect of facilities planning and it involves determining the amount of space required by each activity, and since the design year for a facility is between 5 to 10 years in the future, it is always difficult for a facility planner to project true space requirements for the uncertain future because of uncertainty in technology change, product mix and changes in demand levels. It is, therefore, necessary to have a systematic approach in order to have adequate space for the predetermined activity relationship diagram.

According to Tompkins, (2010), a workstation is a facility that performs specific production operation and it should have ample space for equipment, materials, and personnel. The equipment space for the workstation should consist of enough space for the equipment itself, space for machine motion and travel, space for maintenance of the machine and space for other plant services. Information on the space requirement for the equipment should be available from the data sheet or inventory records of the machine as supplied by the manufacturer. The space for the materials of a workstation should be ample for; receiving and storing incoming materials, holding work in progress, storing outgoing materials and storing any waste or scrap. The personnel space for the workstation should have ample space for operator working area and material handling.

Step 6: Space Available

After the determination of all space requirements for the workstations in the layout designs, a comparison should be made between the required space requirement and the available space in the facility. At times, the required space is not in accordance with the available space. If that is so, it means that the required space has to be adjusted to suit to what is available and this should involve trimming the required space of the workstations depending on the criticality of the operations at the workstation. Space should only be trimmed in areas that are less likely to cause bottlenecks and accidents. This step is purely a question of correct addition and comparison so as to create a balance between the required and available space.

Step 7: Space Relationship Diagram

According to Muther, (1973), a space relationship diagram, as shown in figure 2.13, is an activity relationship diagram with the space requirement component incorporated in it.

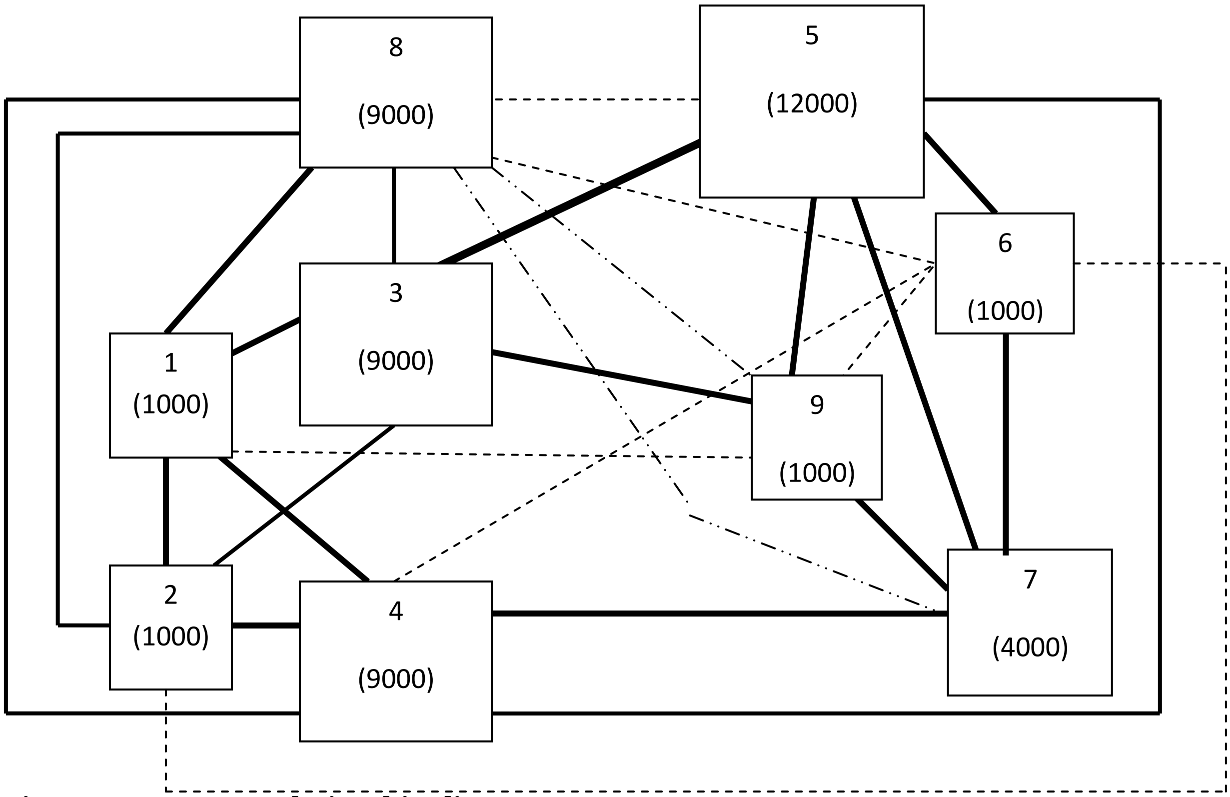


Figure 2.14: Space relationship diagram

Source: Tompkins, (2010)

Step 7: Modifying Considerations

According to Muther, (1973), there are modifying considerations that a facility designer needs to consider during the layout planning process. These considerations could be already existing utilities, such as handling systems and storage facilities. It is important to consider these factors depending on what is available for that particular layout design since different projects have different modifying considerations.

Step 8: Practical Limitations

These are the actual limitations that may limit the scope of the layout planning process and these limitations can be in terms of resources, both human and budget capital, and space availability.

Step 9: Developing layout Alternatives

By using the space relationship diagram, and, putting modifying considerations and practical limitations into perspective, a number of different layout alternatives are developed. These layouts consist of blocks of space and they are developed and positioned according to the relationship defined by the relationship chart. An example of a block layout is shown in figure 2.14.

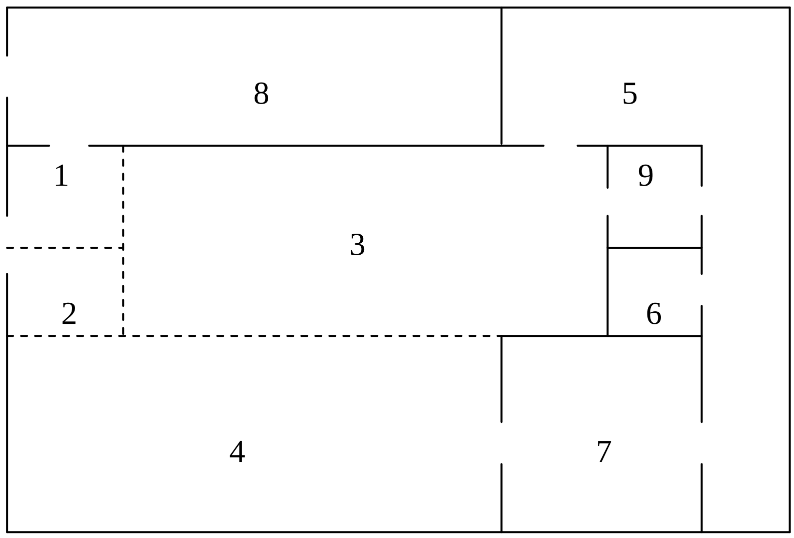


Figure 2.15: A developed block layout

Source: Tompkins, (2010)

Step 10: Evaluation

After developing a few blocks of alternative layouts, the evaluation process of each block begins. Here, the pros and cons of each block are identified and compared. The distances of movement are compared and a final block selected. Before the final selection of the most suitable alternative, it is important to have the input and views of the management.

2.5 Measurement of Flow

According to Tompkins, (2003), the flow among departments is one of the most important aspects in the arrangement of departments within the facility. The measurement of flow must be established in order to evaluate any alternatives that many be generated while carrying out desired improvements. Flow can be measured in two ways. Quantitative way and the qualitative way.

2.5.1 Quantitative Flow Measurement

In this manner, flow is measured in terms of the amount of materials moved between workstations. This flow may include pieces moved per hour, per day, per week, or per month. The chart that is used to record these flows is the from-to-chart as described in the SLP procedure and demonstrated in figure 2.10. A from-to-chart is constructed as follows, (Tompkins 2003)

a) List all workstations down the row and across the column following the overall flow pattern. Flow patterns can be straight-line, U-Shaped, S-Shaped and W-Shaped.

b) Establish a measure of flow for the facility that accurately indicates equivalent flow volumes. If the items moved are equivalent with respect to ease of movement, the number of trips may be recorded in the "From-To chart".

c) Based on the flow paths for the items to be moved and the established measure of flow, the flow volumes are recorded in the from-to-chart.

2.5.2 Qualitative Flow Measurement

According to (Tompkins, 2003), the flow is measured qualitatively using the closeness relationship ratings derived in the activity relationship chart in the SLP procedure. A relationship chart is constructed as follows:

a) List all departments on the relationship chart.

b) Conduct interviews or surveys with persons from each department listed on the relationship chart and with the management responsible for all departments.

c) Define the criteria for assigning closeness relationships and itemize and record the criteria as the reasons for relationship values on the relationship chart.

d) Establish the relationship value and the reason for the value for all pairs of departments.

e) Allow everyone having input to the development of the relationship chart an opportunity to evaluate and discuss changes in the chart.

The above steps are used to develop an activity relationship chart illustrated in figure 2.11 of the SLP procedure.

2.6 Material Handling

Material handling decisions are critical during the facilities design process. According to Suresh, (2008), material handling is both the art and science that involves the movement, handling, control and storage of materials throughout the manufacturing process of a product. The design of a material handling system impacts on the layout design of a facility; therefore, it is critical to consider the design of the material handling system and the layout simultaneously (Tompkins, 2010). Since material handling contributes to 20-50% of the manufacturing cost of a product (Tompkins, 2003), it is one of the key areas where significant improvements can be achieved resulting in good cost savings (Asef-Vaziri, 2005), and (Tompkins, 2010).

The material flow cost, which is the cost of moving a material from one workstation to another, is directly related to material handling cost. A justified change in the location of a workstation in a layout can result in a significant reduction of the material handling costs. This can be achieved by minimizing the distance of travel of the material handling equipment between the workstations. According to Aiello, (2002), the material flow cost is more often assumed to be an increasing function of the number of movements between workstations and the total distance that a product moves during the manufacturing process. The distance is calculated from the centres of the workstations using a predefined standard metric.

The College Industry Council on Material Handling Education recognizes ten material handling principles namely: planning principle, standardization principle, ergonomic principle, unit load principle, space utilization, system principle, automation principle, environmental principle and life-cycle cost principle. According to (Tompkins, 2010), these principles are guidelines that should aid in the design of an effective material handling system and it is important to note that not all principles can be applied to a single material handling project.

2.7 Pairwise Exchange Method

According to Tompkins, (2003), Pairwise Exchange Method is a heuristic method for layout improvement that is based on minimizing the total cost of transporting materials among all workstations or departments in a facility. It uses a distance objective between workstations and the distance is measured from the centroid of one department to the centroid of another. Distance measurement can either be rectilinear or euclidean based. It uses the material flow matrix of a from-to-chart and for each layout alteration, all the material flow in the location of workstations are evaluated and the alteration with the largest reduction in the total cost is selected. The final outcome of any alteration is compared to the initial layout.

The procedure for this method is:

1. To calculate the total cost of the existing layout
2. For each alteration, evaluate all material movement in the locations of workstations pairs
3. Select the pair that results in the largest reduction in total cost
4. Re-compute the distance matrix each time an exchange is performed
5. If the lowest total cost for your next alteration is worse than the total cost for the previous alteration, terminate the procedure.

An example to illustrate the procedure is outlined below. Consider four departments of equal sizes as illustrated in figure 2.15. Assume the distance between the departments to be rectilinear and is measured from the department centroids.
Material flows between departments is shown in table 2.1.

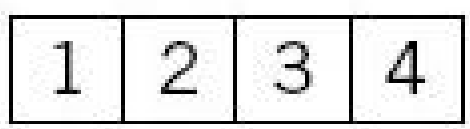


Figure 2.16: Initial layout diagram

Table 2.1: Material flow matrix

From Department	To Department 1	2	3	4
1	—	10	15	20
2		—	10	5
3			—	5
4				—

The distance matrix based on the existing layout is shown in table 2.2.

Table 2.2: Distance matrix

		To Department			
		1	2	3	4
From Department	1	—	1	2	3
	2		—	1	2
	3			—	1
	4				—

The total cost for the existing layout is computed as follows:

TC = 10(1) + 15(2) + 20(3) + 10(1) + 5(2) + 5(1) = 125

If an alteration is done and the following layout is developed, then the computed cost is as follows:

Table 2.3: Developed sample layout

3	**2**	**1**	**4**

TC = 10(1) + 15(2) + 20(1) + 10(1) + 5(2) + 5(3) = 95

The procedure is repeated and terminated after all the available alterations are exhausted and the lowest cost calculated. A suitable alteration is selected based on the lowest cost.

2.8 Multi-Criteria Decision Making

Decision-making is a complex process that involves identifying and choosing alternatives in order to find the best solution based on different prevailing factors. The difficulty with decision-making is the multiplicity of the criteria set for determining the alternatives. In most times, the objectives are usually conflicting as different groups of decision-makers are involved in the process too.

According to Wang (2010), Multi-criteria decision-making method is a general branch of Operations Research models that is used for addressing complex problems involving high degree of uncertainty, different forms of data, information, conflicting objectives, and multiple interests and perspectives.

According to Opricovic (2004), Multi-criteria decision-making can be considered as a dynamic process involving two levels: managerial and engineering. The managerial level defines the goals and objectives, and makes the final decision of choosing the final optimal alternative whereas the engineering level derives the alternatives, performs the multi-criteria ranking of these alternatives and highlight the merits and demerits of choosing among the alternatives. Basically, the engineering level conducts the optimization procedure. In facilities planning, the engineering level represents the facility designers whereas the managerial level is the senior level management. Facility designers develop the alternatives and the criteria for selection for the senior management to make the final decision on the most suitable alternative.

The main steps of Multi-criteria decision-making are the following:

a) Defining the problem, generating alternatives and establishing criteria

With respect to facilities planning, the facility designer should start by defining the problem at hand, establishing the objectives, and generating the alternatives. It can be either in designing a new layout or improving an existing one. Any existing constraints, conflicts and the degree of uncertainty should be identified after which the evaluation criteria is developed.

b) Assigning criteria weights

The next step involves assigning criteria weights. These weights show the relationship between various factors under consideration based on the priority requirements of the facility designer and they can be determined by various techniques such as the Analytical Hierarchy Process and Analytic Network Process.

c) Construction of the evaluation method of Aggregation

The next phase involves constructing a suitable method of calculating the aggregate values of the stated alternatives. The specified criteria, assigned weights and the priority scores are considered in developing a suitable method of aggregation. The aggregation method can be an average or a function built based on the need of the facility designer. The result of this aggregation will normally separate the best alternative from the available options.

d) Selecting the appropriate method

After ranking the alternatives from the aggregation method, the best alternative is proposed as the solution to the identified problem. In making this decision, a balance should be created between the quantitative and qualitative factors at play.

2.9 Deductions from Literature Review

This section compares the presented layout procedures with a view of determining why researchers continue to prefer and use the Systematic Layout Planning procedure compared to the other approaches. Although most facility designers recognize traditional layout procedures as important, in practice, majority do not use them. SLP remains attractive to many facility designers mostly because of its procedural nature.

There exists much research concerning the use of SLP in practice, either in the design of new layouts or in the improvement of existing ones. SLP is a proven procedural tool that uses flow analysis of materials quantitatively and qualitatively. The discussed approaches, on the other hand, do not consider the flow of materials digestively and they are not procedural. The Immer approach, for example, does not make any provisions for the planning and construction of a new layout and its steps would be best suited for improving a product type of layout that is less complex, rather than a process type configuration. The Nadler's Ideal Systems Approach is more of a philosophy and a facility designer, based on individual needs of the facilities being developed, can only use its theoretical view.

Apple's Layout Procedure makes it difficult for facility designers to use it in practice, especially in improving existing layouts because the given steps are not necessarily, performed in the given sequence. There is a lot of jumping around between them and this causes backtracking, just as Apple had foreseen. This backtracking costs resources and decreases the effectiveness of the layouts being developed.

Reed's "systematic plan of attack", is not suitable for improvement of existing facility layouts. Furthermore, it does not lay any emphasis on the flow of materials as an important aspect when it comes to layout development, thereby making it unattractive to facility designers. Conclusively, it is critical to note that SLP will continue to be a suitable tool for layout development and improvement for facility designers in the foreseeable future.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Overview

In this chapter, the improved model was created with inclusion of rearrangement and downtime costs, which are not included in the SLP procedure.

3.2 Research Design

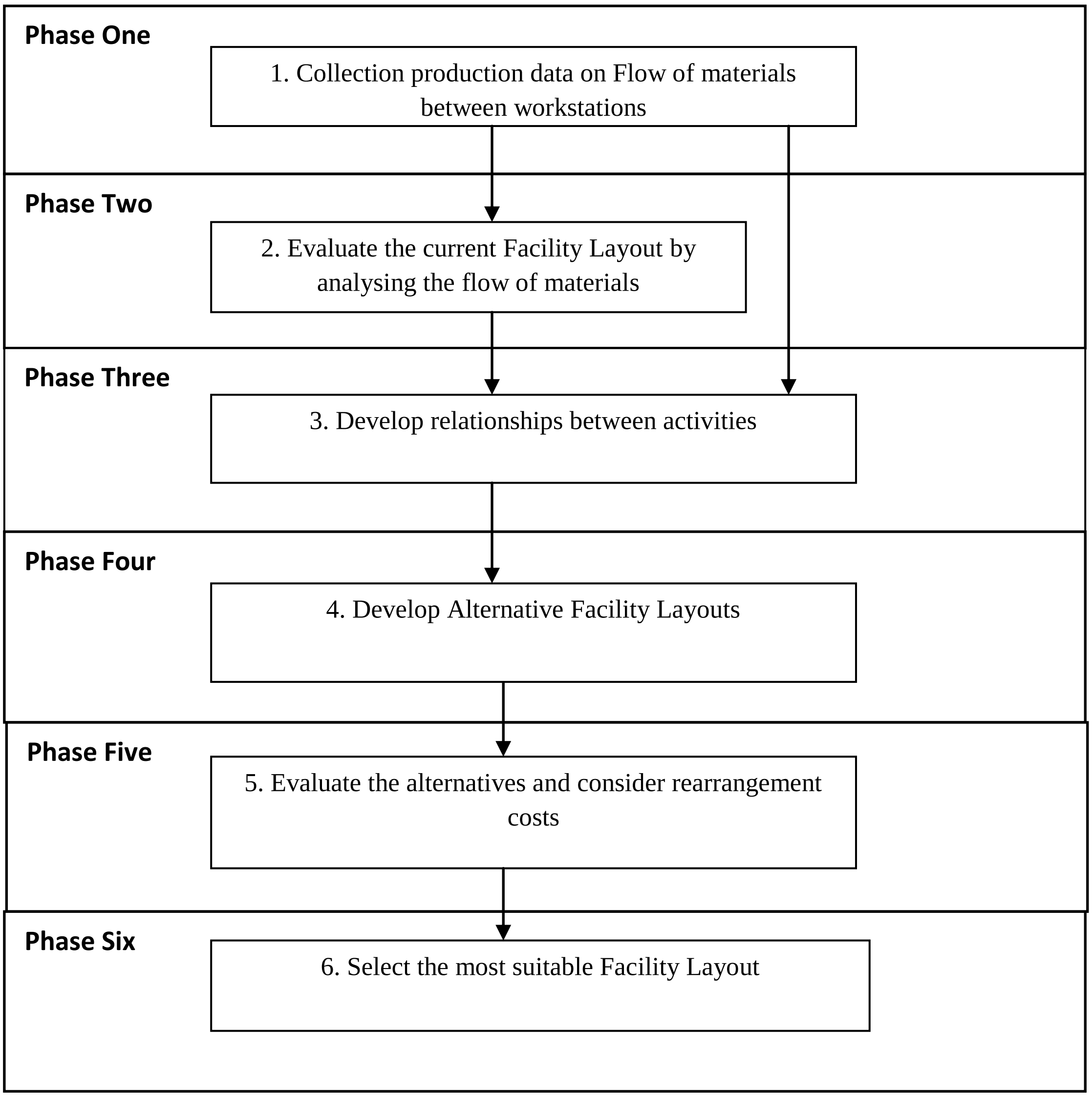


Figure 3.1: Research Design

The main objective of this research is to develop an improved model using SLP to enable NMC to create and effectively evaluate facility layouts. In order to achieve this, the above research design was developed. The first objective set to evaluate the current facility layout.

The purpose was to study the arrangement of machines and analyse the flow of materials in the current configuration with an aim of laying a foundation for improvement and comparison with the future created layouts. The quantitative data was recorded in a from-to-chart. This flow data was then analysed qualitatively by developing an activity relationship chart. A closeness rating was assigned depending on the importance of the relationship between workstations. The workstations with the highest closeness rating were placed together. In summary, the chart sought to maximize the closeness rating scores between workstations with an aim of laying a foundation for developing alternative layouts. This was achieved by conducting phase one and two as illustrated in figure 3.1.

The second objective set to determine the relationship between activities across the workstations. The aim here was to help the facility designer to position the workstations for the required improvement by developing a relationship diagram that positioned the workstations spatially. Phase three of figure 3.1 above achieved this objective

Based on the data gained from the quantitative and qualitative flow measurement, the key improvement areas were noted and highlighted. These improvements aided in developing new layouts.

The third objective set to develop alternative facility layouts. This was based on the relationship diagram that was developed qualitatively from the relationship chart. In this step, the practical and modifying considerations, such as space and the sections which cannot be moved such as the heat treatment section and the workshop stores were considered. The fourth phase achieved this purpose.

The fourth objective set to evaluate the developed alternative facility layouts and selecting the most suitable one. This was done using the Pairwise Exchange Method (PEM) and Multi-Criteria Decision Making (MCDM) technique. This approach involved calculating material handling costs between workstations based on the distance of travel and the number of trips of materials between workstations of the current layout and also for the developed alternatives. Phases five and six were used to achieve this objective.

3.3 Improved Model Development

The improved model for the creation and evaluation of the facility layout consisted of six main phases as earlier mentioned and they are highlighted in detail in figure 3.2.

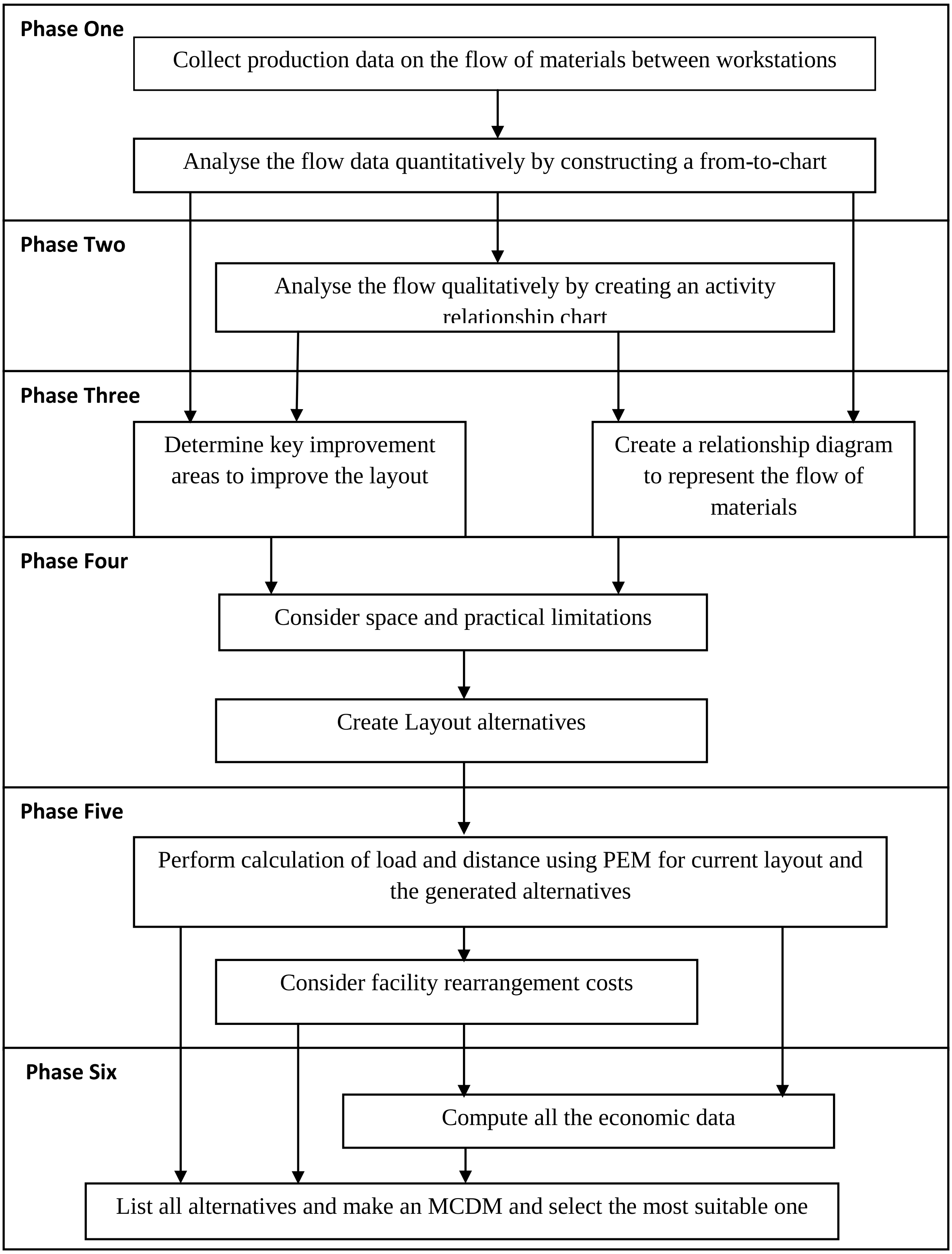


Figure 3.2: The developed model

3.3.1 Phase One - Collect production data on the flow of materials between workstations

In the workshop, there are many machines performing different machining operations. These are designed as workstations since they perform manufacturing operations. Each day, every workstation performs different machining operations and this data is recorded by the production department. If a product needs further machining, it moves to the next workstation until the production sequence is complete. This flow data is what was used as the backbone of improving the layout.

The aspects that were considered were the number of material movements, the distance moved by the materials across the workstations and the material handling equipment used. Information on the amount of material movement was found in the stored data of the production department. Material handling equipment and the distance movement was found on the daily operations across the workshop. All the data on the flow between workstations was captured and recorded in a from-to-chart. The distances for the flows were available in the original design of the workshops' AutoCAD drawings.

3.3.2 Phase Two – Evaluate the Current Facility Layout

After constructing a from-to-chart, the recorded data was used to develop an activity relationship chart qualitatively. A from-to-chart represented all the flow volumes between activities across the workstations and it is the backbone of the analysis for evaluating the layout. Its purpose was to analyse the arrangement of machines and study the flow of materials in the current configuration.

The production data gathered in the from-to-chart helped in the qualitative flow measurement. There was high flow in some machines such as the turn mill and the universal milling machines. Normally, such machines are normally placed closed to each other in order to minimize material handling costs. In determining how close the machines should be placed with respect to each other, an activity relationship chart was developed.

A closeness rating was assigned to represent the importance of the relationship between workstations and this was done according to the SLP procedure where the ratings were A, E, I and O. A, represented absolutely necessary relationship of high flow volume E, represented especially important relationship of moderate volume flow, I, represented important relationship of low to moderate volume flow and O, represented ordinary relationship of low volume flow. The workstations with the highest closeness rating were placed together and those with the least were placed based on practical considerations. This chart helped the facility designer to establish the workstations that are critical in minimizing the material handling costs that result from distance movement, thereby creating avenues for improvement.

3.3.3 Phase Three – Develop Relationships between Activities

A workstation performs different activities ranging from turning, facing, grinding, etc. As mentioned in phase two, it was important to determine how the workstations relate to each other based on the different activities they perform. However, a facility designer cannot use an activity relationship chart alone to get a clear view of the existing layout arrangement. He needs to dissect the chart by developing a relationship diagram. A relationship diagram positions the workstations spatially thus making the facility designer to finally highlight the key areas of the layout that necessitate improvement. This diagram was then constructed accordingly.

3.3.4 Phase Four – Develop New Facility Layouts

Based on the established improvements, realized during the development of the relationship chart and diagram, suitable alternatives were developed. Space requirements of the machines, the practical limitations (such as available funds and workforce), and modifying considerations were considered. Space is a problem at the company and different machines have different sizes, therefore, making rearrangement a nightmare if not all available factors are put into consideration. Modifying considerations means existing utilities that are difficult or impossible to move due to their original configuration. These utilities included; heat treatment section, research development section, workshop store and storage store were considered at this stage. The input of the workshop workforce was also considered with respect to all the mentioned factors.

3.3.5 Phase Five – Evaluate the Alternative Layouts and consider Rearrangement costs

Here, the developed layouts were evaluated by calculating material handling costs using Pairwise Exchange Method (PEM). A distance matrix showing the distance movement between workstations was constructed at this stage and the number of trips of the materials across the workstations in the existing layout was retained but the distance between workstations changed because of the rearrangement. The evaluation was done both for the existing layout and the developed alternatives. Rearrangement costs were also considered at this point. These included costs for planning, dismantling and moving equipment from one area to another. Downtime costs were not considered because of the other similar machines that would continue to operate during the rearrangement period. Rearrangement costs were estimated by the maintenance department of the company.

3.3.6 Phase Six – Select the Most Suitable Facility Layout

Here, all the computed data on the existing layout of the company and the developed alternatives were listed and a Multi-Criteria Decision-Making technique considered. The considered method was the Simple Additive weighting (SAW). This method involves assigning to each alternative a sum of values or priority scores, each one associated with the corresponding criteria and weighted according to the importance of the corresponding criteria. The factors considered for the criteria by the author for this purpose were: safety, flexibility, space, material handling and flow effectiveness. From the developed MCDM, data was analysed and non-economic factors considered to aid in the selection of the most suitable alternative layout. A preferable alternative was then selected and recommended to the company for consideration.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Overview

The main objective of this research is to develop an improved model using SLP to enable NMC to create and effectively evaluate facility layouts. First, the existing layout was evaluated by analysing the relationships between workstations, improvement areas were identified, and alternative layouts developed. The alternatives were finally evaluated and the most suitable one selected.

4.2 Flow Analysis

4.2.1 Quantitative Flow Analysis

The flow was measured in terms of the amount of materials moved between workstations. The measured flow included pieces which were moved per day and this was consolidated to months. The selected data was for a period of eighteen months, from January 2016 to June 2017. To understand the flow, all workstations were listed down in a row and across the column following the overall flow pattern and based on the flow paths for the materials that were moved, and the established measure of flow, the flow volumes were represented and recorded in the from-to-chart.

From this chart, the author noted high levels of flow at the band saw, the storage section and at the universal, horizontal and turning machines and at the turn mill machine. There was moderate flow at the heat treatment section. Many workstations highlighted low flow volumes as shown in table 4.1.

4.2.2 Qualitative Flow Analysis

The flow was measured qualitatively by developing an activity relationship chart based on the flow volumes in the from-to-chart. To achieve this, all the workstations were listed and the criteria for assigning closeness relationships was defined and established. The following four closeness ratings were assigned by the author: A – Absolutely necessary representing high volume flow of 300 and above, E – Especially important representing moderate volume flow between 100 to 299, I – Important representing low to moderate volume flow between 40 to 99 and O – Ordinary representing low volume flow between less than 40. The resulting activity relationship chart is shown in figure 4.2.

Table 4.1: From-to-chart: Quantitative flow measurement

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1		-	135	102	102	96	364	364	300	382	267	267	267	680	155	-	-	-	-	18	-	-
2			80	59	68	60	443	443	196	196	10	5	5	-	-	-	-	16	16	-	-	185
3				-	-	-	-	-	-	-	6	6	6	-	7	12	10	18	18	-	51	4
4					-	-	-	-	-	-	6	6	6	-	7	12	10	18	18	-	51	4
5						-	-	-	-	-	6	6	6	-	7	12	10	18	18	-	51	4
6							-	-	-	-	6	6	6	-	7	12	10	18	18	-	51	4
7								-	-	-	-	-	-	-	-	4	3	7	7	-	17	22
8									-	-	-	-	-	-	-	4	3	7	7	-	17	22
9										-	-	-	-	-	-	4	3	7	7	-	17	22
10											-	-	-	-	-	4	3	7	7	-	17	22
11												-	-	-	-	20	16	-	-	-	-	13
12													-	-	-	20	16	-	-	-	-	13
13														-	-	20	16	-	-	-	-	13
14															-	-	-	-	-	-	-	2000
15																20	12	-	-	-	-	10
16																	-	-	-	-	-	48
17																		-	-	-	-	48
18																			-	-	-	-
19																				-	-	-
20																					-	-
21																						-
22																						

KEY FOR THE CHART

1. Band saw
2. Storage section
3. Universal Machine centre (UMC) – High Capacity
4. Universal Machine centre (UMC) – Lower Capacity
5. Universal Machine centre (UMC) – Lower Capacity
6. Universal Machine centre (UMC) – Lower Capacity
7. Horizontal Machine Centre (HMC) – 4 Axis
8. Horizontal Machine Centre (HMC) – 4 Axis
9. Horizontal Machine Centre (HMC) – 5 Axis
10. Horizontal Machine Centre (HMC) – Lower Capacity
11. Turning Machine Centre (TMC) 1
12. Turning Machine Centre (TMC) 2
13. Turning Machine Centre (TMC) 3 - Bar feeder
14. Turn-mill Centre
15. CNC Lathe Machine
16. Gear Hobbing Machine 1 – Helical and Spur Gears
17. Gear Hobbing Machine 2 – Spur Gears
18. Surface Grinders – Cylindrical type
19. Surface Grinders - Flat
20. Conventional Lathe Machine
21. Finishing Section
22. Heat Treatment Section

Note: The row represents "from" and the column "to". That's why its referred a from-to-chart.

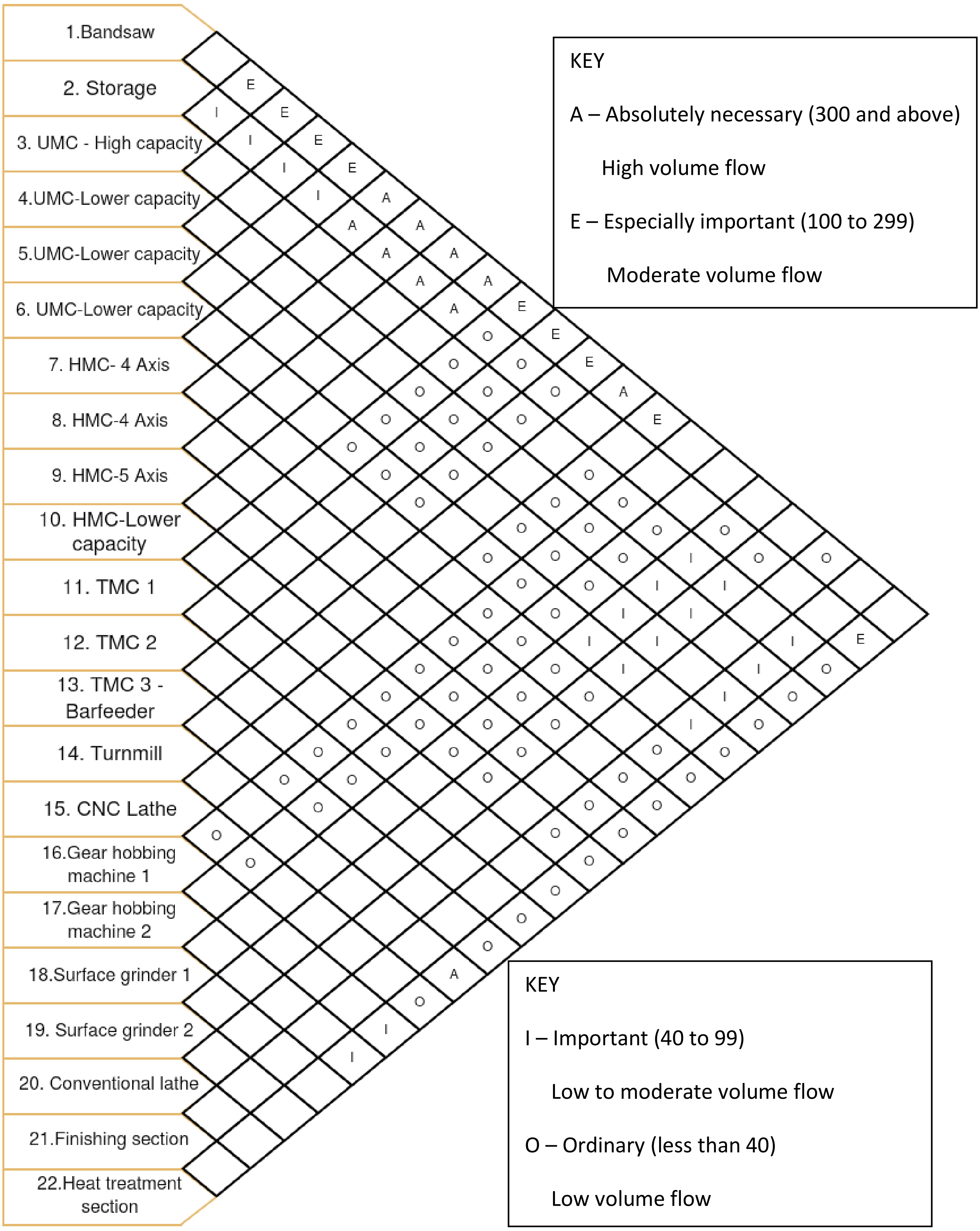
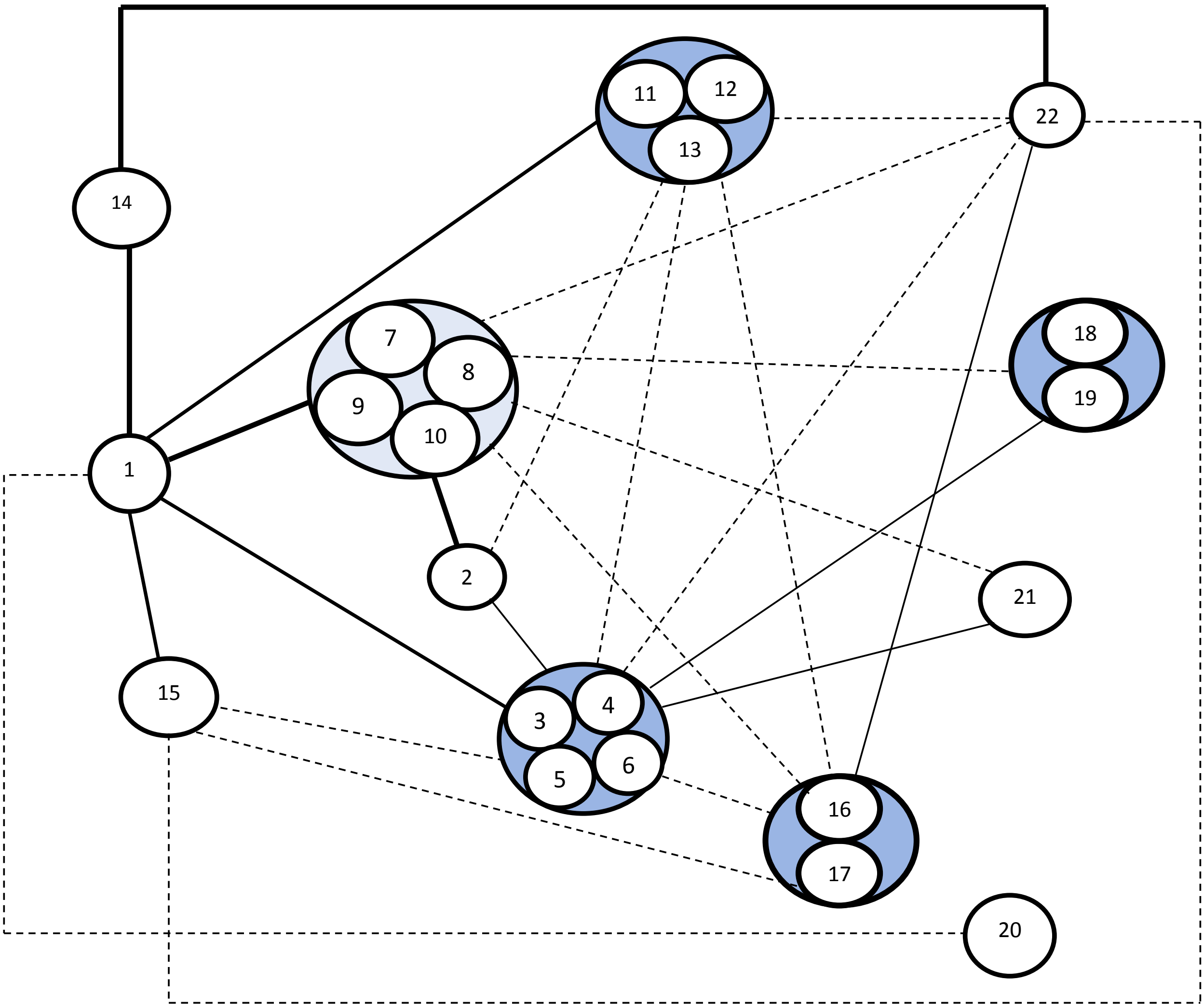


Figure 4.1: Activity relationship chart

4.3 Considered Improvements

In order to consider improvements, an activity relationship diagram was created from the relationship chart, where the workstations were placed spatially, with those with the highest closeness rating being placed close to each other. Relationship lines were drawn to represent the closeness rating. The main purpose of the relationship diagram is to indicate the relationship between workstations and it helps in positioning workstations during improvement. The relationship diagram that resulted is shown in figure 4.3.



Line	Closeness ratio
	A- Absolutely necessary
	E-Especially important
	I-Important
	O-Ordinary

Figure 4.2: Relationship diagram

From the flow analysis, observations and the relationship diagram, key improvements were suggested in order to improve the flow and movement of materials across the workstations and utilize space effectively. First, the non-operational machines that continue to occupy space and increase the flow movement of materials and people should be eliminated from the workshop. When these machines are removed, the distance movement in the remaining workstations reduces, thereby reducing the material handling costs and this can be justified by comparing the distance matrix analysis of the current layout and that of the alternatives, *(the distance matrix are available in the appendix).*

Secondly, there are many assorted components in the workshop. They continue to occupy space and pose as health hazards despite their un-utilization. It would be prudent to get a solution to such parts. Thirdly, the light fabrication section along a gangway, next to the heat treatment section should be relocated outside the workshop. Welding releases toxic fumes not fit for any human inhalation and it is therefore important to consider an area with fume extractors and away from other equipment. Finally, by considering that the existing layout has a process type configuration, it would be important to arrange the existing machines based on the functions they perform. Machines with similar functions should be placed together in one area. The specific changes to be considered are discussed in detail in the alternatives generated.

4.4 Development of New Layouts

The layout of the existing workshop floor is a process-oriented one as illustrated in figure 4.3. It occupies 80 x 40 - metre square (m^2). Based on the considered improvement areas, new alternative layouts were created. Several factors were considered: the space requirements and availability, the safety of the equipment and workers, size and bulkiness of the equipment, material handling, practical and modifying considerations, and ease of access. The input of the workshop workforce was also considered in designing the new layouts. Due to modifying considerations; the heat treatment section, research development section, the storage area and the workshop store could not be moved. These sections are enclosed with permanent enclosures and gates. Space was an important factor to consider as mentioned and the space requirements of the workstations is shown in table 4.2. Three alternatives were developed and they are discussed hereon.

Table 4.2: Relationship between Equipment/Section size and area.

Serial No.	Equipment/ Section	Equipment capacity	Number of Equipment	Equipment and working area (m²)-(Length*Width)
1.	Band saw	High/Low capacity	1	14.0
2.	Storage section	High/moderate capacity	1	80.0
3.	Universal Machine centre (UMC)	High capacity	1	120
4	Universal Machine centre (UMC)	Low capacity	1	100
5.	Universal Machine centre (UMC)	Low capacity	1	68.25
6.	Universal Machine centre (UMC)	Low capacity	1	55.0
7,8.	Horizontal Machine Centre (HMC)	4 Axis, High capacity	2	118
9.	Horizontal Machine Centre (HMC)	5 Axis, High capacity	1	78.0
10.	Horizontal Machine Centre (HMC)	Low capacity	1	65.0
11.	Turning Machine Centre (TMC)	High capacity	1	87.75
12.	Turning Machine Centre (TMC)	High capacity	1	97.5
13.	Turning Machine Centre (TMC) - Bar feeder	High capacity	1	87.7
14.	Turn-mill Centre	High capacity	1	74.1
15.	CNC Lathe Machine	Low capacity	1	65.0
16, 17	Gear Hobbing Machine	Helical and spur gears	2	88.5
18.	Surface Grinders	Cylindrical type	1	55.0
19.	Surface Grinders	Flat type	1	58.5
20.	Conventional Lathe Machine	Low capacity	1	45.0
21.	Finishing Section	Low/Moderate capacity	1	20.0
22.	Heat Treatment Section	Moderate capacity	1	220.0
23.	Maintenance cabinets	Moderate capacity	10	56.25
24.	Workshop store for spare parts	High/moderate capacity	1	114.7
25.	Crankshaft and assorted parts	Assorted parts	Many parts	81.0
26.	Conventional drilling machine	Low capacity	1	20.0
27.	Conventional lathe and shaping machine	Low capacity	3	50.0
28.	Research and development section	Low capacity	1	28.0
29.	Light fabrication section	Low capacity	1	120
30.	Turning machine centre (TMC)	Non-operational	1	87.75
31.	Turning machine and horizontal machine	Non-operational	2	72.0
32	GANGWAY 1, 2, 3			3*73.5
33	GANGWAY 4			6*20

4.4.1 Alternative 1

This alternative eliminates all the machines that have broken down and are unutilized in the workshop. They include two turning machines and one horizontal milling machine. All the assorted parts are also eliminated in this layout. The light fabrication section that lies along the gangway is completely eliminated and relocated outside the workshop. The band saw, the cylindrical surface grinder, the conventional lathe and shaping machine, one horizontal milling machine, one universal milling machine and the finishing section are all relocated in this layout. A tool setting centre and a material loading bay is also created in this layout. The layout is shown in figure 4.4.

4.4.2 Alternative 2

This alternative eliminates all the broken-down machines, assorted parts, and the light fabrication section. It relocates the band saw, the cylindrical surface grinder, one universal milling machine, the conventional lathe and shaping machine and the finishing section. This layout creates a tool setting section and a material loading bay as shown in figure 4.5.

4.4.3 Alternative 3

This alternative eliminates all unutilized machines and the assorted parts just like the previous two alternatives. It also relocates machines just like in the two alternatives but interchanges some of them as shown in figure 4.6.

It should be noted that developing new facility alternative layouts is a qualitative process that involves the subjective skills of a facility designer. Most times, the facility designer is faced by many conflicting objectives based on the different operating environments. An effective layout has to consider both quantitative and qualitative factors and therefore facility designers seek to create a balance between the two in order to achieve an optimized solution. It is therefore important for the reader to understand that these decisions are not made based on quantitative analysis only.

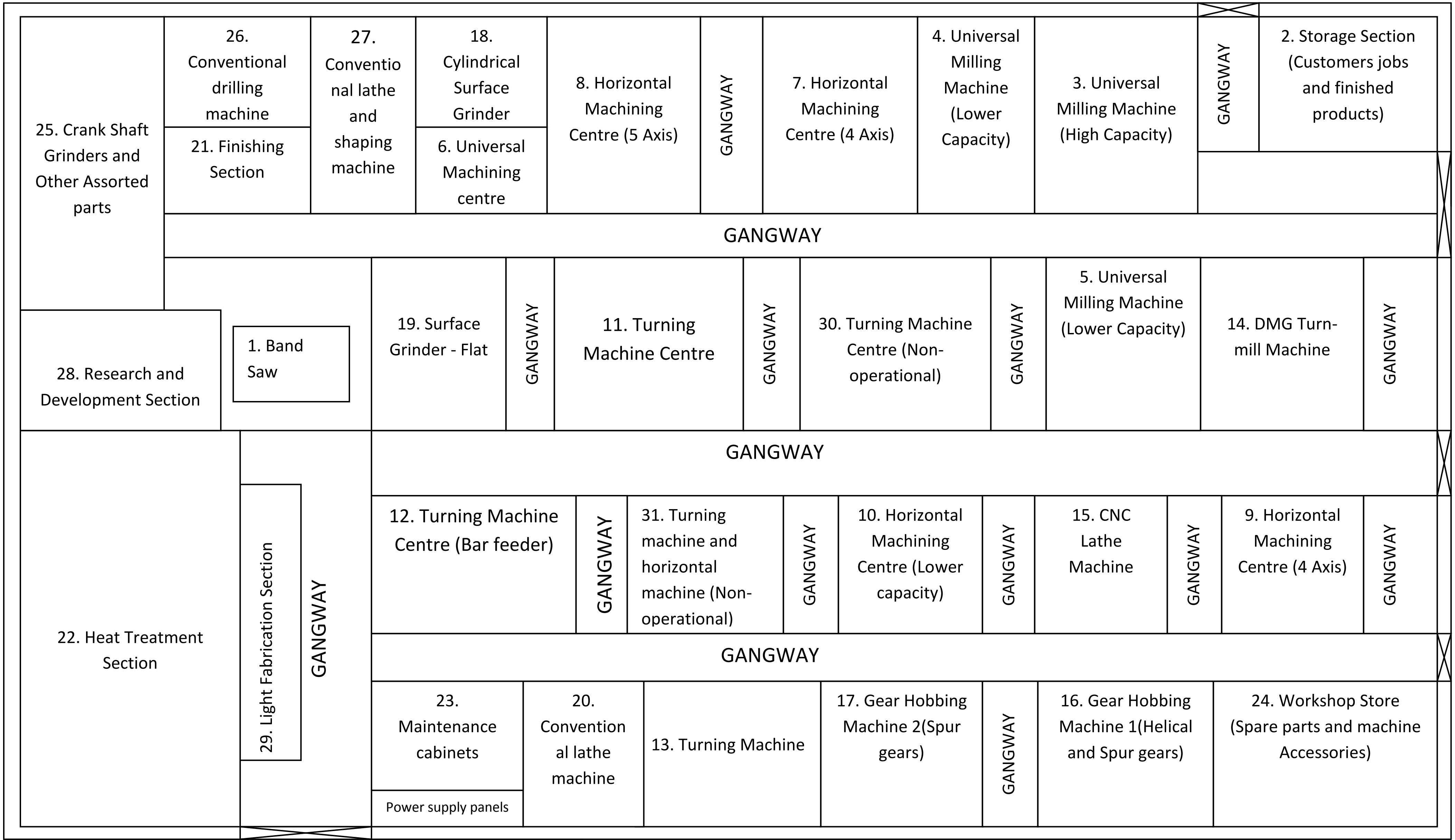


Figure 4.3 NMC Existing Workshop Layout

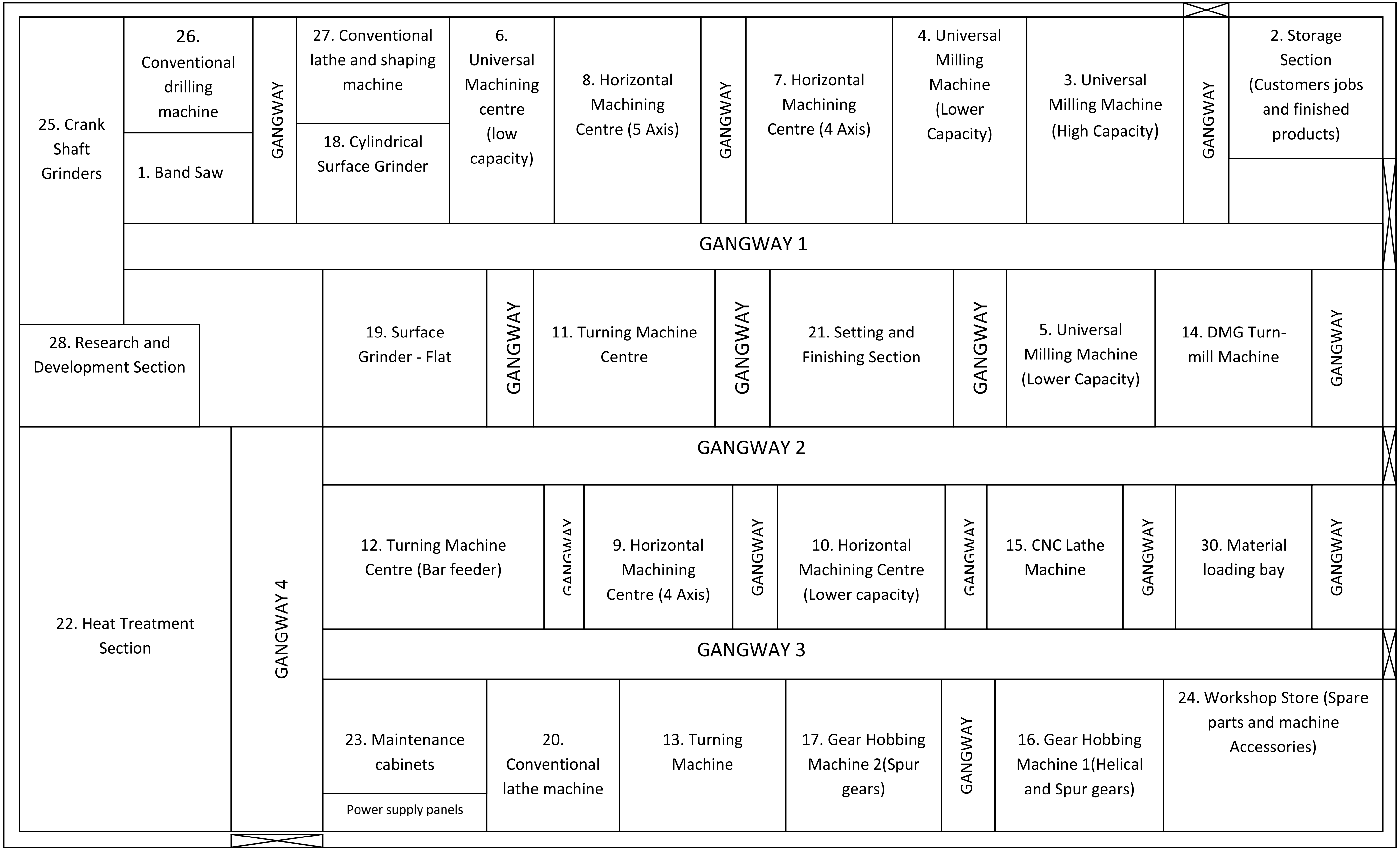


Figure 4.4 Alternative Layout 1

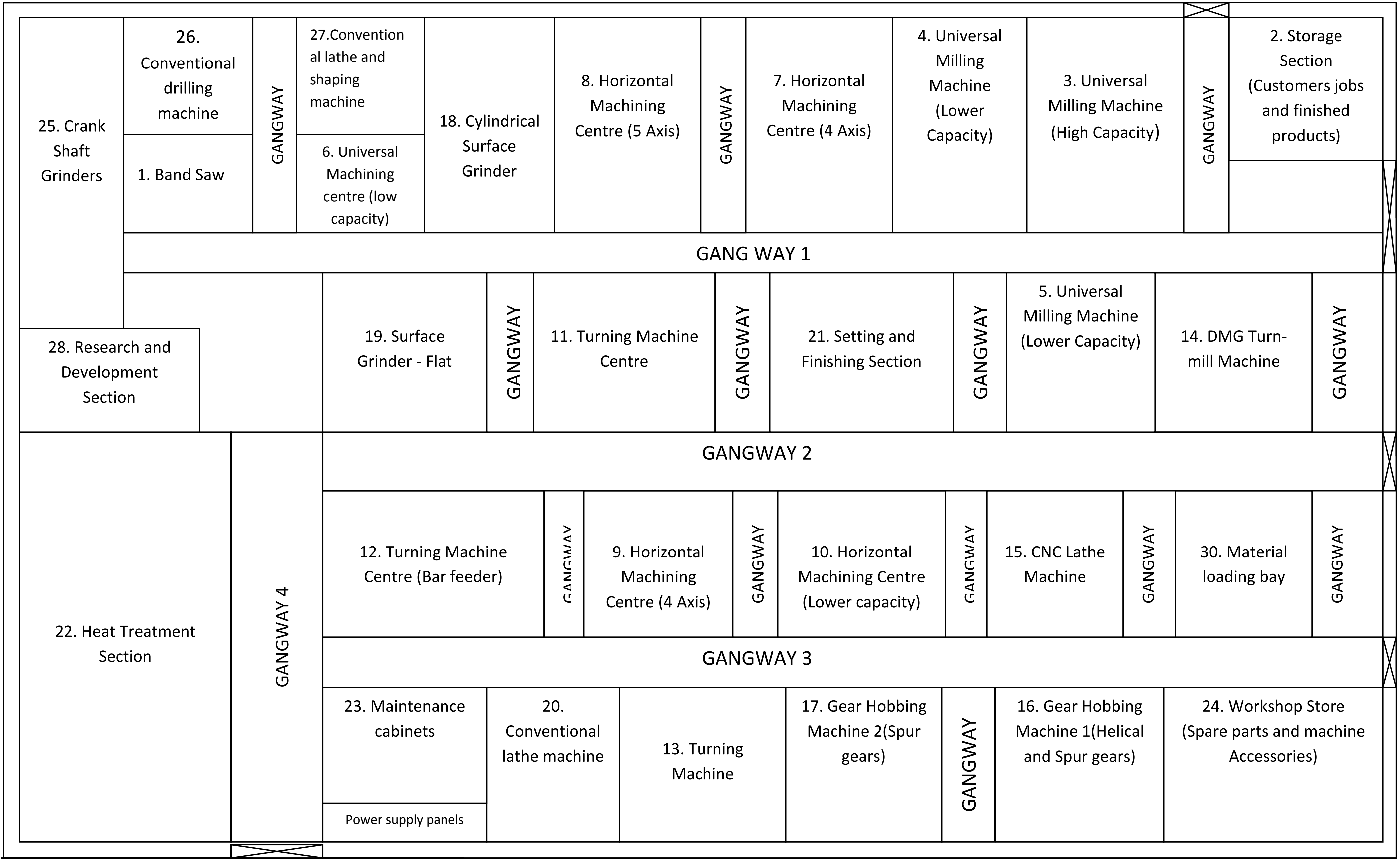


Figure 4.5 Alternative Layout 2

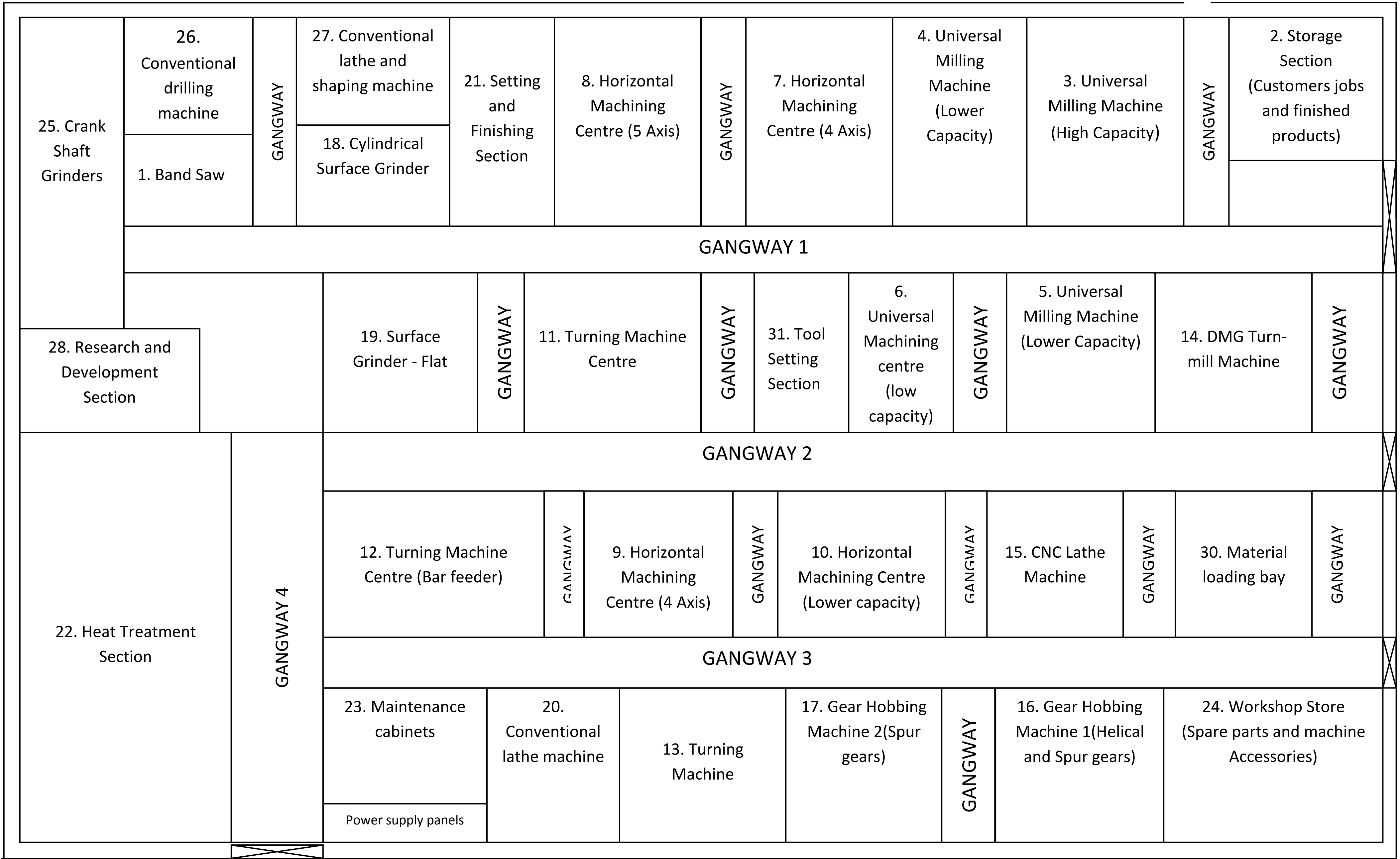


Figure 4.6 Alternative Layout 3

4.5 Evaluation of Alternative Layouts

As earlier mentioned, developing alternative layouts is a qualitative subjective process, and so is the evaluation of these alternatives. Determining the most suitable alternative requires creating a balance between different set of elements. In this research, three elements were considered in selecting a suitable alternative. They include: material handling costs, rearrangement costs and multi-criteria decision-making analysis. Material handling costs are very critical and they were calculated using the Pairwise Exchange Method (PEM). PEM is a heuristic method for layout improvement that is based on minimizing the total cost of transporting materials among all workstations in a facility. It uses a distance objective between workstations and the distance was measured (in metres) from the centroid of one workstation to the centroid of another. Distance measurement can either be rectilinear or Euclidean-based.

In this case, rectilinear measurement was used. For example, if you have two workstations, the flow volume from the from-to-chart will be multiplied by the respective distance measurement of that flow to get the material handling costs between the two workstations. In order to get the total material handling costs of the whole layout, a summation of all the calculated material handling costs between workstations is done. After each layout alteration, the placement of the workstations changed, thereby changing the distance movements, but the material flow from the from-to-chart remained the same. The change in distance affected the total material handling costs of the developed alternatives. All the material flow in the location of workstations were evaluated and the alterations recorded as shown in table 4.3, for comparison. An efficiency ratio (ER) was derived to indicate either an increase or a decrease of the alternatives' material handling costs compared to the existing layout costs. *The calculated material handling costs for the existing layout and the alternatives are shown in the appendix section.*

Rearrangement costs are of two types of costs according to Adil Baykasoglu, (2006) and Keragu, (1999): the cost due to losses in production time and the cost of the physical movement of equipment to the new location. Movement costs include costs for planning, dismantling, constructing, moving and installing. In this research, only movement costs were considered, the reason being that since the company has similar machines doing similar operations of milling, loss of production would not occur as the available work would be directed to certain machines while the others are being rearranged. The costs considered in this case were costs for dismantling and moving machines from their original location to the new desired location and costs for moving machines that have broken down outside the workshop. Installation, labour and overhead costs, such as electricity were also included. The maintenance department of the company estimated these costs, as it is responsible for any arrangement of machines in the workshop. The rearrangement costs are shown in table 4.4.

Table 4.3: Material-handling costs

Layout type	Material Handling Cost	Efficiency Ratio (ER) – percentage increase/decrease
Existing Layout	434494.32	Nil
Alternative 1	448185.92	0.031511574
Alternative 2	447418.62	0.029745613
Alternative 3	453241.12	0.043146249

Table 4.4: Rearrangement costs

Alternatives	Movement costs for unutilized machines (KES)	Movement costs for operational machines (KES)	Overhead costs, such as electricity (KES)	Labour cost (KES)	Total cost (KES)
Alternative 1	400,000	100,000	80,000	70,000	650,000
Alternative 2	400,000	130,000	80,000	90,000	700,000
Alternative 3	400,000	150,000	80,000	90,000	720,000

A multi-criteria decision analysis technique was used to evaluate the alternatives where several factors were considered in analyzing the characteristics of the layout. They include safety considerations, the flexibility of the layout, space utilization, material handling effectiveness and flow movement effectiveness. The Simple Additive Weighting (SAW) method was used. This method involved assigning to each alternative a sum of values or priority scores, each one associated with the corresponding criteria and weighted according to the importance of the corresponding criteria. The weights were assigned to the existing layout and the developed alternatives. The developed criterion is shown in table 4.5.

It should be noted by the reader that developing this criterion is a qualitative process. The priority scores were developed by the author based on the factors earlier mentioned and different layouts would have different scores based on the needs of the required improvement.

Table 4.5: Multi-criteria evaluation

		Requirement Priority Scores			
Criteria	Weight	Existing Layout	Alternative Layout 1	Alternative Layout 2	Alternative Layout 3
Flexibility	25%	1	3	3	2
Safety considerations	25%	2	3	3	3
Material handling effectiveness	20%	2	3	3	3
Flow effectiveness	20%	2	3	2	2
Space utilization	10%	1	3	2	2
Weighted Scores	100%	1.65	3	2.7	2.45

Key: 1 – Poor, 2 – Fair, 3 – Good, 4 – Very Good

A final tabulation of the material handling costs, rearrangement costs and the multi-criteria analysis was generated as shown in table 4.6.

Table 4.6: Tabulation summary

Layout type	Material Handling Cost	Efficiency Ratio (ER) - percentage increase/decrease)	Rearrangement costs (KSH)	(MCDM)Requirement Priority Scores
Existing Layout	434494.32	Nil	Nil	1.65
Alternative 1	448185.92	0.031511574	650,000	3
Alternative 2	447418.62	0.029745613	700,000	2.7
Alternative 3	453241.12	0.043146249	720,000	2.45

4.6 Selection of Suitable Alternative

From the analysis, the preferable alternative selected by the author is layout 1. First, it's an improvement of the existing layout in many aspects. It has the highest priority score in the multi-criteria analysis of the considered factors, though it slightly increases material handling costs. These costs were mainly altered by the location of the band saw but considering the safety aspects, it was found safer to have an increase in handling costs, rather than posing safety risks by relocating it (band saw) to reduce these costs. The selected alternative also has the least rearrangement costs according to the maintenance department of the company.

The reader should note that selecting a suitable layout is a subjective process that involves all levels of management. It is upon the senior management of the company to select the most suitable layout that meets their production needs and no matter the selected layout, from the generated alternatives, the bottom line is that its better in many aspects compared with the existing layout.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

This chapter contains the conclusions on the findings of the research problem and makes recommendations that may be useful for future research in this area.

5.2 Review of the Research Objectives

This research set out to develop an improved model using SLP to enable NMC to create and effectively evaluate facility layouts. The model has been developed to aid in the selection of the most suitable layout. It includes the aspects of rearrangement costs and multi-criteria decision-making technique. It has been developed to offer guidance to NMC on how to create, evaluate and select a suitable layout from a number of several generated alternatives. The model offers good results and an improved layout alternative has been recommended to the company for implementation.

5.3 Key Findings

The main objective of this research is to develop an improved model using SLP to enable NMC to create and effectively evaluate facility layouts. To achieve this, a model, consisting of six phases was created. The first objective that set to evaluate the existing layout was achieved through phases one and two, which consisted of production flow analysis, with an aim of determining the key improvement areas in terms of flow, space, and safety. This was conducted and from the analysis, it gives the expected results.

The second objective set to develop relationships between activities across workstations. This was achieved through phase three where a relationship diagram was created to aid in generating improved layout alternatives. This was conducted, thereby fulfilling the intended aim.

The third objective required developing alternative layouts. In phase four, three alternatives were developed in consideration of several factors, such as space requirements and safety considerations; thereby fulfilling the intended purpose.

The fourth objective set to evaluate the alternatives with an aim of selecting the most suitable one. Phases five and six fulfilled this purpose by evaluating the alternatives using MCDM and considering rearrangement costs thereby selecting a suitable alternative layout. The selected layout is better compared to the existing one. It's flexible, utilizes space effectively, improves productivity and reorganizes the machines in an orderly and effective manner. It considers the safety of the workers and offers good material handling effectiveness. It also offers a material loading bay and a tool and work setting station thereby enabling an effective flow of people, materials, and information.

5.4 Conclusion

This study set out to improve the facilities design of the workshop floor of NMC. A model consisting of several phases was developed and it achieved this purpose. The model in general, can be applied to any manufacturing company with a process type of layout arrangement. All that is required is modification at every phase based on the specific company.

The output data of the model is highly dependent on the input data, thereby affecting the validity of calculations and results. In this regard, it's important to capture accurate input data so as to have good results. The company case study validates the model by showing that if all the phases are followed, an effective layout alternative is generated. Most of this information was on work distribution among the set of similar machines performing similar operations. This information was tabulated, analyzed and captured objectively so as to give desired results. Most of the data is accurate as it was captured from production records and AutoCAD drawings.

5.5 Recommendations

The following recommendations are made based on the results of this research:

1. NMC should study the model, consider the generated layouts and implement the preferred one based on their financial capabilities.

2. NMC should use the model to study the process flow of materials and people with a view of highlighting the key areas of improvement.

3. The company should eliminate and dispose of all the machines that have broken down in the workshop. They should plan on the most efficient and effective way of carrying out this purpose.

4. The company should also get rid of all assorted parts that remain unutilized mostly in the right-hand corner of the workshop. Alternative space outside the workshop should be used to store such parts.

5. After rearrangement, the company should clearly mark out the workshop and highlight all the gangways.

6. The light fabrication section, along the gangway, next to the heat treatment section should be moved to another location outside the workshop.

7. The company should purchase cabinets to store machine tools in the created setting and finishing section in order to have a central location of storing different tools to increase productivity.

5.6 Research contribution

This research work considered rearrangement costs in the evaluation of facility layout improvement and in practice; it gives NMC an improved layout that utilizes space and coordinates the flow of materials, people and information. Additionally, the model can be utilized in companies with similar set up of process layout arrangement.

5.7 Future Research

On future research, there is a need to test the model in more different companies so that to highlight more improvement areas. As mentioned, the model's accuracy depends on the accurate input of the collected data based on the process design of a product, and assuming that this information is mostly qualitative, it's, therefore, important to investigate the model to determine if there are any important aspects that should be included.

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APPENDIX

Appendix I: A picture showing machine arrangement in the workshop

Appendix II; A picture showing different materials along the gang way in the workshop

Appendix III: Distance matrix for the existing layout

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1		-	63.4	52.4	47.4	15.8	41.8	29.3	67.8	44.8	21	21.3	44.1	57.6	55.8	-	-	-	-	35.6	-	-
2			12.5	23.5	30.7	60.1	34	46.6	29.2	52.2	57.1	75.7	73.9	-	-	-	-	56.5	69.27	-	-	96.9
3				-	-	-	-	-	-	-	44.6	63.2	61.4	-	28.7	37.7	50.7	45.7	56.7	-	60.1	84.2
4					-	-	-	-	-	-	33.6	52.2	50.4	-	22.6	35	39.7	36.6	45.7	-	49.1	73.2
5						-	-	-	-	-	26.5	45.1	43.3	-	10.6	19.6	32.6	51.1	38.6	-	58.6	66.1
6							-	-	-	-	19.7	20.1	42.9	-	54.6	66.6	53.6	5	8.5	-	12.5	36.8
7								-	-	-	-	-	-	-	-	45.5	32.5	26.1	35.2	-	38.6	62.7
8									-	-	-	-	-	-	-	58.4	45.1	13.5	22.6	-	26	50.1
9										-	-	-	-	-	-	21	34	71.5	59	-	79	67.5
10											-	-	-	-	-	23.1	11	48.6	36	-	56.1	44.5
11												-	-	-	-	46.4	33.4	-	-	-	-	39.7
12													-	-	-	46.5	33.5	-	-	-	-	21.1
13														-	-	23.8	10.8	-	-	-	-	37.4
14															-	-	-	-	-	-	-	76.4
15																12.1	22	-	-	-	-	56.6
16																	-	-	-	-	-	61.1
17																		-	-	-	-	48.1
18																			-	-	-	-
19																				-	-	-
20																					-	-
21																						-
22																						

Appendix IV: Distance matrix for alternative layout 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1		-	60	49	58.4	16.8	38.5	25.8	45.8	55.8	31.9	32.4	55.1	68.6	66.8	-	-	-	-	46.9	-	-
2			12.5	23.5	30.7	55.8	34	46.6	62.3	52.2	57.1	75.7	73.9	-	-	-	-	65.4	69.27	-	-	96.9
3				-	-	-	-	-	-	-	44.6	63.2	61.4	-	28.7	37.7	50.7	53	56.7	-	30.1	84.2
4					-	-	-	-	-	-	33.6	52.2	50.4	-	22.6	35	39.7	42	45.7	-	19.4	73.2
5						-	-	-	-	-	26.5	45.1	43.3	-	10.6	19.6	32.6	51.4	38.6	-	11.7	66.1
6							-	-	-	-	20.2	20.3	43.3	-	55	67.2	54.1	10	13.6	-	34.5	41
7								-	-	-	-	-	-	-	-	45.5	32.5	31.5	35.2	-	13	62.7
8									-	-	-	-	-	-	-	58.4	45.1	18.8	22.6	-	25.6	50.1
9										-	-	-	-	-	-	33.2	20.2	38.8	26	-	19.6	34.3
10											-	-	-	-	-	23.1	11	48.8	36	-	56.1	44.5
11												-	-	-	-	46.4	33.4	-	-	-	-	39.7
12													-	-	-	46.5	33.5	-	-	-	-	21.1
13														-	-	23.8	10.8	-	-	-	-	37.4
14															-	-	-	-	-	-	-	76.4
15																12.1	22	-	-	-	-	56.6
16																	-	-	-	-	-	61.1
17																		-	-	-	-	48.1
18																			-	-	-	-
19																				-	-	-
20																					-	-
21																						-
22																						

Appendix V: Distance matrix for alternative layout 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1		-	60	49	58.4	7.3	38.5	25.8	45.8	55.8	31.9	32.4	55.1	68.6	66.8	-	-	-	-	46.9	-	-
2			12.5	23.5	30.7	65.2	34	46.6	62.3	52.2	57.1	75.7	73.9	-	-	-	-	55.8	69.27	-	-	96.9
3				-	-	-	-	-	-	-	44.6	63.2	61.4	-	28.7	37.7	50.7	43.1	56.7	-	30.1	84.2
4					-	-	-	-	-	-	33.6	52.2	50.4	-	22.6	35	39.7	32.1	45.7	-	19.4	73.2
5						-	-	-	-	-	26.5	45.1	43.3	-	10.6	19.6	32.6	46.6	38.6	-	11.7	66.1
6							-	-	-	-	24.6	25.1	48	-	59.7	71.8	58.8	9.5	12.6	-	39	31.3
7								-	-	-	-	-	-	-	-	45.5	32.5	21.6	35.2	-	13	62.7
8									-	-	-	-	-	-	-	58.4	45.1	9	22.6	-	25.6	50.1
9										-	-	-	-	-	-	33.2	20.2	34	26	-	19.6	34.3
10											-	-	-	-	-	23.1	11	44	36	-	56.1	44.5
11												-	-	-	-	46.4	33.4	-	-	-	-	39.7
12													-	-	-	46.5	33.5	-	-	-	-	21.1
13														-	-	23.8	10.8	-	-	-	-	37.4
14															-	-	-	-	-	-	-	76.4
15																12.1	22	-	-	-	-	56.6
16																	-	-	-	-	-	61.1
17																		-	-	-	-	48.1
18																			-	-	-	-
19																				-	-	-
20																					-	-
21																						-
22																						

Appendix VI: Distance matrix for alternative layout 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1		-	60	49	58.4	48.3	38.5	25.8	45.8	55.8	31.9	32.4	55.1	68.6	66.8	-	-	-	-	46.9	-	-
2			12.5	23.5	30.7	40.7	34	46.6	62.3	52.2	57.1	75.7	73.9	-	-	-	-	65.2	69.27	-	-	96.9
3				-	-	-	-	-	-	-	44.6	63.2	61.4	-	28.7	37.7	50.7	52.6	56.7	-	43.1	84.2
4					-	-	-	-	-	-	33.6	52.2	50.4	-	22.6	35	39.7	41.6	45.7	-	32.1	73.2
5						-	-	-	-	-	26.5	45.1	43.3	-	10.6	19.6	32.6	51.1	38.6	-	46.6	66.1
6							-	-	-	-	16.4	35	33.2	-	18.5	30.6	22.5	41	28.5	-	37.5	56.2
7								-	-	-	-	-	-	-	-	45.5	32.5	31.1	35.2	-	21.6	62.7
8									-	-	-	-	-	-	-	58.4	45.1	18.5	22.6	-	9	50.1
9										-	-	-	-	-	-	33.2	20.2	38.4	26	-	34	34.3
10											-	-	-	-	-	23.1	11	48.5	36	-	40.6	44.5
11												-	-	-	-	46.4	33.4	-	-	-	-	39.7
12													-	-	-	46.5	33.5	-	-	-	-	21.1
13														-	-	23.8	10.8	-	-	-	-	37.4
14															-	-	-	-	-	-	-	76.4
15																12.1	22	-	-	-	-	56.6
16																	-	-	-	-	-	61.1
17																		-	-	-	-	48.1
18																			-	-	-	-
19																				-	-	-
20																					-	-
21																						-
22																						