MANUFACTURED HOUSING PRODUCTION PLANT LAYOUT-DESIGN PROCESS

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ABSTRACT

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Manufactured homes have come a long way, from the pre-World War II trailers to one of the most preferred and popular forms of factory-built housing. In 1999, 21.4 million American lived in manufactured homes. Like other manufactured products, the manufactured homes are built in a factory on an assembly line. The assembly line consists of many activity stations supported by sub activity stations, feeder stations, and storage areas. However, the space considerations for these assembly lines are not well defined. Workers in the factory frequently must walk long distances in order to get raw materials or tools for different activities. Visit to a factory and discussions with its productions managers have revealed that these factories were previously warehouses or other big storage spaces.

The goal of this research is to produce systematic guidelines for the design of a layout for a manufactured housing production plant. For this purpose, the tools and techniques available in the field of industrial engineering are adopted. Space and proximity requirements in a production plant are understood and a layout design software program namely FactoryPLAN, is used to prepare production line layouts. Based on the complete process, layout design guidelines are produced in the form of a process flowchart.

Dedicated to Ma, Papa, and Gudia

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CHAPTER ONE

INTRODUCTION AND PROPOSED RESEARCH

1.1 OVERVIEW

Manufactured homes have come a long way from the pre-World War II trailers to one of the popular forms of housing. In comparison to the mobile homes of the past, today manufactured homes vary in design and appearance and are often mistaken for conventional site-built homes. Manufactured homes, which were previously placed in mobile home parks, have now found place in privately owned lots too. In 1999, over 68 percent of manufactured homes were placed on private property, while the remaining 32 percent were sited in residential land-lease communities (MHI-1). Research in the area of manufactured housing has also shown that more Americans are living full-time in manufactured homes. In 1999, 21.4 million Americans lived in manufactured homes. In addition, 88% of the owners of manufactured homeowners were very satisfied with their housing preference (MHI-1).

In the 1990s, the demand for manufactured homes grew tremendously, although it has shown a downward trend in recent years. Table 1.1 shows the different types of factory-built homes and their share in the housing sector. In 1998, about 22.7% (MHI-2) of the housing sector was dominated by manufactured housing, followed by, modular, panelized, and pre-cut housing sectors. Affordability is one of the major factors for this success. In addition, homebuyers get a chance to choose from a variety of features when they decide to purchase a manufactured home.

Table 1.1 Share of factory built homes in the total housing sector

(Willenbrock 1998, MHI-2, AUTOB 2002)

Housing Type	1986	1993	1998	2001
Precut	3.0%	3.3%	3.3%	3.2%
Panelized	7.0%	6.7%	6.3%	6.2%
Modular	2.4%	3.3%	3.4%	2.9%
Manufactured	16.3%	18%	22.7%	18.9%

Manufactured homes can be classified into single-section and double-section homes. Double-section homes are manufactured as two separate single-section modules/units and after production they are transported to the site individually. At the site, they are re-joined and connected to utilities. Some homes are manufactured as multiple-section homes (more than double-section) also. Single-section homes are typically 16'0" wide with a total area of 1200 sq.ft. whereas, double-section homes are about 32'0" wide with an average area of 1550sq.ft. In 2000, 273,000 manufactured homes were installed, of which 87,200 (32%) were single-section homes and 183,600 (67.25%) were double-section homes (Census, 2000). Also, in 1999, a single-section home with an average area of 1,245 sq.ft. cost about $ 31,800; whereas a double-section home with an average area of 1,605 sq.ft. cost about $ 50,200 (MHI-3).

The manufactured home, as the name suggests, is manufactured in the controlled environment of a factory. From Station One where the chassis is brought in to the factory to the final station where the home is cleaned up and material to be delivered to the site is placed inside, the home goes through five separate stages where each of the major elements (such as floors, walls, etc.) are installed. The assembly-line techniques remove many of the problems of the site-built sector. Each home meets the codes and construction standards specified by the federal government and is very similar to a site built home in appearance.

1.2 NEED STATEMENT

The manufactured housing industry has been going through many changes in the past few years. There has been an increase in the demand for manufactured housing and more people are choosing double-section homes rather than single-section homes. In addition, manufactured homes have become a popular and affordable option to permanent housing needs. Because of the increase in demand and shift to double-section housing, more production plants are being opened. In addition, the old production plants, which were primarily used for single-section home production, have been either expanded or redesigned. Therefore, there is a need to understand and prepare proper guidelines for the layout design of a manufactured housing factory.

1.2.1 INCREASE IN DEMAND FOR MANUFACTURED HOUSING

The history of manufactured homes starts in the 1920s, when the first trailer-coaches were built. These were made for travelers on vacation who wanted to rest in something better than a tent. After World War II, when the Veterans came back from the war, they found both jobs and affordable housing nonexistent. The mobile housing industry, as it was then called, fulfilled their requirements by building homes that were large enough to house a family, yet mobile enough to move the trailer to new job sites. In the 1960s, as the demand for these homes grew, the need for bigger trailers with more conveniences and the new appliances also grew. Mobile homes were now bigger, had a better appearance, and met the needs and demands of young homeowners. In June 1976, the United States Congress passed the National Manufactured Housing Construction and Safety Act (42 U.S.C.). This act required that beginning in 1976, Housing and Urban Development (HUD) authority assured that all manufactured homes were built to strict, consistent national standards (Anzer, 2002). In 1999, the industry shipped 338,200 homes from 337 manufacturing facilities (MHI-1). Table 1.2 shows the increase in both the number of units produced and the number of plants producing manufactured homes, a clear indication of the growing demand in the industry. Though in recent years the demand for manufactured homes has not grown, the author feels that by providing guidelines for layout design of a production plant, the construction of efficient plants will be facilitated. These better-designed plants would help in the production of more affordable manufactured homes and, the more affordable the homes are, the greater the demand for the homes will be.

Table 1.2: Increase in units produced and plants

(Census, 2000; MHI-3)

Year	Total Units Produced	Number of Plants Producing Units
1994	290,900	269
1995	319,400	285
1996	337,700	313
1997	336,300	323
1998	373,700	330
1999	338,200	337

1.2.2 SHIFT IN DEMAND FROM SINGLE-SECTION HOMES TO DOUBLE-SECTION HOMES

There has been a growing demand for homes. More and more people look at manufactured homes as an option for permanent housing and expect manufactured homes to be similar in size, appearance, and standards to site built homes. Double-section homes were first introduced in 1969 and since then have captured a large share of the market, while single-section homes have become less popular. The increase in demand for the double-section homes can be mainly attributed to the following two reasons (Bernhardt, 1980):

- The acceptance of manufactured homes as a permanent rather than transient form of housing.
- The relaxation of restrictions regarding width of the manufactured homes and hence the permission to transport wider sections on the highways.

In 2000, multisection home shipments outpaced single-section home shipments, making up 70.1 percent of total shipments (MHI-1). Figure 1.1 shows the increase in demand for double-section homes over single-section homes. However, the facilities in which manufactured homes are built have not changed adequately. Many of the present production plants were actually designed for single-section homes. When the demand for double-section homes grew, the same production plants were changed to cater to new demands. These plants were only slightly modified by additions to the existing facilities or use of more external storage areas for the raw materials. In addition, with the increase in demand for multi-section manufactured homes, the existing facilities for housing construction have proven less efficient, and in some cases, even unusable.

1.2.3 COMPETITION

Manufactured housing has been one of the fastest growing housing options. A greater number of homes are being built each year. A few top manufacturers produce

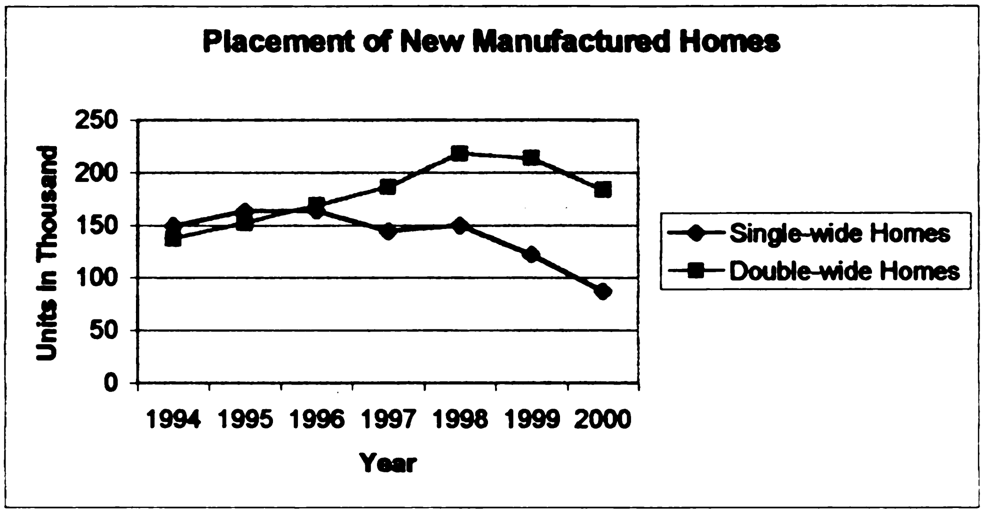


Figure 1.1: Placement of New Single and Multi Section Homes

(Census, 2000)

a large percentage of the homes. Table 1.3 shows the top five manufactured home builders in the U.S. for the year 2000. These top-five producers manufacture 153,284 units, which makes up almost 60% of the total production of manufactured housing units. The increase in demand and strong competition among producers also highlights the need to have better and more efficient and state of art production facilities.

Table 1.3: Top five Manufactured Home Builders in 2000

(MHI-3)

Ranking	Company	Total Homes	Dollar Volume
1	Champion Homes	50,145	$ 1,490,658,000
2	Fleetwood Enterprises	45,082	$ 1,145,595,000
3	Clayton Homes	23,402	$ 580,000,000
4	Oakwood Homes	22,936	$ 741,238,000
5	Skyline Corp.	11,719	$ 394,498,000

1.2.4 TECHNOLOGY

Automation and robotic technology are commonly used in many manufacturing-related industries. However this is not true in the case of the manufactured housing production facilities. Most production facilities, such as, automobile industry have undergone tremendous improvement and have evolved not only into more efficient and productive facilities but also into more technically up to date and advanced facilities. The manufactured housing industry can learn many lessons from these industries.

The highly seasonal nature of the sale of the manufactured housing and the availability of semiskilled labor has led to the low level of mechanization in production plant (Bernhardt 1980). Depending upon the capacity of the production plant being designed, different types of equipment are used during the production process. A few of the pieces of equipment presently used in manufactured housing factory are forklifts, narrow aisle trucks, mobile catwalks, crane systems for material handling, pneumatic hammers and staplers, power screwdrivers, and spray painters.

Despite the above-described needs trends, little effort has been made to study and understand the planning and design processes of a manufactured housing production plant. Therefore, the author feels that there is a need to understand the layout design process and come up with guidelines for the layout design of new and more efficient production facilities.

1.3 EXISTING RESEARCH

One major source of information regarding production plant design of Manufactured Homes is *Building Tomorrow: The Mobile/Manufactured Housing Industry* by Bernhardt (1980). It provides some information on existing design concepts used in manufactured homes production plants. No other research work has been done in the area of manufactured housing production plant design and layout. However, there is an extensive body of knowledge related to production facility planning and design in the field of industrial engineering. Therefore, the author has divided the areas of possible sources of information into two major topics, which are:

- Manufactured housing
    - The manufactured housing industry (Burkhardt, Mireley, Syal 1996; Syal & Mehrotra, 2001)
    - The manufactured housing production process (Senghore, 2001; Abu Hammad, 2001)
- Facilities planning and design (Tompkins et al., 1996; Heragu, 1997)

1.4 SCOPE AND UNIQUENESS OF RESEARCH

The scope of the existing research is to develop design layout alternatives and process guidelines for manufactured housing production plants. This author does not attempt to address other issues related to the design of production plants (like architectural design, site design and layout, HVAC systems, construction process or materials). Also, this research work mainly attempts to address issues related to space management and allocation. The author plans to visit and interview floor managers and production engineers from two manufactured housing production plants for the purpose of data collection for this research work.

Though manufactured housing production plants are similar to most other production plants, they differ from them in one unique way. In most production plants, like those in the auto industry, the product to be manufactured is standard, defined by the manufacturers, and not custom-built to meet the consumers needs. Each item produced on the assembly/production line is same as the one produced before and after it. In the case of manufactured housing production plant, each home produced is unique by itself. It is designed based on the needs and requirements of the consumer. No two homes that come down the production line are same. They vary in aspects like design, size, height, types and color of finishes etc. Hence, the assembly line in the manufactured housing production plant needs to be flexible in order to adjust to the requirements of each home being produced. This makes the production plant design of a manufactured housing facility a unique problem.

1.5 GOALS AND OBJECTIVES

The overall goal of this research is to understand and develop layout design process guidelines for a manufactured housing production plant. The major objectives are:

1. To compile the process details of Manufactured Housing production
2. To understand techniques related to manufacturing facility layout design available in the field of industrial engineering
3. To collect space- and proximity-related data, based on the layout design techniques and manufactured housing production process details
4. To develop layout design for the manufactured housing production plant
   - 4 (a) To acquire and understand appropriate plant layout design software
   - 4 (b) To produce alternative layouts
   - 4 (c) To evaluate alternative layouts
5. To formulate layout design process guidelines based on objectives 1 to 4.

1.6 METHODOLOGY

As Tompkins et al.(1996) explains, the planning process of a manufacturing facility can be subdivided into a series of phases and sub phases. The model in Figure 1.2 has been modified to match the scope of the present research, and the phases have been adapted to respond to the objectives of this research.

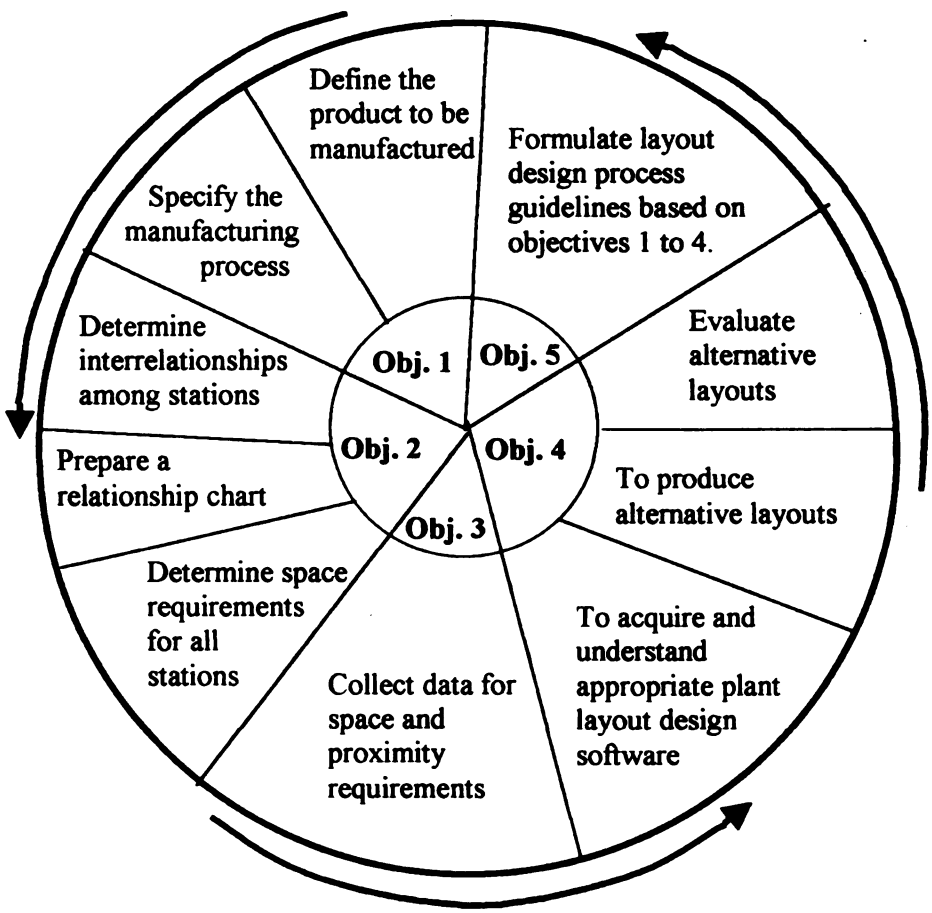


Figure 1.2: The facilities planning process-manufacturing facilities

Modified from (Tompkins et al., 1996)

The following section describes the different steps involved in meeting each of the above objectives.

Objective I: To compile the process details of Manufactured Housing production

Define the product to be manufactured

A complete housing module is the output of a manufactured housing plant. Manufactured homes can be classified into two types: the single section home which is usually 16'0" wide, and the double section home which is usually 32'0" wide.

The author plans to review existing literature based on the design and production of manufactured homes. Additional information will be obtained by visiting two manufactured housing production plants in northern Indiana.

Specify the manufacturing process required to produce the product

Manufactured homes are built in a factory on an assembly line. The author plans to study existing research works, like the research report written by Ayman Abdullah Abu Hammad, (2001) "Simulation Modeling for Manufactured Processes in Construction," which provides details on identifying ways of improving the productivity of the manufacturing process. This research work deals with the complete production process, taking all stations into account. A report prepared by Omar Senghore (2001), "The Production and Material Flow Process Model for Manufactured Housing," deals with the documentation of the production process and material flow in the manufactured housing factory and comes up with a simulation model for this process. This research focuses on a few critical assembly stations and subassembly stations. In addition, during the visits to the manufactured housing production plants, the author plans to observe the systematic production process. The production process at different production plants will be compared and a generic model will be developed.

The steps described above will be followed to develop a systematic, detailed description of all the activities involved in the production of a manufactured home. These activities are grouped into five major clusters: floors, walls, roofing, exterior, and finishes. Each of the clusters of activities takes place in one of the main assembly stations, which are in turn supported by subassembly stations, feeder stations and internal and external storage areas. The major activities that are included in each of these clusters are as follows:

Floors cluster: The floors cluster mainly consists of two to three stations where the installation of floor joist, HVAC systems and waterlines in the floor takes place. The floor is insulated in these stations also.

Walls cluster: This cluster mainly consists of installation of both interior and exterior walls with insulation. Some of the bathroom appliances are also installed in this cluster.

Roofing cluster: This cluster mainly consists of a substation where the roof truss is fabricated (in some factories pre-fabricated roof trusses are used) and two main stations where the roof is placed over the house and roof deck, and insulation and shingles are installed.

Exterior cluster: The exterior finishes are usually carried out simultaneously with the roof decking. The major activities that happen at these stations are installation of doors and windows, exterior boards and siding.

Finishes cluster: This cluster mainly consists of three to four stations. Electrical, mechanical and HVAC installations and inspections are carried out in the first two stations. At the next station, carpeting is installed and the interior of the house is painted or wallpaper is put up. Finally, axles and wheels, window curtains and appliances are installed at the last station.

Objective II: To understand techniques related to manufacturing facility layout design available in the field of industrial engineering

Determine the interrelationships among stations

The interrelationships among different activity stations can be understood in two ways:

- Referring to existing research by Omar Senghore (2001), "The Production and Material Flow Process Model for Manufactured Housing" and another by Ayman Abdullah Abu Hammad (2001) namely, "Simulation Modeling for Manufactured Processes in Construction," which provide details on identifying ways of improving the productivity of the manufacturing process. An example illustrating the roofing clusters is presented in Figure 1.3.
- Visiting the production plants and preparing the relationship charts.

  Constructing a home in a factory is a systematic process. Certain activities need to be completed before others can begin. For example, the roof can only be installed after the framework for the external walls has been put in place, which in turn can only be done after the floor insulation and ductwork have been completed.

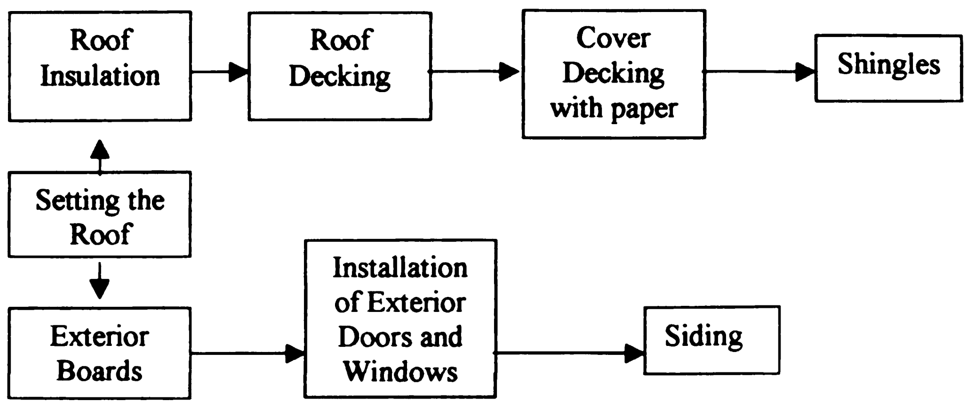


Figure 1.3: Schematic Relationship of Constituent Activities on a Roofing Station

(Senghore 2001)

On the other hand, there are certain activities that can be carried out at the same time as other activities. For example, the installation of external floorboards is usually done at the same time as the carpeting is being installed inside the home. It is important to understand that in the manufactured housing production process scenario certain activities need to be completed before the home can be moved from one station to the other.

Relationship chart

The relationship charts represent qualitative measure of flow (flow can be flow of material, information, or people).

"The relationship chart describes qualitatively the degree of closeness that the analyst feels should exist between different work centers" (Sule 1988).

The Relationship Chart can be used to determine adjacency between departments. If material flow is an important consideration, or if common supervisory control is important, then a high rating between two departments suggests that these departments should be geographically close to each other. The shape and size of the departments limits the number of departments that can be adjacent to one another (Tompkins et al., 1996).

Determine the space requirements for all stations

Once the specific stations and their interrelationships in the production plant are defined, their space requirements need to be understood. The visits to the production plants will be utilized to collect the data. Floor plans will be referred and if required spaces will be measured. Floor managers at these plants will be contacted and their opinion on the space requirements and utilization will be collected. In addition, existing work done in this area will be researched. The author will also meet with industrial designers and architects and understand the methods and procedures used by them.

Space requirements will be determined primarily for work areas, worker movement areas and equipment movement areas. The space requirements for individual assembly stations, sub assembly stations, feeder stations, sub-feeder stations, and internal and external storage areas also need to be determined. The following section describes the major stations in the production plant and the factors that determine their space requirements.

Assembly and subassembly stations

The stations' space requirements mainly depend on the size of the home being manufactured. As the length of the homes varies from 40'0" to 72'0", the space needs to be flexible. In addition, aisle space requirement needs to be determined. Similarly, depending upon the type of subassembly being assembled or placed, the space requirements for the sub-activity stations will also need to be adjusted.

Feeder stations and storage areas

The space requirement for feeder stations and storage areas depends upon the amount of inventory the manufacturer maintains both inside and outside of the facility. The inventory can be maintained on either a per-home basis or a number-of-day basis. For example, the internal storage for external boards is usually a week, whereas the inventory for appliances is for a month.

Aisle allowance estimates

Planning aisles that are too narrow will cause congestion and safety problems and may give rise to high levels of damage. Depending upon the type of material handling equipment used and the activity being carried out, the aisle width can be determined. For example, activities like carpet installation require little external space, whereas activities like installation of external boards, doors and windows require more external space.

Equipment allowance estimates

The equipment used in a manufactured housing production plant can be classified into two sections, namely (Bernhardt, 1980)

- Equipment used at activity stations, which are very similar to the equipment used in conventional home construction. This equipment mainly consists of pneumatic hammers and staplers, power screwdrivers, spray painters, and mechanical glue applicators.
- Equipment used for material handling: their three major types of material handling equipment used expansively in the production process. They are hand-propelled conveyers (carts and dollies), self-powered conveyers (folk lifts), and overhead equipment (overhead hoists and monorails).

Special area considerations if required will be included during the layout design of the production plant.

Objective III: To collect space- and proximity-related data, based on the layout design techniques and manufactured housing production process details

Proximity relationships

The relationship chart method was selected as the basis for data interpretation for activity interrelationships. The different steps involved in the construction of a relationship chart are explained in chapter three. Figure 1.4 shows a basic relationship chart, which presents the relationships between the major clusters of stations in a manufactured housing plant.

Space requirements

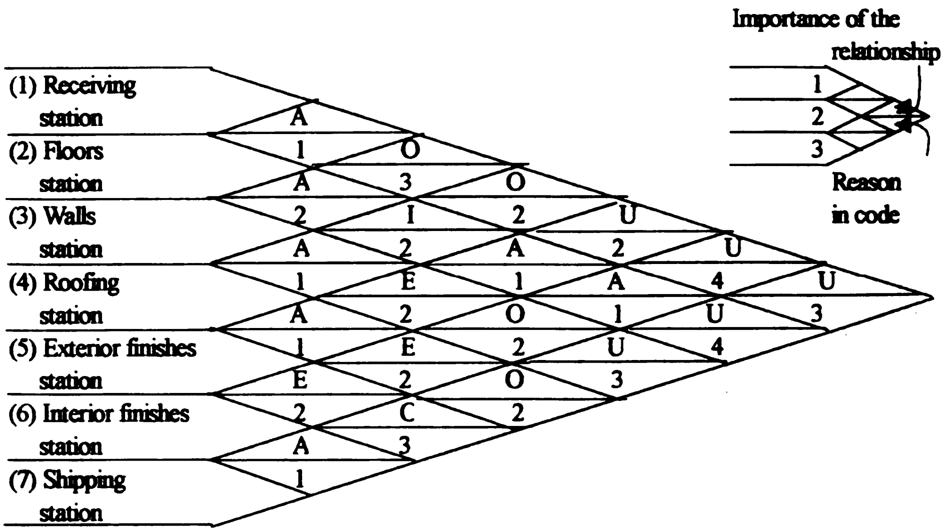
Table 1.6 shows the format in which space requirement data is collected for the major clusters. Once space requirements for major clusters are collected, the author will subdivide each of the clusters into smaller spaces and gather area information for them. Table 1.7 shows the different divisions for which space requirements for each activity will be collected.

Objective IV: To develop a layout design for the manufactured housing production plant

To acquire and understand appropriate plant layout design software

Production plant layout design software programs have come a long way from the traditional layout design solutions, first developed in 1960s. The following section first describes a few of the preliminary layout design software solutions and then goes on to cover more recent software programs in the later section. These software solutions are discussed in detail in later chapters.

ALDEP: ALDEP uses the Relationship chart to determine the importance of station proximity. It requires a threshold closeness rating. The selection procedure used encourages stations that have high ratings to be close to each other. For example, if a threshold rating of E is selected, then the I, O and U ratings are considered equally unimportant. (Where A-absolutely necessary, E-especially important, I-important, O-ordinary, U-unimportant, and X-undesirable).



Value	Closeness
A	Abosolutely important
E	Espically important
I	Important
O	Ordinary closeness
U	Unimportant
X	undesirable

Closeness rating

Code	Reasons
1	High sequence
2	Medium proximity
3	Low proximity
4	Not related
5	Same equipment
6	Same labor

Reason behind closeness value

Figure 1.4: Relationship chart

(Tompkins et al., 1996)

Table 1.6: Data collection for space requirements

Number	Function	Area (sq.ft.)
1	Receiving station	2000
2	Floor stations	8000
3	Walls stations	9000
4	Roofing station	7600
5	Exterior finishes stations	8600
6	Interior finishes stations	7500
7	Shipping station	2500

Table 1.7: Detailed data collection table for space requirements

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:

The placement procedure in ALDEP creates several alternative layouts. The user must specify the length and width of the facility and the area of each station. The user is also required to specify a sweep width. By changing this sweep width, the user can obtain several different layouts. ALDEP then creates a grid on the facility and assigns a number of grid squares to each station in proportion to its area. ALDEP creates a block layout by placing stations in the order determined by the selection procedure and blocks out an appropriate number of grid squares. After a layout is completed, ALDEP determines how good the layout is by giving it a numerical score (Palekar, 1998).

CORELAP: CORELAP also requires relationship charts asan input. However, weights must be assigned to the ratings in the Chart. These weights are called "closeness ratings" (CR). CORELAP computes a total CR (TCR) for each station by summing all the CRs associated with that station. CORELAP does not consider the building shape. The final shape of the facility created depends on the placement of stations that CORELAP has selected. The procedure begins by placing the first department in the center of the layout.

Each subsequent department is situated according to already-placed departments in the position that gives the best placement rating. The arrangement with the best placement rating is selected. After the layout is completed, CORELAP calculates a numerical score for the layout. A small layout score indicates a good layout [Palekar 1998].

BLOCPLAN : This program accepts data input from both From-To charts and Relationship charts, i.e. both quantitative and qualitative data are accepted. The major purpose of BLOCPLAN is to generate and evaluate block type layouts in response to the user-supplied data. BLOCPLAN also uses relationship codes specified by Muther in Systematic Layout Planning (Donaghey, 2000).

AUTOCAD based tools: These tools can be utilized for the purpose of layout design. The factory products group at Engineering Animation, Inc. (EAI, 1999) developed software that simplifies designing a new factory or improving an existing one. Three programs (FactoryCAD, FactoryPLAN, and FactoryFLOW) run inside AutoCAD and allow for both qualitative and graphical analysis as well as provide valuable tools for creating a layout [Owen 2002]. FactoryPLAN is a qualitative layout design tool, which like BLOCPLAN uses Muther's Systematic Layout Planning for design process. It allows the user to position stations based on different flow patterns and does not restrict the positioning of stations like other software programs. FactoryPLAN was used for preparing layout design alternatives for the manufactured housing production plant in this research work.

To produce alternative layouts

Once the layout design software solution is chosen for the layout design of a manufactured housing production plant, layout alternatives will be developed for different layout patterns based on the space- and proximity-related data collected from the two factories. Each of the layouts will consist of the major assembly, subassembly and feeder stations.

To evaluate alternative layouts

An effective score analysis related to the selection of a layout from the alternatives will be computed. This process will show the areas where each of the layouts could be improved.

Objective V: To formulate layout design process guidelines based on objectives 1-4

Formulate guidelines using plant layout techniques

Once the interrelationships between spaces and space requirements are determined, the designer needs to come up with different facility layout options. The options can be better understood by preparing evaluation charts, in which nodal relations of the graphical representation of the relationship chart and From-To charts are converted into semi scaled-grid representations. The layout design process guidelines will mainly consist of the major steps involved in producing layout design alternatives for a manufactured housing production plant. Figure 1.5 presents the major steps involved in the development of the guidelines. This flowchart outlines the important steps involved in this research.

Input from the manufactured housing industry on plant layouts

The author plans to seek industry input for the evaluation of the layouts produced. In order to get input from the industry the author will visit and interview the production plant managers to get their comments about the layouts.

Input from industrial design consultants on process guidelines

The author also plans to contact leading industrial design firms in the United States, to get their input on the procedures they have adopted to come up with the design of a manufacturing facility. Based on their input, the layout design process guidelines will be finalized.

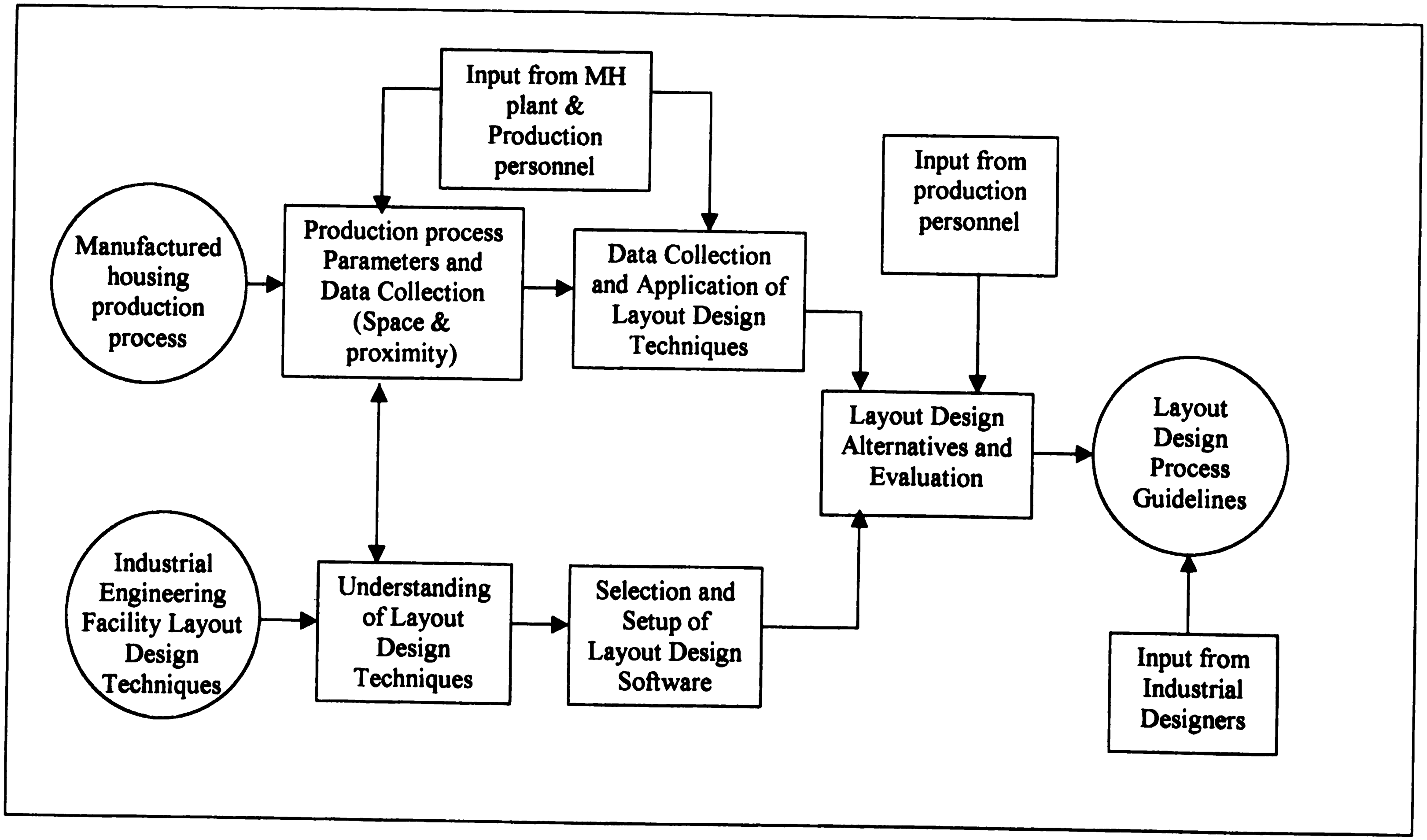


Figure 1.5: Milestone for the layout design process of a manufactured housing production plan

1.7 DELIVERABLES/OUTCOMES

As an outcome to this thesis, the author plans to produce a systematic process approach to the layout design of a manufactured housing production plant.

The other major deliverables would be:

- Documentation of the complete production process of manufactured housing
- Space and proximity requirements based on the process details
- Description of appropriate layout design techniques and software
- Process of guidelines and layout alternatives based on space and proximity requirements

1.8 SUMMARY

The manufactured housing industry has made a lot of progress in the last few years; this progress has always been concentrated on the product that is being manufactured. No attempts have been made to understand the requirements of the facilities in which the product is being manufactured. This thesis is an attempt better understand this issue.

Through this proposed research, the author has tried to emphasize the need for a systematic process in the design of a manufactured housing production plant. The objectives and methodology in this research will result in better understanding of the requirements and tools and techniques used in designing better production facilities for the manufactured housing plants.

CHAPTER TWO

EXISTING LITERATURE REVIEW

2.1 INTRODUCTION

The literature in this chapter can be divided into two major categories: the manufactured housing industry and facilities design and planning. Though, Senghore (2001) has provided definitions for most of the manufactured housing related terminology, the author has restated the definitions for the convenience of the reader. As this thesis presents design and planning of facilities from the industrial engineering perspective, the author will also present both terminology and existing literature related to this field. Each category is further classified into two areas, which are terminology and existing literature.

2.2 MANUFACTURED HOUSING

The manufactured housing industry has helped alleviate to the ever-growing need for affordable housing all over the world. Manufactured homes are a part of the family of factory built housing; modular homes, panelized homes and the pre-cut homes are other members.

2.2.1 TERMINOLOGY

This section is further divided into two areas dealing with terminology related to manufactured housing, terminology related to the manufactured housing industry in general and terminology related to manufactured housing as a product.

2.2.1.1 MANUFACTURED HOSUING INDUSTRY

The Michigan Manufactured Housing Association has introduced some of the following definitions (MMHA, 2000):

Manufactured Home: A home on permanent chassis built in a controlled, factory environment and designed to be used with or without a permanent foundation when connected to utilities. Manufactured homes are built to the federal Manufactured Home Construction Safety Standards, enforced by the Department of Housing and Urban Development (HUD) in Washington, D.C. Manufactured homes are single story and are delivered to the home site in one, two, or occasionally, three sections; they may be placed on private property or in a manufactured home community.

Manufactured Home Communities: Private land developed as homes sites for manufactured homes. In Michigan, most sites are leased to the homeowner for a monthly fee. They are sometimes referred to as a land-lease communities.

Single-Section Home: A manufactured home delivered to the home site in one intact section; the average square footage is 1,130 square feet.

Multi-Section Home: A manufactured home delivered to the home site in two or three sections. The average square footage is 1,640 square feet, but multi-section homes may be as large as 2,400 square feet. It may have a (site-built) garage attached after the home is installed.

Manufacturer: Any person engaged in manufacturing or assembling manufactured homes, including any person engaged in reselling of manufactured homes.

HUD Code: Code developed by the Department of Housing and Urban Development. The HUD code regulates the home's design and construction, strength and durability, transportation, fire resistance, energy efficiency, and quality control. It also sets stringent performance standards for the heating, plumbing, air-conditioning, and electrical systems. The HUD Code specifically preempts local building codes as they relate to construction codes for manufactured homes.

International Residential Code: Code provisions for one- and two-family dwellings which apply to the construction, alteration, movement, enlargement, replacement, repair, equipment, use and occupancy, location, removal and demolition of detached one- and two-family dwellings and multiple single family dwellings (townhouses) not more than three stories in height with a separate means of egress and their accessory structures (IRC, 2001).

2.2.1.2 MANUFACTURED HOUSING PRODUCT & PROCESS

Manufactured homes are designed with one major objective: Provide a completely furnished permanent housing unit that can be transported from the factory to the final home site. A manufactured home as a product consists of a lot of elements/materials that are similar to a site-built home, but there are other elements that are specific to the manufactured homes. The following section defines some of these elements and processes.

Foundation footing: Part of the support system located at or below ground level. Piers are placed on foundation footings, which are made from concrete or treated lumber (MMHA 2000).

Pier: The portion of the support system between the foundation footing and the manufactured home, exclusive of caps, plates and shims (MMHA 2000).

Chassis: The structural base over which the manufactured home is constructed. It is made of solid steel, an I-beam, a frame header, and outriggers to add extra support to load bearing areas. The frame is sealed with rust-inhibitive black paint. The chassis ensures the primary and continued transportability of the home. Once the house is installed, the chassis receives all the vertical loads from the roof, walls and floor and transfers the load to the foundation (Bernhardt 1980).

Marriage Wall: In a double-section manufactured home, the walls that are located where the two sections join are called marriage walls. They are usually installed at a later stage in the production process. The marriage wall is a double wall consisting of 2x4 studs. Therefore, the marriage wall is an 8" thick centerline wall.

Single-station alarm device: An assembly incorporating the smoke detector sensor, the electrical control equipment, and the alarm-sounding device in one unit (HUDMHCSS, 1999).

Anchoring equipment: The straps, cables, turnbuckles, and chains, including tensioning devices, which are used with ties to secure a manufactured home to ground anchors (HUDMHCSS, 1999).

Anchoring system: A combination of ties, anchoring equipment, and ground anchors that will, when properly designed and installed, resist overturning and lateral movement of the manufactured home from wind forces (HUDMHCSS 1999).

Diagonal tie: A tie intended to primarily resist horizontal forces, but it may also be used to resist vertical forces (HUDMHCSS, 1999).

Ground anchor: Any device in the manufactured home that is designed to transfer manufactured home anchoring loads to the ground (HUDMHCSS, 1999).

Stabilizing devices: All components of the anchoring and support system, such as piers, footings, ties, anchoring equipment, ground anchors, and other equipment that supports the manufactured home and secures it to the ground (HUDMHCSS, 1999).

Support system: A combination of footings, piers, caps, and shims that will, when properly installed, support the manufactured home (HUDMHCSS, 1999).

Tie: Straps, cable, or securing devices used to connect the manufactured home to ground anchors (HUDMHCSS, 1999).

Vertical tie: A tie intended to resist the uplifting or overturning forces (HUDMHCSS, 1999).

Factory-built fireplace: A hearth, fire chamber, and chimney assembly composed of listed factory-built components assembled in accordance with the terms of listing which form a complete fireplace (HUDMHCSS, 1999).

Running gear assembly: The subsystem consisting of suspension springs, axles, bearings, wheels, hubs, tires, brakes, and their related hardware (HUDMHCSS, 1999).

Drawbar and coupling mechanism: The rigid assembly, usually an A frame upon which is mounted a coupling mechanism, which connects the manufactured home's frame to the towing vehicle (HUDMHCSS, 1999).

2.2.2 LITERATURE REVIEW-MANUFACTURED HOUSING

The existing literature in the field of manufactured housing can be mainly found in related research projects, dissertations, magazines, and books. Like the subdivisions in the terminology section, this section is again classified into two parts, literature related to general manufactured housing and literature related to product and production process.

2.2.2.1 MANUFACTURED HOUSING INDUSTRY

Many sources of literature addressing the manufactured housing industry in general are available, but *Building Tomorrow: The Mobile/Manufactured Housing Industry* (Bernhardt, 1980) is one of the only books available which discusses both manufactured homes as a product and reports the industrial organization and cost and price structures in different associated areas, like the manufactured home production system, distribution system, the Community parks, and the supporting and regulatory environment. Bernhardt, as a part of two major industrialized housing related research projects, examined the status of the industry and became convinced that, "... *unless the building industry on its own initiative undertakes strategic restructuring of its own business organization as well as of its supporting, regulatory and political environments, it will attain no major performance improvements,"pg:* maintains that low cost and high quality shelter can be produced in high volume.

In his book *Manufactured Homes – Making Sense of a Housing Opportunity* (Nutt-Powell, 1982), the authors express their views on manufactured housing policies covering market demand and need, design and construction, costs, legal issues and public acceptance of housing recommendations.

A report prepared by the National Association of Home Builders (NAHB) Research Center, Inc., for the U.S. Department of Housing and Urban Development, Office of Policy Development and Research, titled *"Factory and Site-Built Housing A* *comparision for the 21st Century"* (NAHB, 1998), offers information on several important dimensions in the area of manufactured housing. The information is catagorized under the following headings, overview of the housing industry and recent trends; characterstics of conventional and manufactured homes; household characterstics; design and material characterstics; comparision of the regulatory processes; approval, design, and inspection; code requirements, and finally the cost analysis. Based on the recent growth of the HUD-code approved manufactured housing sector, the report also suggests strategies using which home builders can improve efficiency, reduce production costs and help deliver affordable homes to buyers.

Another report prepared by NAHB Research Center, called *Home Builders' Guide to Manufactured Housing* (PATH, 2000) is a guidebook that provides conventional builders and land developers with information on manufactured housing, focusing on differences between manufactured and conventional homes that are likely to be encountered in practice. The sections describe a variety of options for using these homes. The report also covers issues related to finding a manufacturer, developing product specifications, arranging potential contracts, working with local zoning and land-use planning, considering installation and foundation options, improving the building on-site, and understanding regulatory issues and consumer financing.

The College of Architecture and Urban Planning at the University of Michigan, published a report called the "Manufactured Housing Research Project" (MHRP, 1993), in the form of six reports describing manufactured housing quality, manufactured housing costs and finance, manufactured housing values, manufactured housing impacts on adjacent property values, manufactured housing and the senior population, and manufactured housing as a form of alternative ownership with innovative uses.

Another report prepared at the Construction Management Program, Michigan State University (Syal & Mehrotra, 2002) introduces the different factory built housing options available and describes trends and terminology related to the housing industry both nationally and in Michigan in the first part. The second volume of the report is an assessment of the site regulatory requirements that impact the use of manufactured housing (Morzoski & Sambrae, 2002).

2.2.2.2 THE MANUFACTURED HOUSING PRODUCTION PROCESS

According to Partnership Advancement of Technology in Housing (PATH), the manufactured housing industry has been lagging behind in its technological innovations compared to site-built housing.

In 2000, a team from Michigan State University and the University of Cincinnati was funded by the National Science Foundation (NSF) to conduct research called *Modeling of manufactured housing production and material utilization*. As a part of this project, two masters theses have emerged (Senghore, 2001; Hammad, 2001). In both, production process models of construction of a manufactured house were described and simulation-based tools are utilized to streamline the production process and test "what if" scenarios. Below is a summary of both the theses.

The first thesis was written by Ayman Abdullah Abu Hammad, of the Civil and Environmental Engineering Department, University of Cincinnati, and was titled *Simulation Modeling For Manufactured Processes In Construction* (Hammad, 2001). This dissertation identified ways of improving the productivity of the manufacturing process in a housing factory that would lead to a more cost-effective and efficient system, utilizing the following procedure: First, the entire factory plan was mapped. Then a computer-based simulation model for the manufactured housing production process was developed using Arena software, and finally the model was verified and validated with real performance measures in the factory. Hammad documented and simulated the complete production process of a manufactured home in a factory at a macro level.

The second thesis prepared by Omar Senghore, (Senghore 2001), at Michigan State University, was titled *The Production and Material Flow Process Model for Manufactured Housing*. This report is also a contribution to the improvement of the production process of manufactured housing. The overall goal of the report is to show how the production process of manufactured housing can be improved and resource utilization streamlined. To achieve this goal, the following objectives were identified. First, process flow diagrams were developed for multi-section manufactured housing production, and then production and material flow process models were developed. Finally, three-four stations were selected and the process model was transformed into a simulation model in EZSTROBE (Martinez, 1998). The simulation model for example, suggested that the productivity at the roofing station was less that at to other stations.

"What if" scenarios were developed, and a solution to the poor productivity was provided by adding specific numbers of resources. Though, Senghore describes the complete production process in detail using the flow charts, he finally selected few of the major stations on the production line and prepared, ran, and validated the simulation model.

2.3 FACILITIES PLANNING AND DESIGN

The proposed research work deals with developing a layout for a manufactured housing production plant. The tools and techniques that have been used to develop the layout have been adapted from the field of industrial engineering. This section summarizes the terminology and the existing literature related to developing plant layouts.

2.3.1 TERMINOLOGY

Facilities planning: "how an activity's tangible fixed assets support achieving the activities objectives" (Tompkins et al., 1996).

Product analysis: The process of breaking down the product into subassemblies and the subassemblies to individual parts in order to assist in the development of the production process (Tompkins et al., 1996).

Quantitative measure: Flow can be measured quantitatively in terms of the amount moved between departments. It includes pieces per hour, moves per day, etc. In facilities with a large volume of materials, information, or people moving between the departments this kind of measure is important (Tompkins et al., 1996).

Qualitative measure: Flow can be measured qualitatively based on the designer's perception as to the degree of closeness that should exist between departments. It may range from absolutely necessary that two departments be close to each other to a preference that the two departments not be close to each other. In facilities having very little movement of material, information or people, qualitative measure is the basis of arrangements of departments. A relationship chart is one of the common ways of presenting the qualitative measure of flow (Tompkins et al., 1996).

Relationship charts: A qualitative description of the degree of closeness that the analyst feels should exist between different work centers. Degree of closeness is expressed in form of values, namely, A=Absolutely important, E=Especially important, I=Important, O=Ordinary closeness, U=Unimportant, and X=Undesirable (Tompkins et al., 1996).

From-to charts: Quantitative measure that represents flow (flow can be flow of material, information, or people). Flow can be measured in terms of amount moved between departments/stations. The From-To chart is a square matrix (Tompkins et al., 1996).

Algorithms: Solution techniques or procedures used to solve a problem (Heragu, 1997).

2.3.2 LITERATURE REVIEW

Plant Layout and Materials Handling (Apple, 1963), one of the earliest books on plant layout and design, is presented from an engineering standpoint without becoming too involved in the technical features of equipment design and construction. Apple emphasizes the major issues of the coordination between plant layout, materials handling, methods engineering and production planning and control. One of the major goals of the book is to take advantage of all the different interrelated techniques so as to develop a satisfactory and practical layout. Layout design techniques can be used for several facilities like manufacturing plants, warehouses, offices, or other industrial and business facilities

Facility Layout and Location- An analytical approach (Francis & White, 1994), the authors suggest that studying of Facility layout and location offers considerable potential for the application of operations research. A few of the major objectives of this book are:

- To provide the facilities analyst with new techniques, approaches, and philosophies for the solution of facility layout and location problem.
- To stimulate interest in facility layout and location problems within a wide variety of academic disciplines.
- To provide an opportunity for a shift in the emphasis on quantitative and qualitative aspects of facility layout and location.

- To provide a classification of the rapidly expanding body of literature on facility layout and location problems and attempt to treat a selected portion of the literature in a unified manner.

In 1954, the literature available on plant layout was in the form of papers and articles in periodicals. The book *Factory Planning and Plant Layout* (Ireson, 1954) was an attempt to organize the literature available and the author's own ideas about planning and design of layouts. The author suggests that the final measure of the effectiveness of a factory plan lies in the cost of manufacturing the product in the plant, and therefore cost must be an important measure to be applied in the design procedures. Small and medium size plants have been used in the design problems. The reason for this, the author explains is that any complicated product consists of a number of smaller problems of planning facilities from the production of component parts and subassemblies to the final assembly line. Hence procedures described in this book are simple and direct.

The book *Facilities Design* (Heragu, 1997) deals with the proper design, layout, and location of facilities. The author suggests, "*poor facility design can be costly and may result in poor-quality products, low employee morale, and customer dissatisfaction.*" (Heragu, 1997). Heragu provides information on types of layout problems, traditional approaches to layout design, tools and techniques for layout design, generic modeling tools, algorithms and group technology. Basic and advanced models are also available for plant location problems.

Facilities Planning (Tompkins et al., 1996), has been and is being used as a textbook for facilities design in several Industrial Engineering schools in the country. The book is divided into five parts. Part one focuses on the determination of the requirements for people, equipment, space, and material in the facility. Part two presents concepts and techniques to facilitate the generation of alternative facility plans. Part three continues the focus on producing alternatives but focuses on the functions of the organization. Part four presents a variety of quantitative approaches that can be used to model specific aspects of facilities planning. Part five concludes the treatment of facility planning and deals with evaluating, selecting, preparing, presenting, and maintaining the facility layouts.

Layout Design and Analysis Software (Sly et al., 1996) is the third part of a three part series published in *IIE Solutions*. This paper discusses issues related to facilities layout and design that software needs to consider in order to produce layouts of high efficiency and exceptional quality. The issues that need to be addressed by factory layout software include physical, organizational, and capacity transformations. Basic design skeletons like that of Reed (1967), Muther (1973) and Apple (1963) are also described. The paper goes on to suggest the interactive computer-aided relationships and flow-based layout design techniques like relationship charts, diagramming, flow diagramming, and flow paths (1996). Finally, Sly et al. explains the classification of layout algorithms in terms of mathematical procedures, heuristics, probabilistic approaches and graph theory (1996). The authors argues that "*a good layout well suited to the manufacturing philosophy is the fundamental starting point for total production system design, and provides a solid foundation on which to build dynamic simulation studies should they be appropriate.*"

(Sly et al., 1996). Also, with the layouts produced by the software solutions available can reduce material flow, WIP, and throughput times.

2.4 SUMMARY

In this chapter, a detailed literature review and the terminology used in manufactured housing and facilities planning and design have been provided. The area of manufactured housing was further subdivided into the manufactured housing industry and the manufactured housing product and process details.

CHAPTER THREE

TECHNIQUES AND TOOLS FOR PRODUCTION PLANT LAYOUT DESIGN

3.1 INTRODUCTION

The facilities design of a manufactured housing production plant requires input from the field of industrial engineering. In this chapter, the author has made an attempt to summarize the different general and specific techniques used for process of design of manufacturing facilities. In addition, different tools used for presenting and developing the design layout have been discussed.

3.2 TECHNIQUES USED FOR MANUFACTURING FACILITIES DESIGN

The techniques used in facilities design come from the larger domain of manufacturing facilities planning, and therefore it is important to understand the concepts in this area first. Facilities planning, in general can be defined as "how an activity's tangible fixed assets best support achieving the activities objectives"(Tompkins et al., 1996). In the specific case of manufacturing facilities planning, the above definition can be modified into the "determination of how a manufacturing facility best supports production" (Tompkins et al., 1996).

In the U.S, approximately 8% of the gross national product is spent on new facilities, with about 3.2 % spent on manufacturing facilities specifically. Over 250 billion dollars are spent on the planning and replanning of facilities (Tompkins et al., 1996). There is a significant opportunity to improve the planning and design process of the production plants. If effective facilities planning processes were applied to manufacturing plants, then the annual manufacturing productivity in the U.S. would increase approximately three times more than it has in any of the last fifteen years (Tompkins et al., 1996).

3.2.1 THE MANUFACTURING FACILITIES PLANNING PROCESS

The field of manufacturing facilities planning can be subdivided into plant location, and plant design. Plant location refers to the placement with respect to the customers, suppliers, and other facilities in the supply chain. As shown in Figure 3.1, plant design is further subdivided into plant facility system, plant layout, and material handling. Plant facility system consists of the structure, atmosphere, enclosure, lighting, electric, communication, life safety, and sanitation related systems.

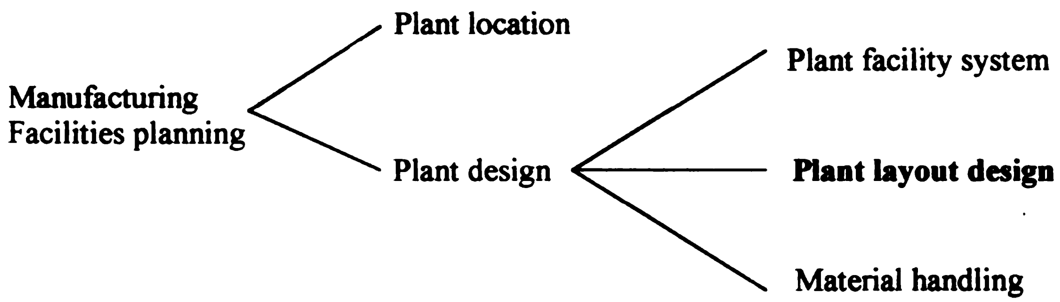


Figure 3.1: Subdivisions of Facilities planning for a manufacturing plant facility
(Tompkins et al., 1996)

Layout design consists of production areas, production-related areas (support areas), and personnel areas within the plant. With manufactured housing production plant layout specifically, the layout design consists of the production line, the major assembly stations, subassembly stations, feeder stations, storage areas, and personnel areas, like rest rooms, first-aid rooms, tool rooms and lunchrooms. Finally, material handling includes handling of material, personnel, equipment and information.

In this thesis the production plant and assembly line related areas have been addressed and emphasized.

3.2.2 OBJECTIVES OF PLANT LAYOUT

Plant layout is the result of integration of several components, like product design, process design, and schedule design. According to Apple (1963), plant layout can be defined as

"Planning and integrating the paths of the component parts of a product to obtain the most effective and economical interrelationship between men; equipment; and the movement of materials from receiving, through fabrication, to the shipment of the finished product." (Apple, 1963)

Apple (1963) defines the objectives of plant layout as:

- *Facilitates manufacturing process:* The layout should be designed such that the manufacturing process can be carried out in an efficient way. This objective can be attained by (a) arranging machines, material, and work areas so that material moves smoothly, (b) eliminating all delays possible, (c) planning flow so that work passing can be easily identified, and (d) planning for maintenance of conditions.

- *Minimizes material handling:* In a good layout, material handling can be reduced to a minimum by using mechanical equipment and by the parts continually being in transit and moving towards the shipping area.
- *Maintains flexibility of arrangement and operation:* The layout design should be flexible enough to incorporate space for any defective material found and should be able to rectify problems.
- *Maintains a high turnover of WIP:* If the in-process storage of material is reduced, the over-all material turnover time is also reduced, thereby decreasing the working capital.
- *Holds down investment in equipment:* In a good layout with a proper arrangement of machines and departments, the number of pieces of equipment used can be reduced.
- *Makes economical use of floor area:* Only if each sq.ft. of floor area in a plant is used to attain maximum advantage, the layout would be good.
- *Promotes effective utilization of manpower:* Proper layout can increase the effective utilization of labor.
- *Provides for employee satisfaction:* This objective can be met only if attention is given to items like light, heat, ventilation, safety, removal of moisture, dust, dirt etc.

In this thesis, the issue of space requirements in a manufactured housing production plant will be studied. Also, an attempt will be made to design a layout based on the interrelationships between departments.

3.2.3 TRADITIONAL APPROACHES TO LAYOUT PROCEDURES

Over the years, several new layout procedures have evolved to assist the planner in designing layouts. Described below are some original approaches to layout problems. The concepts used in these approaches are still the backbone for many approaches presented today (Tompkins et al. 1996).

3.2.3.1 APPLE'S PLANT LAYOUT PROCEDURE

Apple (1977) proposed the following steps in producing a plant layout:

1. Procure the basic data
2. Analyze the basic data
3. Design the productive process
4. Plan the material flow patterns
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 appropriate persons

18. Obtain approvals

19. Install the layout

20. Follow up on implementation of the layout

Apple (1977) also specifies that no two projects are the same and hence the procedures for designing them are also different. Therefore, the steps described above need not take place in the specified order. They might change based on the layout design problem that is being addressed.

3.2.3.2 REED'S LAYOUT PROCEDURE

Reed (1967) recommended the following systematic plan as steps in planning and preparing layouts.

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 the plant

10. Provide for future expansion

3.2.3.3 SYSTEMATIC LAYOUT PLANNING (Muther, 1973)

Richard Muther (1973) formulated a high-level approach to the entire process of plant layout design. The method developed, is called Systematic Layout Planning (SLP) and outlines the sequence of steps that should be followed while designing a plant layout. Figure 3.2 depicts Systematic Layout Planning (SLP) procedure in a flowchart format. Most of the present day layout design tools use Systematic Layout Planning techniques developed by Muther, in their tools.

- Quantify the flow of material between departments
- Create an activity relationship chart
- Create a relationship diagram
- Determine the space requirements
- Create a space relationship chart
- Create alternate layouts

3.2.3.4 ALGORITHIMIC APPROACHES

The placements of departments on the basis of their "closeness ratings" or "material flow intensities" is an issue that has been developed into algorithmic process approaches. The following the methods are available (Tompkins et al., 1996):

1. Relationship diagramming
2. Pairwise exchange methods
3. Graph-based construction methods

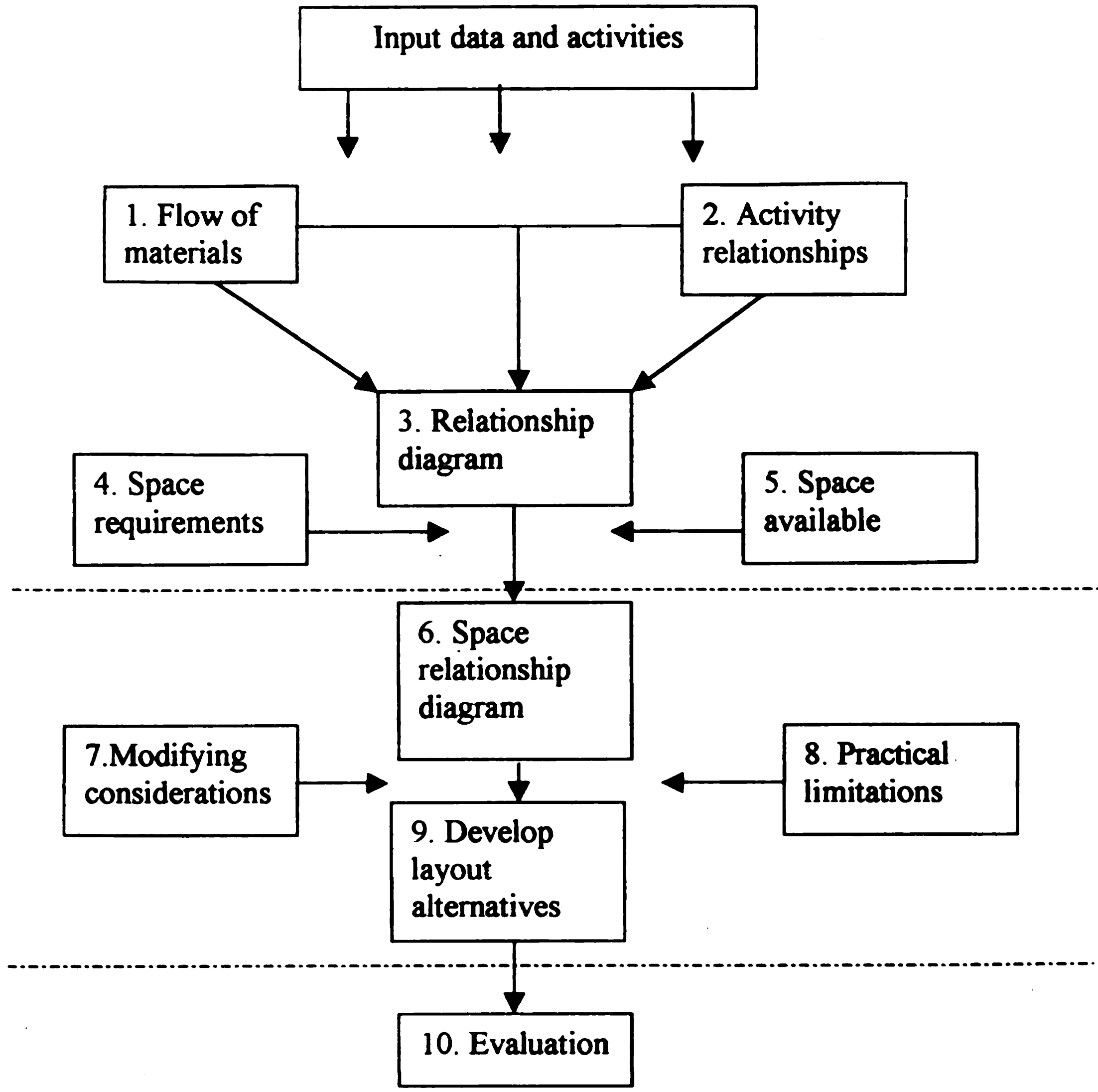


Figure 3.2: systematic layout planning (SLP) procedure
(Muther, 1973)

The relationship diagramming algorithmic approach is a well known model that has been used to design a number of plants. It is a variation of Systematic Layout Planning (SLP; Muther, 1973) and the method developed by Reed (1967). Relationship diagramming will be further studied and utilized in the thesis. The pairwise exchange method is based on the travel chart method developed by Reed (1967) and the CRAFT procedure (which is discussed in detail in this chapter). The graph-based construction method is purely based on graph theory. Graph theory methods are mathematical tools with conceptual similarities to the SLP method. The graph based construction method uses both planner and dual plane graphs to compare the layout alternatives.

3.2.4 TYPES OF LAYOUT PROBLEMS

Layout problems arise both in manufacturing facilities but also in service-based facilities. These problems may occur both in the case of design of new facilities and in the case of expansion or modification of existing facilities. In general, the layout problems can be classified into four major categories (Heragu, 1997):

- Service system layout problem
- Manufacturing layout problem
- Warehouse layout problem
- Nontraditional layout problem

"Service system layout problem" refers to layout problems in facilities like restaurants, offices, hospitals, airports, etc. For example, while designing an office space, the planner needs to consider issues like the available space, the location, the company's image, flexibility, etc. The general layout structures in service facility can be (a) closed structure, (b) semi-closed structure, (c) open structure and (d) semi-open structure.

"Manufacturing layout problem" refers to the design, expansion, and modification of manufacturing systems. The major concerns while designing manufacturing layouts are minimizing material handling costs and providing a safe environment for employees. A manufacturing facility, not only includes workstations and machines but also rest rooms, inspection stations, tool rooms, etc.

"Warehouse layout problem" refers to the requirement to use the available storage space effectively so as to minimize the cost involved in storage and material handling. The planner needs to consider factors like shape and size of warehouse, height, location, and orientation of the warehouse.

"Nontraditional layout problem" refers to those types of layout problems that have not been discussed above. For example the design of the layout for keys on the keyboard or the layout for the arrangement of CPU, keyboard, monitor, and mouse (and their wiring) in such a way that they utilize minimum space. These types of problems are termed as "nontraditional layout problems".

3.2.5 TYPES OF LAYOUTS

A facilities planner needs to decide the type of layout that best suits the product being manufactured. Described below are the major types of layouts (Palekar, 1998) and (Heragu, 1997).

Static/fixed layout: These are used when the product to be made is large and bulky. In such cases, the product is manufactured or assembled at a fixed location and machinery is moved around the product as needed. Examples: aircraft manufacture, ship building yards, etc.

Product or Production Line Layout: These are used when a single or a closely-related set of products are manufactured in high volume. Machines/workstations are arranged in a manufacturing/assembly line. The order of machines in the line follows the order in which processing is to be performed.

Group or Cellular Layout: These are used when a family of components is to be manufactured by a small manufacturing cell. In this arrangement, a cluster of machines forms a cell. Each cell has its own material handling system, typically a robot or a conveyor system.

Process Layout: These layouts group machines that perform similar activities into processing departments. Thus, in a plant with a process layout, there may be a turning department (all lathes), a milling department, a grinding department, etc. Process layouts are common in older plants and in job-shops.

Hybrid Layout: Not all the manufacturing facilities can adopt one of the layout types described above. Hence, they use a combination of the above layouts; such types of layouts are called as hybrid layouts.

3.2.6 TYPES OF FLOW PATTERNS

Depending upon the product being manufactured and the production process being used, a variety of flow patterns can be utilized in layout design. Product flow can be considered within workstations and departments and between departments, where individual/single stations are called as workstations and group pf workstations and called as a department. Described below are these product flow options (Tompkins et al., 1996):

Flow within workstations: can be established based on motion studies and ergonomic considerations. The flow within workstations should be simultaneous, symmetrical, natural, rhythmical, and habitual.

Flow within departments: depends on the type of departments involved. For example, in a product family department, the flow follows the product. Some of the major flow patterns followed are depicted in Figure 3.3. End-to-end, back-to-back, and odd angle flow patterns are used in product departments where one operator works at each workstation, whereas a front-to-front flow pattern is used when one operator works on two workstations, and a circular flow pattern is used when one operator works on two or more workstations. In a process department, little flow occurs between departments, it mainly occurs between aisles and workstations. Figure 3.4 illustrates the different flow patterns within process departments.

Flow between departments: is a factor that is used to assess the overall flow within the facility. Typically, the flow patterns consist of a combination of the few general flow patterns shown in Figure 3.5. Depending on the application and available space the machines may be placed in one of the patterns described:

- The straight line and L flow patterns are used when the production process is short and simple in nature and contains few or no common components or production equipment.

Flow Patterns

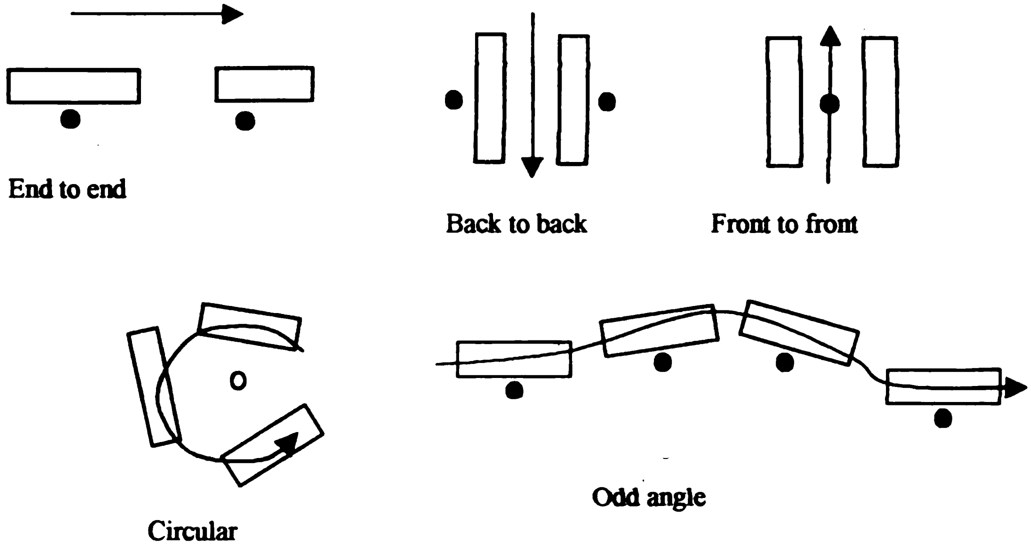


Figure 3.3 Flow within product departments
(Tompkins et al. 1996).

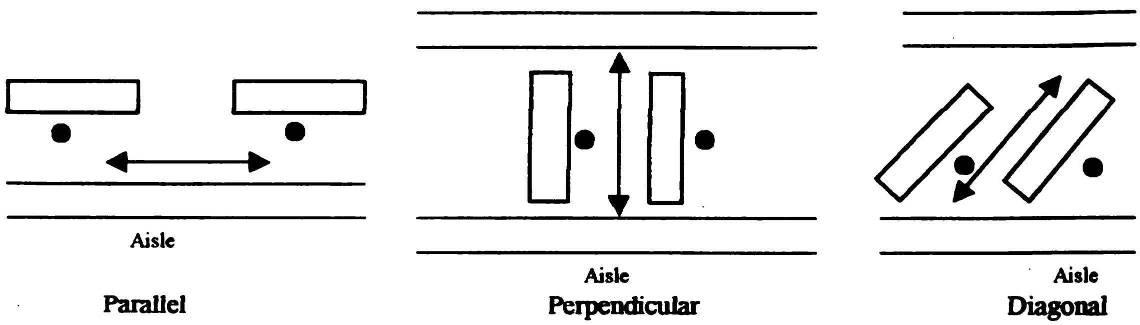


Figure 3.4: Flow within process departments
(Tompkins et al. 1996).

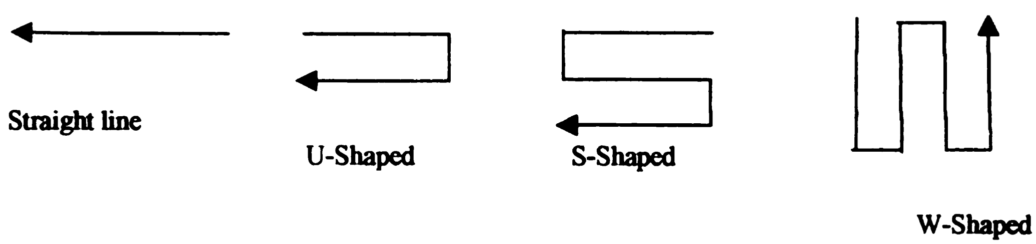


Figure 3.5: General flow patterns
(Tompkins et al., 1996).

- *The U flow pattern* is used when it is necessary to keep both receiving and shipping ends of the line at the same end of the plant. The pattern is also useful when there is a material-handling consideration or external-access consideration.
- *The O flow pattern* is used in machine cells that are serviced by a common material-handling robot.
- *Serpentine patterns* are used for long assembly processes that have to fit in a square area. Such layouts are also called S type layout pattern.

Straight-line flow and L-flow are the other most commonly used flow patterns.

Examples of flow within a facility based on entry and exit restrictions are shown in Figure 3.6.

Certain literature also discusses a combination-type flow pattern the *dendrite pattern* (Heragu, 1997). This pattern is suitable for assembly operations. In this pattern, the subassembly lines are arranged in such a way that they feed the main assembly line directly. In Figure 3.7, the vertical lines represent the subassembly lines and the horizontal lines represent the main assembly line. When the subassembly lines feed the main assembly line from both sides, the pattern is called as *spine arrangement*.

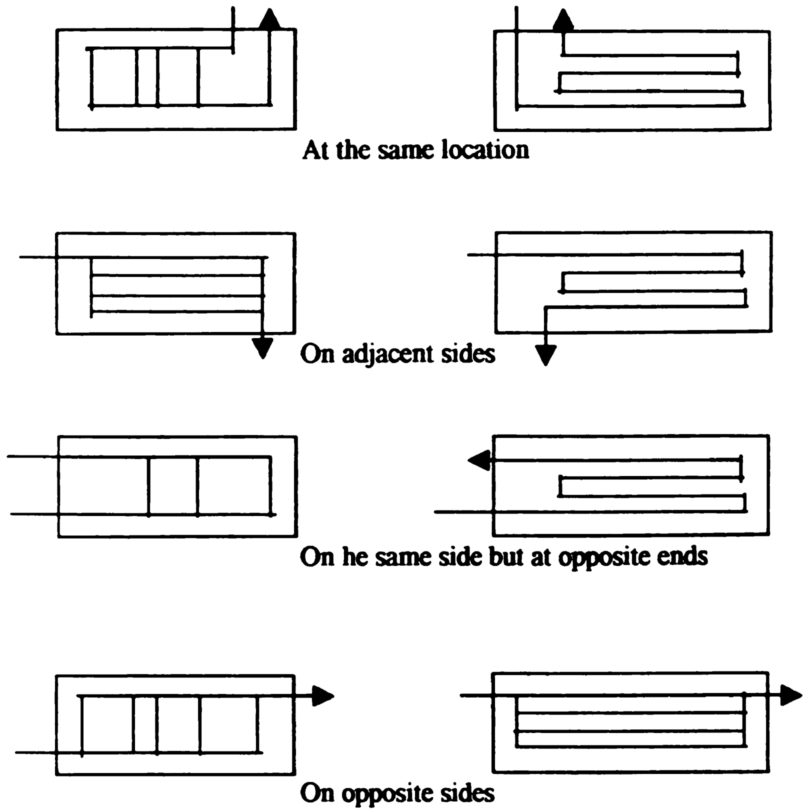


Figure 3.6: Flow within a facility considering the locations of the entrance and exit
(Tompkins et al., 1996)

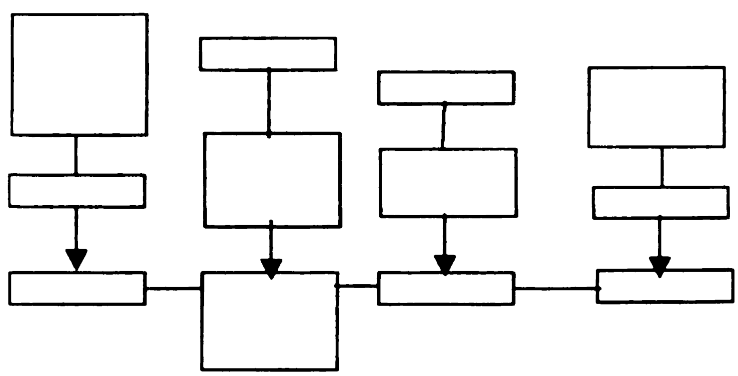


Figure 3.7: Dendeite flow pattern
(Heragu, 1997)

3.3 SPECIFIC TECHNIQUES

This part of the document focuses on the specific layout design techniques that will be utilized in this thesis. The author has made an attempt to provide examples whenever possible to make the text easy to follow for the readers.

3.3.1 SPACE REQUIREMENTS

The space requirements are one of the most difficult determinations in facilities planning. Tremendous uncertainty exists concerning the impact of technology, demand levels, product mix, etc. In manufacturing environments, space requirements should be determined first for individual workstations and then for department requirements must be determined (as each department is a collection of workstations) (Tompkins et al., 1996).

3.3.3.1 Workstation Specification

A workstation includes space for equipment, material and personnel (Tompkins et al. 1996).

- The equipment space for a workstation consists of space for the equipment, machine travel, maintenance, and plant services.
- The material area in a workstation covers receiving and storing material, in-process material, storing and shipping material, storing and shipping scrap and finally, tools, fixtures, jigs, and maintenance material
- The personnel area for a workstation includes space for the operators, material handling and operator ingress and egress

A facilities planner needs to take into consideration the above space requirements when designing a production plant.

3.3.1.2 Department Specifications

Once space requirements for the individual workstations have been identified, it is easy to determine the space requirements for each departments. It is the sum of the individual workstations involved in that department and the common department service requirements. The department service requirements include common tools, spare parts, housekeeping items, information-communication boards etc.

3.3.1.3 Aisle Arrangement

Aisles are provided within the facility to facilitate effective flow. Planning Too-narrow aisle may result in congested facilities, whereas aisles that are too wide, result in wasted space. Therefore aisle width should be designed considering the type and volume of flow to be handled. Table 3.1 shows the different aisle allowance estimates.

If the largest load is	Aisle allowance percentage is*
Less than 6 ft^2	5-10
Between 6 and 12 ft^2	10-20
Between 12 and 18 ft^2	20-30
Greater than 18ft^2	30-40

*Expressed as a percentage of the net area required for equipment, material, and personnel.

Table 3.1: Aisle allowance estimates
(Tompkins et al., 1996)

3.3.2 RELATIONSHIP CHARTS

Flow among the department is a major factor that influences the arrangement of departments within a facility. Flow can be specified in two ways (Tompkins et al., 1996):

Quantitative measure: Flow can be measured quantitatively, in terms of amount moved between departments. It includes pieces per hour, moves per day, etc. In facilities having large volumes of materials, information, or people moving between departments, this kind of measure is important.

The chart that is used to represent this type of measurement is a From-To chart.

Steps used to construct a From-To chart (Tompkins et al., 1996):

- Following the overall flow pattern, list all departments down the first row and across the top column.
- Establish a measure of flow for the facility that indicates equivalent flow volumes. If items vary in size, weight, value, etc., then items may be established so that the quantities recorded represent the appropriate relationships among the volume of movement.
- Based on the flow path for the items to be moved, establish the measure of flow volumes in the From-To charts.

Figure 3.8 shows a basic From-To chart depicting the major clusters in a manufactured housing production plant. The values represent the distance between the clusters.

	Receiving station	Floor stations	Walls stations	Roofing station	Exterior finishes stations	Interior finishes stations	Shipping station
Receiving station	-	5	8	12	15	17	20
Floor stations	5	-	3	7	10	12	15
Walls stations	8	3	-				
Roofing station							
Exterior finishes stations							
Interior finishes stations							
Shipping station							

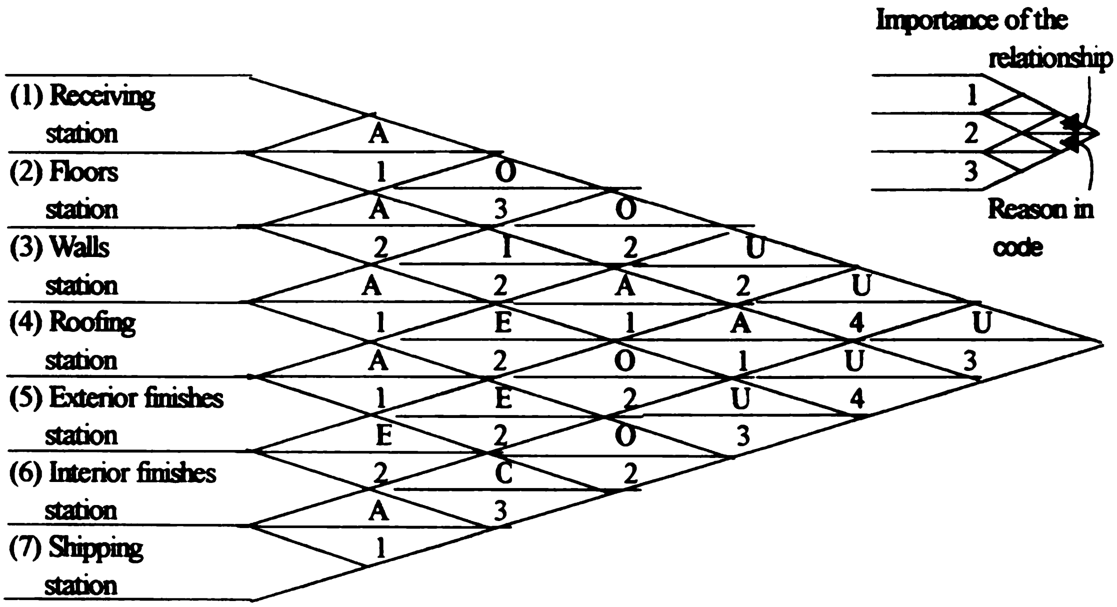
Figure 3.8: From-To Chart
(Modified from: Tompkins et al., 1996)

Qualitative measure: Space relationship between two departments may range from absolutely necessity that the two stations be close to each other to a preference that the two departments not be close to each other. In facilities having very little movement of material, information, or people, qualitative measure is the basis of arrangements of departments. A relationship chart is one of the common ways of presenting the qualitative measure of flow. It describes qualitatively the degree of closeness that should exist between various workstations (Sule, 1988).

Following are the steps used in creating a relationship chart (Tompkins et al., 1996):

- List all the station on the relationship chart.
- Conduct interviews and surveys with persons from each station listed and with the management responsible for all departments.
- Define the criteria for assigning closeness relationships and itemize and record criteria used as reasons for relationship values on the relationship chart.
- Establish relationship values and the reason for the values for all pairs of department.

- Allow everyone having input to the development of the relationship chart to have an opportunity to evaluate and discuss changes in the chart. Figure 3.9 shows a basic relationship chart presenting the different clusters in a manufactured housing production plant.



Value	Closeness
A	Abosolutely important
E	Espically important
I	Important
O	Ordinary closeness
U	Unimportant
X	undesirable

Closeness rating

Code	Reasons
1	High sequence
2	Medium proximity
3	Low proximity
4	Not related
5	Same equipment
6	Same labor

Reason behind closeness value

Figure 3.9: Relationship chart
(Tompkins et al., 1996)

3.4 TOOLS FOR DEVELOPING LAYOUTS

Several computer application-based tools can be used for the purpose of developing layout design. In this section, major attention has been focused on understanding computer based layout development tools. Though the computer based layout algorithm can significantly enhance the quality of the final layout by generating and numerically evaluating a number of layout alternatives, it cannot replace human judgment. However, computer based layouts are very effective in performing "what if" analyses. As most of the algorithms are an outgrowth of industry research, very few of the layout software programs have a commercial version available, though most of the layout-related software in the market is either useful as a presentation tools or as evaluation tools (Tompkins et al., 1996).

3.4.1 ALGORITHM CLASSIFICATION

The layout algorithms can be classified in a number of ways. An algorithm can be defined as a technique or procedure used to solve a problem, in this case a layout design problem. Based on Tompkins et al. (1996), a few of the major classifications are presented in this section.

3.4.1.1 Based on type of input data required:

Most layouts can be classified based on the type of data required. Some algorithms require qualitative flow data like relationship charts, while others work with quantitative flow matrixes expressed as From-To chart. Some algorithms, such as BLOCPLAN, accept both forms of data.

3.4.1.2 Based on the objective function:

Two major objectives by which algorithms can be classified are

(a) *Minimizing the sum of flows times distances* (also called a distance-based objective): this objective is applicable to data in the form of from-to charts. Consider the following example:

The objective is to minimize the cost per unit time for movement among the department. This objective can be mathematically expressed in the form of the following equation (Tompkins et al., 1996):

$$\text{Min } Z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij}\, c_{ij}\, d_{ij}$$

Where:

m = number of departments

f_{ij} = flow from dept i to dept j.

c_{ij} = cost of moving a unit load one distance unit from dept i to dept j.

d_{ij} = distance from dept i to dept j.

(b) *Maximizing the adjacency score*: this objective is applicable to data in the form of relationship charts. Consider the following example:

The objective of this adjacency score based example is to maximize the adjacency score. This objective can be mathematically expressed in the form of the following equation (Tompkins et al., 1996):

$$Max\ Z = \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij}\, x_{ij}$$

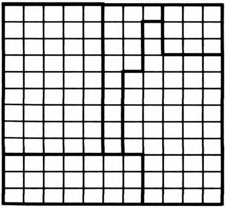
The adjacency score can be computed as the sum of all the flow values (or relationship values) between the departments that are adjacent in the layout.

$x_{ij} = 1$ if departments i and j are adjacent (share a border) in the layout. $x_{ij} = 0$ if the departments i and j are non-adjacent.

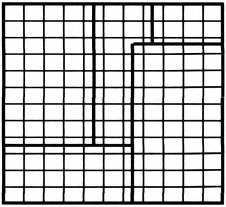
3.4.1.3 Based on format used for layout representation:

Most layout algorithms use discrete representations. In this form of representation, the computer stores and manipulates the layout as a matrix (Figure 3.10). The area of each department is rounded off to the nearest integer in the grids. The other form of representation is a continuous representation, where there is no underlying grid (Figure 3.11). Though this representation is theoretically more flexible, it is difficult to implement on the computer.

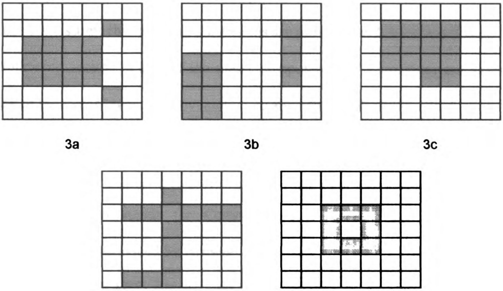
Department shapes play an important role in layout algorithms. A department represents the smallest indivisible entity in layout planning, and a layout algorithm must not split a department. If any department is too big in size, the planner should look at the how the department was defined and, if required, change one big department into two smaller ones. Consider the following examples (Figure 3.12) of discrete representation. Departments are considered adjacent if they share a border of positive length. Figures 3a and 3b are representations of split departments, whereas Figures 3c and 3d are examples of unsplit departments. For facilities layout purpose the layout in Figure 3e is considered not practical, as it has an enclosed void in the center of the layout.



3.10: Discrete representation
(Tompkins et al, 1996)



3.11: Continuous representation
(Tompkins et al, 1996)



3a 3b 3c

3d 3e

3.12: Split and unsplit departments
(Tompkins et al, 1996)

In cases where the planner wishes to create an irregularly shaped layout or has to incorporate non assembly line related objects like stairs, offices, or plant services, then he/she can create a dummy department.

3.4.1.4 Based on the primary function of the layout:

Finally, algorithms can be classified on the basis of the primary function of the algorithm, e.g. (a) layout-improvement type algorithm, and (b) layout-construction type algorithms.

An improvement-type algorithm starts with an initial layout, and improvement on the objective function through incremental changes. A construction type algorithm is developed from scratch. The construction-type algorithm can be further subdivided into algorithms that assume that building dimensions are provided and those that do not.

In the following section, a few of the major computer-based algorithms are described. First, few of the major layout-improvement type algorithms will be discussed.

3.4.2 CRAFT

CRAFT, which stands for Computerized Relative Allocation of Facilities Technique, was first introduced by Armour and Buffa in 1963 and by Buffa, Armour and Vollmann in 1964. CRAFT, which is an improvement-type algorithm, uses From-To charts as the input data for the measuring flow. CRAFT first calculates the rectilinear distance between pairs of department centroids on the initial layout and stores the value as a distance matrix. The initial layout cost is determined by multiplying each entry in the from-to chart with the corresponding entries in the unit cost matrix (e.g. c_{ij} values) and the distance matrix.

Then CRAFT considers all the possible two-way or three-way department exchanges and identifies the best exchange (the one with the least cost). After identifying of the best exchange, CRAFT updates the layout and computes new department centroids and the new layout cost, completing the first iteration. The next iteration starts by the identification of best exchanges in the updated layout. This process continues until no reduction in layout cost can be obtained. The final layout thus obtained is also called two-opt (three-opt) layout as no exchanges can further reduce the layout cost. Departments are not restricted to rectangular shapes. Sometimes this feature causes a layout that is not very practical in nature. Also it hampers the ability to have long and continuous aisles (Tompkins et al .,1996).

3.4.3 ALDEP and CORELAP

ALDEP and CORELAP are both construction-type algorithms. The form of data input is qualitative in nature and is given in the form of a relationship charts. Although these two algorithms are no longer supported commercially, they are important in understanding the evolution of computer-aided layout algorithms.

ALDEP, or Automated Layout Design Program, begins by selecting a department at random. It then continues by choosing a second department with an 'A' relationship with the department previously selected. It continues through all departments with ties being broken randomly. The idea is to progressively build around strong relationships.

The placement of departments begins by placing the first department in the upper left corner of a predefined border of the complete facility. The width of the downward extension is input by the designer and is called sweep width. Each of the following departments begins where the previous department ends, and the departments are arranged in a serpentine pattern. After the layouts are prepared, each of the layouts is evaluated. ALDEP rates by assigning values to the relationships among the adjacent departments. Each of the relationship codes (A, E, I, O, U, X) has a preassigned value. ALDEP produces many layouts, rates each one, and leaves the final selection of the layout to the designer (Tompkins et al., 1996).

CORELAP, which is also a construction-type algorithm, stands for COmputerized RElationship LAyout Planning. Like ALDEP, it uses qualitative data for construction of layouts. It constructs a layout by evaluating the total closeness rating (TCR) for each department. TCR is the sum of the values allocated using the relationship codes (A=6, E=5, I=4, O=3, U=2, X=1) between the departments. The department with the highest TCR rating is placed in the center of the layout. The department with the next highest TCR rating that has an A relationship with the first department is placed on the layout next. Once the final layout has been prepared CORELAP evaluates the layout by calculating the layout score which is the sum of the numerical closeness ratings over all departments multiplied by the length of the shortest path (Tompkins et al., 1996).

The basic procedural difference between ALDEP and CORELAP is that ALDEP breaks ties between departments randomly while CORELAP uses TCR, or Total

Closeness Rating. After the final CORELAP layout has been prepared, a score is found for that particular layout using the shortest rectilinear path between departments. One of the problems with CORELAP is that the shortest rectilinear path between departments may not always be a realistic measure (Tompkins et al., 1996).

3.4.4 BLOCPLAN

BLOCPLAN, which was developed by Donaghey and Pire, at the Industrial Engineering Department, University of Huston, accepts data input from both From-To charts and Relationship charts, i.e. both quantitative and qualitative data are accepted. It is a part of the MHAND package (Material Handling and Facility Location models). This algorithm can be used as both an improvement and construction type algorithm. The major purpose of BLOCPLAN is to generate and evaluate block type layouts in response to the user supplied data. BLOCPLAN also uses the relationship codes specified by Muther in Systematic Layout Planning (1973). BLOCPLAN provides an empty relationship chart and the user is prompted to furnish the codes for each of the department relationships. To prepare a layout, BLOCPLAN needs the number value of each of the relationship codes. Both user and program-specified values can be used. BLOCPLAN provides nine zones for locating departments. This feature can be used when the user has to fix certain departments, either due to entry/exit restrictions or due to preplanned positioning of departments.

To evaluate the rel-dist score, BLOCPLAN calculates the sums of the products of the distances between each pair of departments and the corresponding relationship score. The lower the rel-dist score, the better the layout. In the case of a distance-based objective/data from the From-To charts is used. The aim is to minimize the sum of the products of flow, cost and distance. Though it is difficult to capture the initial layout, BLOCPLAN helps in improving the initial layout (Donaghey, 2000)

3.4.5 AUTOCAD BASED DESIGN TOOLS

AutoCAD is a standard design and drafting package for the creation and manipulation of 2-D and 3-D line drawings and images. The factory products group at Engineering Animation, Inc. (EAI) developed software that simplifies designing a new factory or improving an existing one. The three programs FactoryCAD, FactoryPLAN, and FactoryFLOW run inside AutoCAD and allow for both qualitative and graphic analysis as well as provide valuable tools for creating a layout (Owen, 2002).

3.4.5.1 FactoryCAD

FactoryCAD is an AutoCAD-based tool used to develop new factory layouts and modify existing ones. It provides all the equipment objects such as racks, cranes, and conveyors, and design/construction-based elements such as walls, doors, windows, columns, workcenters, utility lines etc. It is a drafting tool that can be used to develop virtual model of the factory. FactoryCAD allows for automatic layering, automatic area and tool clearance hatching, and detailed reporting. FactoryCAD customizes AutoCAD to automate drawing plant layouts and reporting assets. FactoryCAD menus take the user, step-by-step, through the drawing process, from drawing double-line walls of any thickness and creating building grids, to locating individual electrical outlets and gas line valves (Owen, 2002).

3.4.5.2 FactoryPLAN

FactoryPLAN is software that can be used to develop the layout of the factory. It is a qualitative layout tool and uses the SLP-approach developed by Muther (1973). FactoryPLAN requires data input in the form of space requirements and activity relationships. The user can specify the individual department dimensions and the overall facility shape too. With this data FactoryPLAN creates, manipulates, and scores qualitative relationship diagrams. These diagrams can be used to prepare various layout alternatives, and, based on the user's requirements, the best layout can be chosen. FactoryPLAN can be used as either an improvement-type layout algorithm or a construction type layout algorithm (Owen, 2002).

3.4.5.3 FactoryFLOW

FactoryFLOW is neither a planning tool nor a drafting tool. It is a tool that can be used to analyze and evaluate a layout, that has already been created.

"FactoryFLOW integrates AutoCAD facility drawings with production routing and material handling data to compute material travel costs and distances and create product flow diagrams for graphical flow analysis" (Owen, 2002).

FactoryFLOW enables the user to examine the effects of changes in routing and handling methods, from simple changes in lot size to large-scale changes in layout. It helps improve throughput times and WIP levels by decreasing part-travel distance and the number of pick-ups and set-downs of the materials (Owen, 2002).

Each of these programs addresses individual issues related to layout design. With the help of these AutoCAD (FactoryCAD, FactoryPLAN, and FactoryFLOW) based tools, the user can completely develop and present a production plant layout.

3.5 TOOLS FOR PRESENTING LAYOUT DESIGNS

Once the data required for making layout decisions has been acquired, it is used to determine the positioning of different departments, stations, etc. and then to develop the layout design. Different tools, such as drawings, templates, three-dimensional physical models and CAD drawings, can be used to present layouts (Heragu, 1997).

- *Drawings:* Drawings have been one of the oldest means of presenting layout designs. They can be either drawn manually or can be CAD-drawings.
- *Templates:* Templates by definition are a documents or files having a preset format, which is used as a starting point for a particular application so that the format does not have to be recreated each time it is used. Commercial templates of machines can also be used to create layouts.
- *3D Models:* 3D models give a better visual perspective of drawings and templates. They help analysts in deciding the probable path for material handling using big equipment.
- *CAD Tools:* Computer-aided tools are the most effective tools for both preparation and presentation of layout design. CAD Tools are easy and efficient to use and can create both two and three-dimensional drawings. It is also convenient to edit/change or generate new layouts using CAD tools.

3.6 SUMMARY

In this chapter, the author has made an effort to present major techniques and tools used for manufacturing facilities planning, design, development and presentation. The traditional approaches that have been used to develop the current layout techniques and tools have also been discussed. The specific techniques, which will be used in this thesis, were discussed. Finally, the possible specific layout design tools that will be used for the purpose of this research were described.

CHAPTER FOUR

MANUFACTURED HOUSING

PROUDCTION PROCESS AND PLANT LAYOUT DESIGN

4.1 INTRODUCTION

In Chapter 3, major techniques and tools used for facilities planning and design were discussed. Also, the specific techniques that will be used for space and proximity data collection in this study were described. This chapter attempts to document the manufactured housing production process and present the data collected from the two factories in Northern Indiana. Then, appropriate layout design software programs will be explained in detail. The space and proximity related data collected from the two factories will then be input in the software program selected (FactoryPLAN), and the different layout alternatives will be generated. Finally, these layout alternatives will be evaluated on the basis of effectiveness scores obtained.

4.2 MANUFACTURED HOUSING PRODUCTION PROCESS

In order to understand the production process, one needs to understand the product that is to be manufactured. The manufactured home, as described in Chapter Two, is a home on a permanent chassis built in a controlled factory environment and is designed to be used with or without a permanent foundation. Depending upon the requirements of the homebuyer, the manufacturer can provide either a single-section or a multi-section manufactured house.

Two manufactured housing production plants were studied in order to better understand the general production process of a manufactured home. To maintain the privacy of these establishments, their names will not be mentioned in this thesis. After visiting the production managers, and referring to existing research work in this area, the author has developed generic production process details. These details are described below.

4.2.1 STATION CLASSIFICATION

The assembly line in a manufactured housing production plant consists of many different types of stations. Not all the stations on or beside the assembly line in a production plant are of one standard or particular type. The stations can be classified into main assembly stations, sub-assembly stations, feeder stations, and internal and external storage areas, based on the type of activity taking place at that station/area.

Main assembly stations are the major stations (sometimes referred to as primary stations) on the assembly line, and the location where sub-assemblies (components) are installed. The roofing station, for example, is a main assembly station where the roof truss from a roofing sub-assembly station is installed over the home.

Sub-assembly stations are secondary stations that fabricate sub-assembly components for installation at main assembly stations. For example, interior and exterior walls are first assembled at a sub-assembly station, and then they are installed at the walls' main stations.

Feeder stations are stations that provide individual components to the main assembly stations, i.e., the raw material stored at the feeder station itself is installed directly. For example, kitchen appliances are stored beside the assembly line near the interior finishes and cleanup main assembly stations, and the appliances are supplied directly to the interior finishes main activity stations, as and when needed.

Internal or external storage areas are provided, depending upon the inventory maintained for different kinds of material, weather conditions, the bulk/size of the material, and the cost of the material. Some of the materials that are stored externally are chassis, roof shingles, and trusses; whereas material like drywall boards, foam, and carpets are stored internally.

A greater number of sub-assembly/feeder stations are desirable as they not only reduce the overall processing time of the product, but they also reduce the number of operations taking place at main assembly station. Several manufacturers purchase sub-assemblies from suppliers for certain elements and feed them directly to either the sub-assembly or the main assembly line. An efficient assembly line usually has tasks broken down and divided in such a way that they are carried out with the minimum possible idle time on main stations (Bernkardt, 1980).

4.2.2 ASSEMBLY CLUSTERS/PRODUCTION PROCESS DETAILS

The production process of a manufactured home consists of step-by-step and methodical practices of interrelated tasks that are carefully coordinated so as to produce a home. The activities on an assembly line are well planned to ensure continuous production.

The different activities on the assembly line can be grouped into clusters/departments depending upon the element that is being built. The major clusters in a manufactured housing production plant are:

- The floor cluster
- The walls cluster
- The roof cluster
- The exterior finishes cluster
- The interior finishes cluster (Senghore, 2002)

4.2.2.1 THE FLOOR CLUSTER

The production process begins with the chassis, or the structural frame on which the house is built, being pulled from the external storage area into the factory. The floor joists are fabricated based on the structural requirements at a sub-assembly station. Rigid insulation is then installed. Openings are provided in the floor joists to accommodate the ductwork (HVAC) and piping (plumbing) requirements. This floor sub-assembly is then placed over the chassis and glued and nailed in place. The chassis then moves to the next station. The chassis enters the plant on wheels (tires). These chassis are generally either (a) moved on inflated base plates or (b) moved longitudinally on tires and laterally on movable metal tracks with track wheels perpendicular to the direction of the chassis wheels.

At station two, the floor joist is covered with decking. Decking is usually in the form of 5/8" floorboard. It is glued and nailed in place. The size of these main activity stations is governed by the size of the home being manufactured. The station width, in many plants, is designed for the width of a single-section home. If a double-section home is being manufactured, then two individual single-sections are prepared, one after the other.

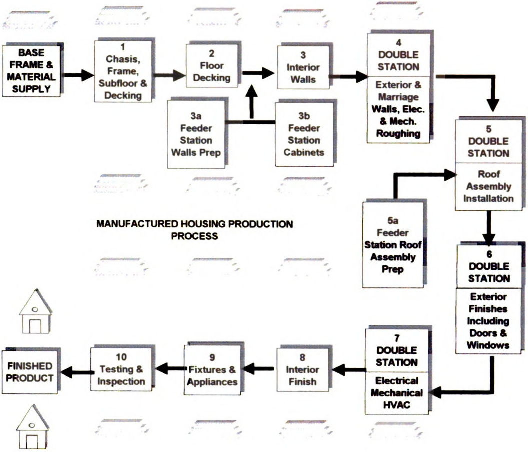


Figure 4.1: Manufactured Housing Production Process
(Senghore, 2001)

4.2.2.2 THE WALLS CLUSTER

The chassis then moves to station three, where wet and dry (kitchen and toilet) areas are demarcated. Vinyl sheet rolls are suspended from a metal roll and vinyl pieces of the correct size are cut and installed in wet areas. The interior walls/partitions are placed next. The walls are usually fabricated at a sub-assembly station and then installed in place, on the main assembly station, using a crane. The sub-assembly also takes place in several steps. First, based on the spacing of the studs provided on the floor plans, the studs are pasted and screwed to the drywall boards. Then, depending upon whether or not the walls are to be painted, the major activity at the next sub-assembly station is spraying paint and drying. Depending on schedule specification, the interior walls are ready for installation by the time the chassis leaves the floor cluster. The heavy cabinetry in the kitchen and other big bathroom fixtures, like sink tops and shower compartments, are also installed at the interior walls main assembly station. Based on the floor plans of the home being manufactured, the cabinets are generally prefabricated and ready for installation. The bathroom fixtures are placed at a feeder station near this main assembly station.

The home then moves to station four, where the exterior walls are installed. Partly fabricated exterior walls are put in place on the main assembly station. Rigid insulation is then installed, and the walls are covered with exterior wallboard at the main assembly station. Rough electrical and plumbing work is also done at this station. In some plants, both interior walls and exterior walls stations have two main assembly stations. In this system the major activities are divided into two.

Until this point the home usually moves longitudinally, but as it enters the roofing cluster, the home is moved laterally. One of the reasons for the change in direction is because of the roofing cluster activities, which in the case of double section homes require both the single sections to be joined together. Additionally the shape of the production area is usually rectangular, and the width of the rectangular space is usually utilized by the previous stations (Figure 4.2).

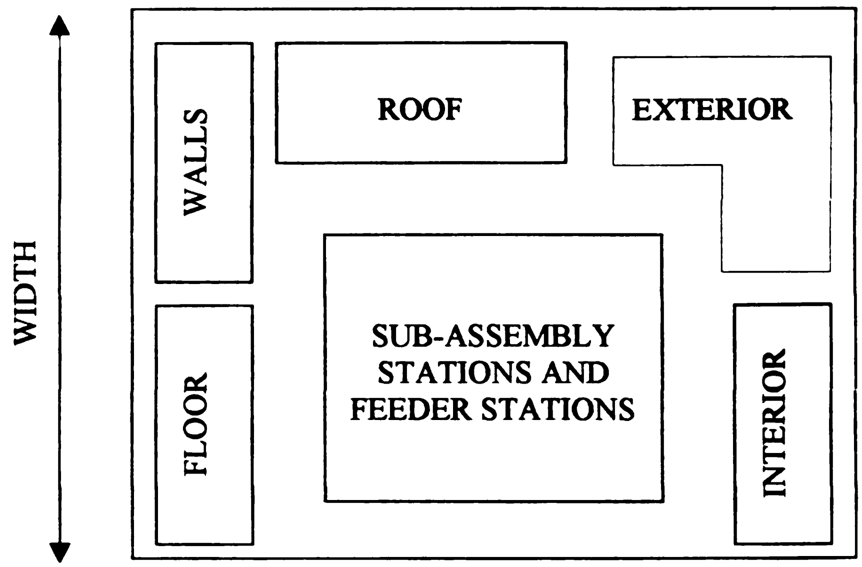


Figure 4.2: Typical Production Plant Layout

4.2.2.2 THE ROOF CLUSTER

In most production plants, the fabrication of roof trusses is sub-contracted and trusses are supplied from a loading dock near the roof assembly station. The roof is then fabricated using these trusses and other raw material at the roof sub-assembly station. First, the individual trusses are positioned correctly based on the spacing specified in the plans, and then the ceiling board is glued at the base of the assembled truss. At the next sub-assembly station, the truss is filled with both rigid and loose insulation, and finally the ceiling boards are taped together and paint is sprayed on them. By the time the home comes to the roof installation station, the roof is dry and ready to be installed. It is then hoisted by a crane and moved from the roof sub-assembly station to main assembly station number five and installed over the home. In the case of a double-section home the two units are joined before installation. The insulation activity in some plants is also carried out at the main assembly station. The next step involves the installation of roof sheathing (Oriented Strand Board). The boards are nailed in place. Installation of shingles is the next major activity in the roof section. Once the shingles are installed, the home is ready to move to the exterior finishes section.

4.2.2.4 THE EXTERIOR FINISHES CLUSTER

Some of the exterior finishes activities are carried out simultaneously with the roofing activities. The first major activity at station six is to cut out the exterior wallboard for the installation of doors and windows. Doors and windows are supplied from a feeder station, and the installation of doors and windows involves checking the spacing, installing of the frame, and finally installing of the door and window units as specified in the drawings. Finally, the exterior sidings, exterior lamps, and doorbell are installed.

4.2.2.5 THE INTERIOR FINISHES CLUSTER

By the time the home comes to the interior finishes cluster the two sections of the double-section home have been separated again. The interior finishes and final cleanup activities are the last set of activities taking place on the assembly line. This section also involves testing and inspection activities. The final electrical, plumbing, HVAC, and mechanical work are carried out at station seven. The installation of foam and carpet happens next. These activities happen at station eight. The toilet is also installed at this station. The heavy kitchen appliances like the refrigerator and cooking range are placed at station nine. The home is vacuumed and all cabinets are cleaned. Finally, the material to be installed in the home after installation on the site is placed inside the home. All final testing takes place at this station also. Additional axles and tires are installed for transportation purposes. At station ten, the home is then covered with white plastic sheets and is pulled out of the plant. It is now ready for delivery.

The production process described above is a typical production process. Different manufacturers may have similar process details but more or fewer main assembly stations or sub-assembly stations, on their production line.

4.3 DATA COLLECTION FOR SPACE REQUIREMENTS AND RELATIONSHIP CHARTS

After understanding the complete production process of a manufactured home, the author worked on developing data collection formats for space and relationship charts. The data was collected from two manufactured housing production establishments. To maintain the privacy of these establishments, they will be referred to as Production Plant A and Production Plant B in this research work. As explained in chapter three, in order to prepare design layout alternatives, data related to space and proximity requirements (i.e. relationship charts) is needed. Data was collected under the following two categories namely:

- Space Requirements
- Activity Relationship Charts

4.3.1 SPACE REQUIREMENTS

From the different methods available for data organization, the author decided to use the table format to order the space requirement data from the two production plants. In order to have accurate data, the table included specific assembly stations, sub-assembly stations, feeder stations, and storage areas for each cluster and related space areas. Details associated with the type of material (stored, subassembled or installed) and area specifications were also collected. Table 4.1 shows a space requirement table for station six in Production Plant A. The space requirements are shown for the roof installations cluster. The table includes the cluster name, such as floor, walls, roof, and interior finishes; a description of type of station such as main assembly station, sub-assembly station, feeder station and storage areas; station area; the major activities taking place at the station (set roof truss, install insulation); source of supply of raw material (ceiling board feeder station, paint feeder station); and finally space requirements. The space requirement tables for all the other stations are available in Appendix A. Similar space requirements were collected from Production Plant B and are also provided in Appendix A.

Table 4.1: Space Requirements station No: 6

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Roof	Installation of roof	Main assembly station	2400			
		Sub-assembly station	1600	set roof truss based on spacing	Trusses	External storage
		Sub-assembly station	1600	glue & nail the ceiling brds	ceiling boards	ceiling board feeder station
		Sub-assembly station	1600	spray paint the ceiling & drying & loose insulation	Roof sub-assembly station	

4.3.2. RELATIONSHIP CHARTS DEVELOPMENT

The data collected for the relationship charts is a qualitative measure, and therefore it is different from a quantitative space requirements measure. The relationship chart development included a series of steps. These steps are described below:

- The process began with the development of an empty relationship chart. Based on the production process information and the station description, all the stations were positioned in the top row and left column. Each of the stations was represented with either numerically or alphabetically (Table 4.2).

- This empty relationship chart was then filled based on the production process information. Each station in the relationship chart is either related or unrelated to every other station. Based on the relationship between each station pair, different closeness ratings were assigned. This rating could be due to one station being a direct source of raw material or sub assembled component supply or due to stations sharing common material, labor, tools, or equipment. The closeness ratings assigned are based the Systematic Layout Planning technique developed by Muther (1973) and are shown in Table 4.3

- Criteria were defined and the closeness ratings were assigned based on the criteria. Example: An A relationship (Absolutely necessary closeness rating) between stations was assigned when the stations had a direct high proximity (criterion). This criterion is shown in table 4.4. A closeness rating and a reason were established for each pair of stations in the relationship chart.

- Once this chart had been developed, it was discussed with two production managers at each plant. Their input was established in the form of suggestions for change of relationships.

- If a production manager disagreed with any of the relationships shown on the chart, based on his/her experience, the author requested him/her to highlight it and provided an empty relationship chart for the manager to use to fill in the changes. Table 4.6 shows the relationship chart developed for production plant A.

Table 4.2: Description of all main assembly, sub-assembly and feeder stations

No./Ab.	Description of Stations
	I-Main assembly stations
1	Chassis on wheel and axle pulled into the factory.
2	Place assembled floor frame with insulation, ductwork and wiring over the chassis
3	Placement of interior walls (studs with panel on one side only),
4	Placement of cabinets, toilet compartment, bathtub, kitchen sink.
5	Placement of exterior walls
6	Rough electrical and mechanical, and final exterior walls installation
7	Installation of all electrical and mechanical equipment
8	Roof installation
9	Installation of shingles on the roof and cut outs for doors and windows
10	Exterior wall finishes and installation of side shingles. Installation of door& windows, and trim
11	Begin interior finishes- install foam for carpeting, complete interior drywall finish
12	Install carpet, final electrical and plumbing finishes, install marriage walls.
13	Interior Finishing and cleanup, placement of material to be installed at site
	II-Sub-assembly stations
A	Fabrication and storage of ductwork and plumbing, and placement of tires.
B	Assemble floor frame- place black sheet, place insulation, place floor joist, place wire and duct work, staple black sheet to the floor joist
C	Sub-assembly of interior walls
D	Assembly of cabinets, kitchen, and toilet sinks
E	Sub-assembly station for roofing main activity stations.
F	Fabrication of roof truss, installation of ceiling board, painting, drying and finishing
G	Installation of loose and rigid insulation
	III-Feeder stations
a	Storage of ductwork and plumbing pipes
b	Storage of cabinets
c	Storage of drywall panels
d	Storage of drywall, doors and windows, and sheathing.
e	Storage of roof shingles
F	Storage of foam and carpet and drywall (marriage)
g	Storage of wall boards and tools
h	Storage of mirror, and appliances.
I	Storage of drapes and appliances.
J	Storage of toilets and materials to be shipped to the site for onsite installation
k	Storage of drywall panels and wooden members for roof frame fabrication

Table 4.3: Closeness ratings

Value	Closeness
A	Absolutely important
E	Especially important
I	Important
O	Ordinary closeness
U	Unimportant
X	Undesirable

Table 4.4: Reason/criterion behind closeness value

Code	Reasons
1	High proximity
2	Medium proximity
3	Low proximity
4	Unrelated

The approach used to develop the relationship chart is described below:

1. All the stations having a direct relationship between each other have been assigned an "A" relationship. This covers the relationship between sub-assembly stations/feeder stations directly feeding the main assembly stations.

2. All stations which are not related, have been assigned "U" (unimportant relationship) and are represented in normal non-bold font.

3. All other relationships assigned in this study between stations are either an "I" (Important) or "E" (Especially important). These relationships are assigned due to the reasons shown in Table 4.5.

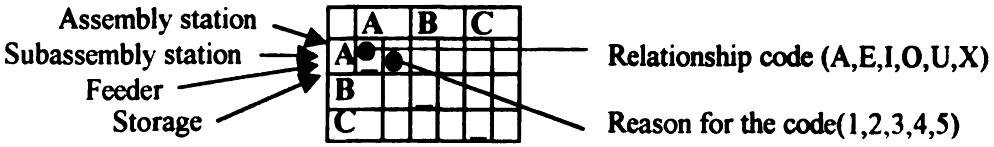
Table 4.5: Reasons for assigning E or I relationship between stations

	Stations having I or E relationship	Reason for relation between stations
1	1 & 6	Assuming that all electrical installation and plumbing works are related
2	2 & 5	Assuming that all insulation work happen together
3	2 & 8	Assuming that all insulation work happen together
4	4 & 6	Assuming that walls need to be aligned with each other
5	5 & 7	Assuming that all electrical installation and plumbing works are related
6	6 & 9	Direct sequential order will help to avoid rework. (Alignment between exterior walls and doors & windows)
7	6 & 11	Direct sequential order will help to avoid rework. (Alignment between marriage walls and exterior walls)
8	7 & 11	Assuming that all electrical installation and plumbing works are related
9	11 & F	Assuming that all drywall paint related actual work and rework takes place together
10	11 & g	In case any wallboard repair has to be done it is identified at the interior finish station

In production plant A, neither production manager X nor production manager Y disagreed with any relationships. Similarly, in production plant B, both the production managers agreed with the closeness ratings provided between the stations. Once the final relationship chart for each production plant was developed, it was used to prepare layout alternatives.

	1	2	3	4	5	6	7	8	9	10	11	12	13	A	B	C	D	E	F	a	b	c	d	e	f	g	h	I	j	k
1	\ \	A1	U4	U4	I2	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4
2		\ \	A1	U4	I2	U4	U4	I2	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4
3			\ \	A1	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	A1	A1	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	U4	U4
4				\ \	A1	E3	U4	U4	U4	U4	U4	U4	U4	U4	A1	A1	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	U4	U4
5					\ \	A1	I2	U4	U4	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	U4	U4
6						\ \	A1	U4	I2	U4	I2	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	U4	U4
7							\ \	A1	U4	U4	I2	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4
8								\ \	U4	A1	U4	U4	U4	U4	U4	U4	I2	E2	A1	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4
9									\ \	A1	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	U4
10										\ \	A1	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4
11											\ \	A1	U4	U4	I2	U4	U4	U4	U4	U4	U4	U4	U4	U4	A1	I2	A1	A1	U4	U4
12												\ \	A1	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4
13													\ \	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	A1	U4
A														\ \	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4
B															\ \	U4	U4	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	U4	U4
C																\ \	U4	U4	U4	U4	A1	U4	U4	U4	U4	U4	U4	U4	U4	U4
D																	\ \	A1	E2	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	I2
E																		\ \	A1	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4
F																			\ \	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4
a																				\ \	U4	U4	U4	U4	U4	U4	U4	U4	U4	U4
b																					\ \	U4	U4	U4	U4	U4	U4	U4	U4	U4
c																						\ \	U4	U4	U4	U4	U4	U4	U4	U4
d																							\ \	U4	U4	U4	U4	U4	U4	U4
e																								\ \	U4	U4	U4	U4	U4	U4
f																									\ \	U4	U4	U4	U4	U4
g																										\ \	U4	U4	U4	U4
h																											\ \	U4	U4	U4
I																												\ \	U4	U4
j																													\ \	U4
k																														\ \

Table 4.6: Relationship chart for production process of a producion plant A.



4.5 PLANT LAYOUT DESIGN WITH AVAILABLE SOFTWARE

After space and proximity related data was collected, there was a need to search for available software programs for preparing the layout alternatives. Upon reviewing different options available for plant layout design, the author narrowed down the scope of the search to two major plant layout design software: BLOCPLAN and FactoryPLAN. In the following section, each of these software programs is described with the help of an example. FactoryPLAN was eventually chosen to develop layout options for this research work. The data collected, including the space requirements and the relationship charts for production plant A, were input into FactoryPLAN.

4.5.1 BLOCPLAN (Donaghey, 2000)

As described in Chapter Three, BLOCPLAN was developed by Donaghey and Pire, at the Industrial Engineering Department, University of Houston. Their algorithm can be used for both the improvement of an existing layout and the construction of new layout. The major purpose of BLOCPLAN is to generate and evaluate block-type layouts in response to user supplied data. Described below is the step-by-step procedure used by this program to generate a layout. (For the convenience of the reader, an example has been used to explain this procedure better. Data collected in the previous section cannot be used, due to certain limitations of the software.)

4.5.1.1 INTRODUCTION

BLOCPLAN can be used in both DOS format and in Windows format. The program is installed under the name MHAND (Material Handling and Facility Location models), of which BLOCPLAN is a part. After activating the program, the user is prompted to enter data.

4.5.1.2 DATA INPUT

Data of space requirement and relationship chart related data could either be supplied from the disk (enter D) or the keyboard (enter K). The input from the disk refers to problems already created and saved in BLOCPLAN. Data can also be entered directly using the keyboard (in the case of new plant layout development). Once the method of data entry has been specified, the program prompts the user to supply Department names and areas.

4.5.1.3 DEPARTMENT NAMES AND AREAS

A maximum of 18 stations can be specified for a single story layout problem. The user can change this information as and when required. Due to limitations like restricted number of stations, real time data could not be used, therefore, an example problem is presented for better understanding. Figure 4.3 presents the list of departments and their respective areas entered for the example problem.

Figure 4.3: List of department and respective areas in BLOCPLAN

4.5.1.4 RELATIONSHIP DATA

BLOCPLAN uses relationship codes specified by Muther (Muther, 1961) in Systematic Layout Planning for relationship chart development. The user is provided with an empty relationship chart in order to enter the relationships between the departments (previously specified). The bottom of the screen displays the relationship codes (A, E, I, O, U) for user convenience. Figure 4.4 presents the relationship chart developed for the example problem.

Figure 4.4: Relationship Chart in BLOCPLAN

4.5.1.5 RELATIONSHIP CODES VALUE

Each of the relationship codes used in BLOCPLAN has a default value. The user can change these codes based on the specific production process details. The default score for each of the codes is presented in Table 4.7. These scores were used for development of layouts.

Table 4.7: Default score for the relationship codes

CODE	SCORES
A	10
E	5
I	2
O	1
U	0
X	-10

Based on the scores assigned, BLOCPLAN sums all the scores for each of the individual departments and computes individual department scores. The department scores for the example problem are presented in Figure 4.5.

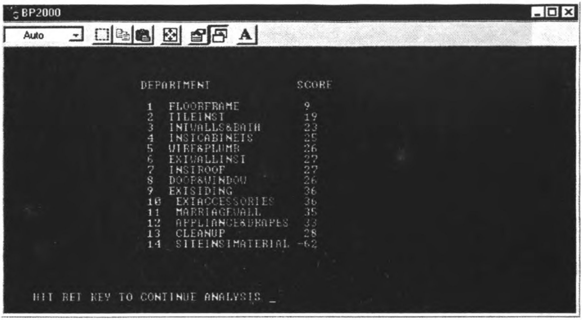


Figure 4.5: Department Scores

The user is then prompted to specify the Length/Width ratio of the facility. This length and width ratio is applicable to the complete facility itself and not to any particular department. The user can specify one of the Length/Width ratios suggested in Figure 4.6. In case the user wants to use a Length/Width ratio other than that shown in the figure, then option 5 can be chosen, and the ratio can be entered manually.

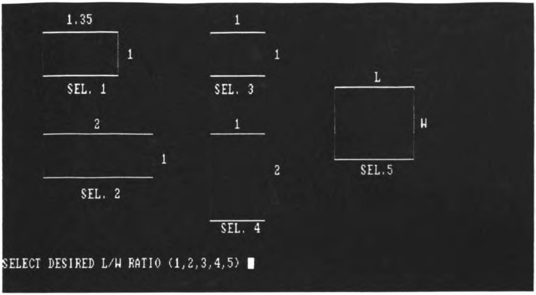


Figure 4.6: Length/Width Ratio

BLOCPLAN allows the user to include specific product flow information, based on the different types of products being manufactured. This information can be supplied by furnishing a list of products and the departments that they will enter during the manufacturing process. A maximum of 13 products can be specified. Though a manufactured housing production plant produces both single-section homes and multi-section homes, the method/process of manufacturing is same, i.e. during the production of either size of manufactured homes, both types of homes use the same stations. No separate product information needs to be specified. At this point, the user is directed to the BLOCPLAN main menu, which has six major options. Figure 4.7 shows these options. Since the manufactured housing production plant layout design problem is a single story layout problem, option 3 is selected. The single-story layout menu is further divided into seven major sections (Figure 4.8). Each of these sections is explained below.

- *Manually insert departments:* BLOCPLAN provides the user with nine zones (each zone, again divided into left and right side) in which to manually insert departments. These zones are designated from A to I and are arranged in three tiers in three zones. The overall layout for manual insertion depends on the Length/Width ration previously specified. This option can be used for fixing departments either due to entry/exit limitations or due to other structural reasons.
- *Random layout:* This option provides a layout based on the department numbers and areas, irrespective of the relationship or product information provided. Based on the layout generated, a layout score is provided. This score can be computed by obtaining the adjacency relationships and scores and calculating their total value. It is then divided by the sum of the positive relationship scores, of individual stations.
- *Improvement algorithm:* This algorithm operates on a layout that has been previously saved. It interchanges each pair of departments in the layout, and scores the layout, and then displays it.
- *Automatic search:* This option starts with an initial random seed layout and operates on the layout until it is unable to improve it any further. This new improved layout then becomes the seed layout and attempts are made to improve upon it by using the pair-wise interchange method. This procedure continues until no more improvements can be made. The resulting layout can be saved for future reference.
- *Review saved layouts:* Layouts that have been previously saved can be reviewed by using this option.

- *Table of saved layouts:* This option creates a table of scores of all of the layouts that are currently saved.
- *Main menu:* This option directs the user to the main menu (shown in Figure 4.7).

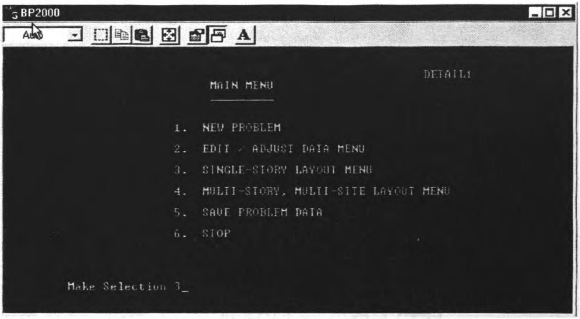


Figure 4.7: BLOCPLAN main menu

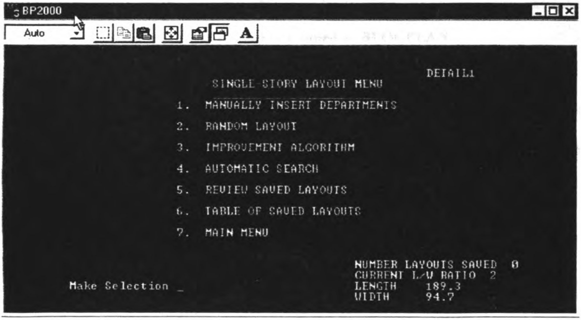


Figure 4.8: BLOCPLAN single story layout menu

One of the layouts generated from the example data using the automatic search option in the single story layout menu is presented in Figure 4.9. The layout score is 0.70, with 1 being the best possible score.

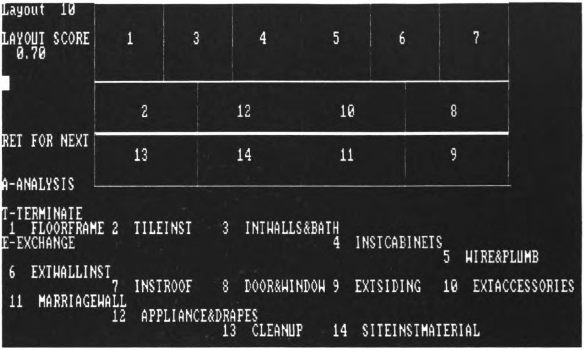


Figure 4.9: Layout developed in BLOCPLAN

4.5.1.6 SUMMARY OF BLOCPLAN

BLOCPLAN is a layout development tool that can be used for simple layout design problems. It has limited effectiveness due to certain limitations, such as the ability to input only limited number of departments and an inability to accept Length/Width ratios for individual departments.

The following section describes another layout design software program available, FactoryPLAN. This software was finally chosen for the purpose of layout design of a manufactured housing production plant.

4.5.2 FACTORYPLAN (EAI, 1999)

As described in chapter 3, FactoryPLAN is an AutoCAD-based tool used for design and analysis of plant layouts. The design group at Engineering Animation Inc. (EAI) has developed this tool. It is a qualitative layout design tool, which, like BLOCPLAN, uses Muther's Systematic Layout Planning for the design process. In the following section, the author documents the methods of this program using data gathered from Production Plant A as a basis for developing Manufactured Housing Production Plant layout alternatives.

4.5.2.1 INTRODUCTION

FactoryPLAN, an AutoCAD-based tool, enables the user to organize the proximity and flow relationships that should be considered when designing a plant layout. Once FactoryPLAN has been loaded in AutoCAD, the user needs to specify the factory drawing parameters (just like specifying parameters for any AutoCAD drawing). Figure 4.10 shows the window that appears for setting these parameters. The user should define the Drawing units and limits (lower left and upper right corners). FactoryPLAN uses the default settings for layer and line type settings.

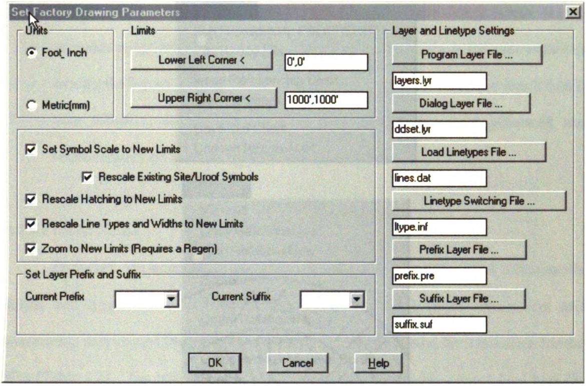


Figure 4.10: Drawing Parameters in FactoryPLAN

Once the user sets the drawing parameters, the main drop down menu bar (Figure 4.11) changes from

To

Figure 4.11: Main menu bar

The major FactoryPLAN functions that are added to the already existing AutoCAD menu bar are:

- *Charts/Data:* Commands on the Chart/Data Menu allow the user to create and manipulate data files and relationship charts (Figure 4.12).

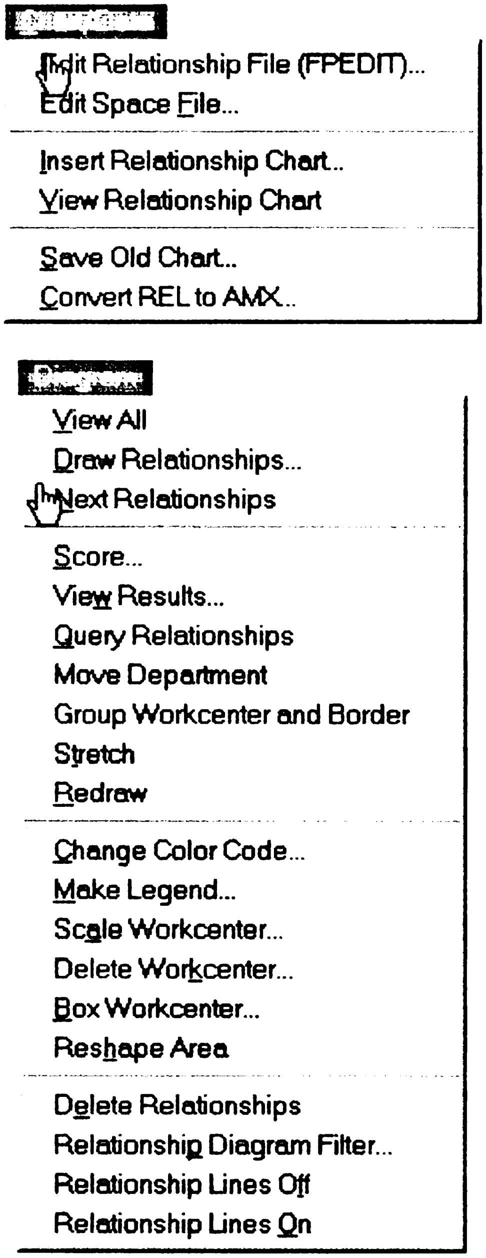


Figure 4.12:Charts/Data and Diagram from the main menu bar

- *Diagram:* Commands on the Diagram Menu manipulate and score a relationship diagram based on the information obtained from the data located in the relationship charts (Figure 4.12).

- *Optimize:* By using this option, FactoryPLAN generates a design layout. It then proceeds to optimize this layout based on the number of times the user wishes to modify the layout. Though this option seems very useful, the author didn't find it very effective, as when optimize is used, a new layout is generated and improvements on an existing layout cannot be performed.

4.5.2.2 DATA FILES

FactoryPLAN stores space and proximity-related information under different file names and types, therefore, the user needs to specify the space requirement and relationship data-related file. FactoryPLAN will provide with valid file extensions for the files (Table 4.8). The user can create new space and relationship related files here (in case these files have not been created).

Table 4.8: FactoryPLAN data file

(EAI 1999)

Nos.	File	Activity
1	**Relationship/ AMX**	File containing a list of activities and their relationships to other activities. Three types of relationships can be specified: • Proximity (closeness-desired) AEIOUXZ • Flow • Aggregate of proximity and flow
2	**Space**	File containing a list of activity names, their size requirement and their height/width ratios
3	**Space Standards**	File containing a list of space types and each type's layer and color
4	**Reason Codes**	File containing a list of reason codes, which can be used to describe the reason for assigning a proximity relationship

After clicking on the "Edit Relationship File (FPEDIT)" command under the Charts/data tab in the dropdown menu bar, the user can specify the file names and the location where these files are stored. Figure 4.13 shows the data files window. FactoryPLAN provides the user with standard space and reason code files.

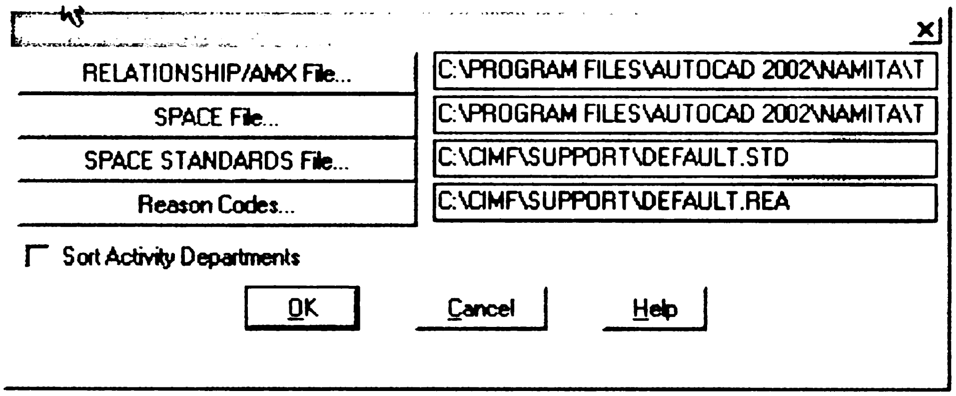


Figure 4.13: FactoryPLAN Data Files

FactoryPLAN prepares and analyzes layouts in the following three steps:

- Enter activity name and space data.
- Enter relationship data.
- Generate and manipulate the layout.

4.5.2.2 ACTIVITY/DEPARTMENT LIST AND SPACE INFORMATION

After specifying the file names and location of storage, the next step is to enter the activity stations. The activity stations/department list dialogue box appears immediately after the FactoryPLAN data files have been specified. As the author is preparing a layout for a manufactured housing production plant, the dialogue boxes/windows shown below display the activity stations for production plant A. Figure 4.14 shows the dialogue box where the abbreviations for the names of the stations (main activity, sub-assembly and feeder stations/storage areas) have been entered. BLDG-OUT is an artificial default activity created by FactoryPLAN to represent relations of real activities with the outside of the building.

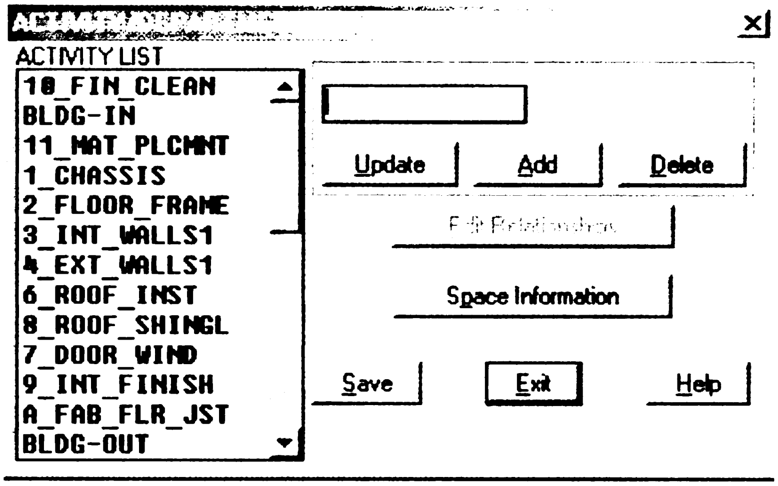


Figure 4.14: Activity/Department List

The user can then enter all the activities required. For the purpose of this research, the activities were divided into three major sections:

- *Main assembly stations* depicted in 1_CHASSIS format
- *Sub-assembly stations* depicted in A_FAB_FLR_JST format and
- *Feeder/storage stations* depicted in SA_DUCT_PIPE format.

A list of all of the abbreviations and the associated station details for the layout design of Production Plant A is shown in Table 4.9.

Table 4.9: Station Descriptions

Main assembly stations		
No	**Abbreviations**	**Station description**
1	1_CHASSIS	Chassis on wheel and axle pulled into the factory
2	2_FLOOR_FRAME	Place floor frame with insulation, ductwork and wiring over chassis
3	3_INT_WALLS1	Placement of interior walls (studs with panel on one side only)
4	3_INT_WALLS2	Placement of cabinets, toilet compartment, bathtub, kitchen sink
5	4_EXT_WALLS1	Placement of exterior walls, rough plumbing and electrical work
6	4_EXT_WALLS2	Installation of exterior walls completed
7	5_ELEC_MECH	Installation of all electrical and mechanical equipment
8	6_ROOF_INST	Roof installation
9	7_DOOR_WIND	Installation of doors & windows
10	8_ROOF_SHINGL	Installation of roof shingles and external finishes (siding)
11	9_INT_FINISH	Install carpet, final electrical and plumbing finishes, and marriage walls.
12	10_FIN_CLEAN	Interior finishing and cleanup
13	11_MAT_PLCMNT	Placement of material to be installed at site
Sub-assembly stations		
14	A_FAB_FLR_JST	Fabrication and storage of ductwork and plumbing, placement of tires, floor joists
15	B_ASM_INT_WAL	Assemble floor frame- place black sheet, place insulation, place floor joist, wire and duct work, and staple black sheet to the floor joist
16	C_ASM_CABINET	Assembly of cabinets, kitchen, and toilet sinks
17	D_FAB_RF_TRUS	Sub-assembly station for roofing main activity stations.
18	E_CEILBD_INSU	Fabrication of roof truss, installation of ceiling board, paint spraying, drying, and finishing
19	F_PAINT_CEIL	Installation of loose and rigid insulation
Feeder stations		
20	SA_DUCT_PIPE	Storage of ductwork and plumbing pipes
21	SB_CABINET	Storage of cabinets
22	SC_DRYWALL	Storage of drywall panels
23	SD_DOOR_WIND	Storage of drywall, doors and windows, sheathing
24	SE_ROOF_SHING	Storage of roof shingles
25	SF_FOAM_CARPT	Storage of foam and carpet and drywall (marriage)
26	SG_WLBDS_TOOL	Storage for wall boards and tools
27	SH_MIROR_FRDG	Storage for mirror, and appliances
28	SI_RANGE_DRPS	Storage for drapes and appliances
29	SJ_CMD_SHP_MT	Storage of toilets and materials to be shipped to the site for installation
30	SK_RF_TRS_MBR	Storage of drywall panels and wooden members for roof frame fabrication

SPACE INFORMATION/REQUIREMENTS

Once the activity stations have been defined, the user needs to specify the individual space requirements for each of the stations. The space requirements can be input by clicking the "Space information" tab in the dialogue box that is shown in Figure 4.14. Figure 4.15 shows the dialogue box that appears for entering the space requirements data. A list of all the stations is given, but the user must provide the area, type, height and width of each of the stations. After inputting this information for each station the user should click the update button to make the information available to be accepted by the software. After the space information has been supplied for all the stations, the information should be saved in the previously specified space file. After clicking on the save tab, the data will be saved in the location specified in the FactoryPLAN data file (Figure 4.14)

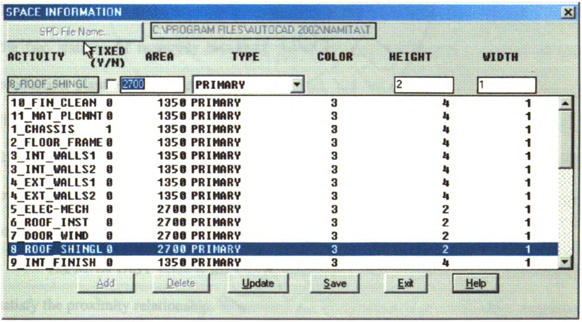


Figure 4.15: Space information

4.5.2.3 RELATIONSHIP DATA

Once the activity station/department name list and the space information/requirements have been provided, data related to the desirable proximity/closeness between each of these activity stations needs to be provided. As described earlier, FactoryPLAN uses Systematic Layout Planning technique developed by Richard Muther (Muther, 1961). FactoryPLAN accepts relationships in the form of closeness ratings like A, E, I, O, and U. These closeness ratings and the reasons assigned for these ratings were presented in Table 4.3 and 4.4, respectively.

In order to input relationships for the departments, the user must click on each of the stations and then the "Edit relationships" tab in the activity/department list dialogue box (Figure 4.14). The dialogue box named the "matrix editor" appears (Figure 4.16). The closeness ratings, the reasons for these ratings, and the maximum distance between the two stations (if required) should be specified here. For example, in the case of production plant A, the relationship of the main activity station, named 1_CHASSIS (Chassis on wheel and axle pulled into the factory), with the main activity station, 2_FLOOR_FRAME (Place assembled floor frame with insulation, ductwork and wiring over the chassis), is an "A", absolutely necessary relationship due to high proximity or logic reasons.

The MAX DIST value is the maximum distance allowed between activities that still satisfy the proximity relationship. When the score is calculated on a relationship diagram, if the distance between the activity pair exceeds the MAX DIST value, FactoryPLAN adds the pair's relationship weight to the E (Euclidian) score and R (rectilinear) score (a lower score is better). Specific MAX DIST values can be entered here if desired. Once all the relationships have been entered, the user should click on the "save" tab in the window shown in Figure 4.16. The relationship details will be saved as a relationship/AMX file.

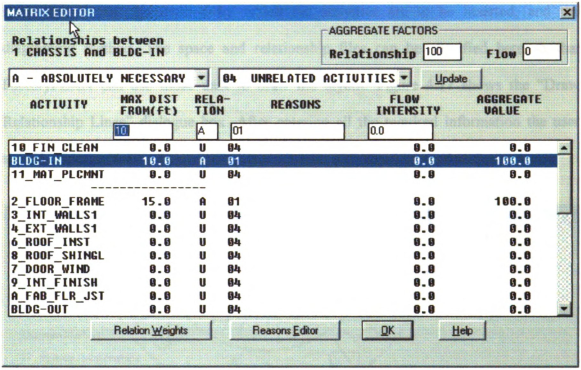


Figure 4.16: Relationship input window

FactoryPLAN can generate a Relationship Chart using the above supplied data. In order to do so, the user should click on the "Insert Relationship Chart" tab in the Chart/Data drop down menu. FactoryPLAN's relationship diagram visually represents the relationships between various areas and allows the user to create, manipulate, and score the diagrams, while ensuring that no relationships are ignored.

4.5.2.4 GENERATE AND MANIPULATE LAYOUTS

After both the space information and activity relationship data files have been created and saved, the user is ready to create a layout. In order to draw the space and relationship based layouts, the user must click on "Draw Relationships" tab, which is located under the diagram drop down menu tab. FactoryPLAN allows the user to select space boundaries, the method by which the activities are to be inserted, and the diagraming method. The space and relationship files can be specified here so that FactoryPLAN can use those data to draw the layout. Figure 4.17 shows the "Draw Relationship Lines" dialogue box. After entering all the required information the user should click the "OK" tab.

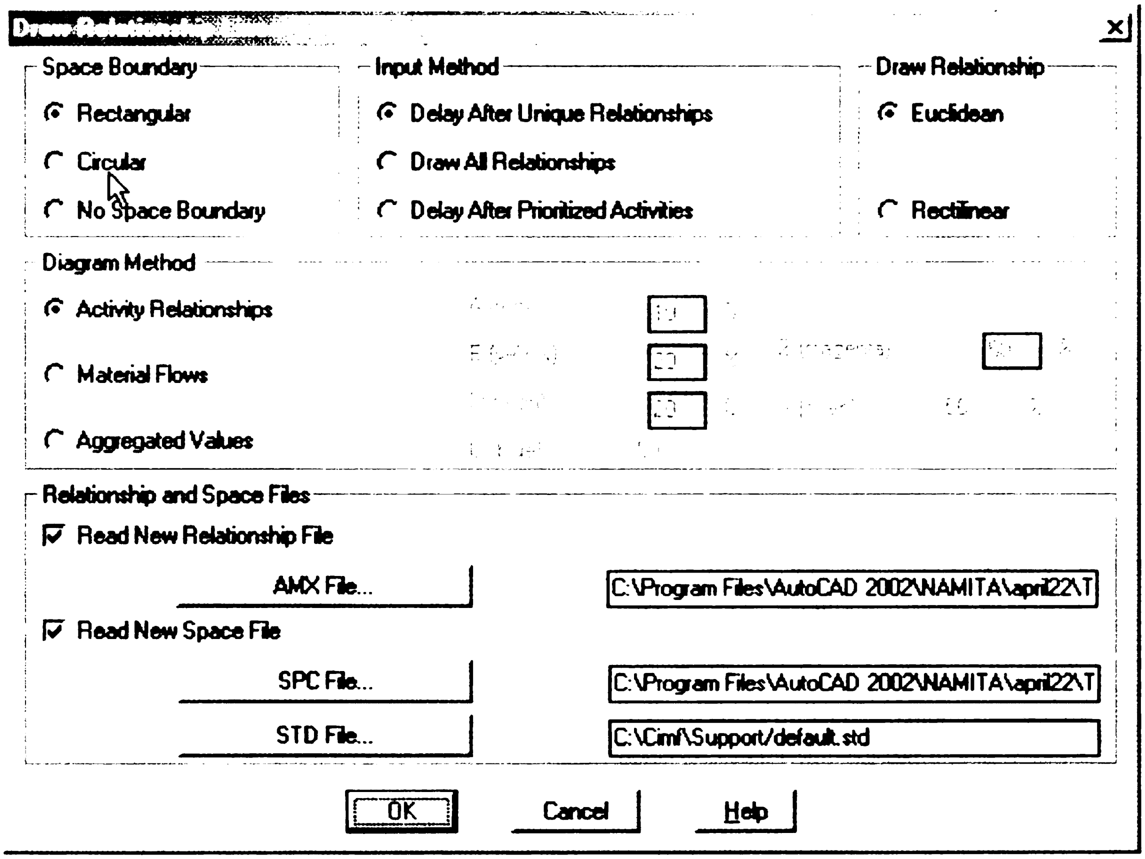


Figure 4.17: Draw Relationships Lines

When the user clicks "OK", FactoryPLAN returns to the drawing screen and searches for existing activity symbols. If the layout is being prepared from scratch and the departments/stations have been specified but not been drawn, the window stating "Workcenter points do not exist" in Figure 4.18 will appear. When "OK" is clicked at this box, FactoryPLAN will prompt the user at the command line to pick a location for each of the work centers (activity stations) specified in the activity/department list.

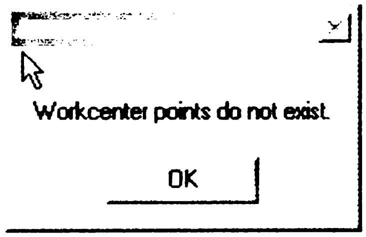


Figure 4.18: Workcenter Points

Based on the user's knowledge of the production process, he/she can position the activity stations when FactoryPLAN requests their placement. After all the stations have been placed, the user can then readjust/reposition stations to obtain a better layout (at this point, the user should concentrate only on the "A", absolutely necessary relationship). The layout then prepared can be scored using the "Score" option under Diagram drop down menu. The score window is shown in Figure 4.19. The user, based on the space information and personal knowledge of the production process, can specify the Min/Max scoring distance for each of the closeness ratings in this window. The basis for score calculation can be specified here, too.

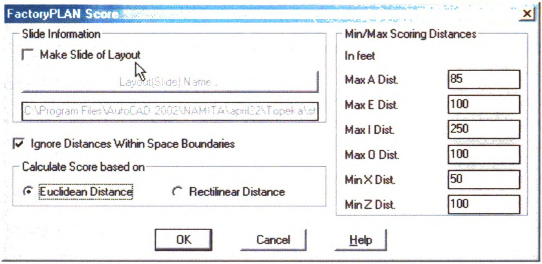


Figure 4.19: FactoryPLAN score

After providing the required information, the user can click on "OK". FactoryPLAN displays the score for the present layout by recalculating the relationships. Figure 4.20 shows the different types of scores FactoryPLAN calculates. The following section will describe each of these scores in detail.

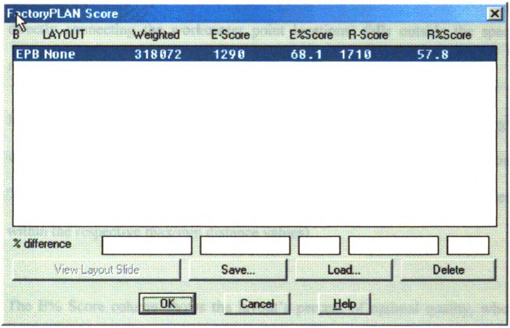


Figure 4.20: Types of Score

4.5.2.5 SCORE

The Layout Column contains the layout slide name that was specified in the Score dialog at the time the layout was scored (EAI, 1999).

- The Weighted column shows the layout score, which is the sum of the relationship line values, each of which is computed using the formula:

Length × Weight

Where

Length = length of the relationship line

Weight= relationship weight for the level of relationship (as specified in FPEDIT) (EAI, 1999).

- The E-Score column shows the sum of the relationship weight values of those relationships whose Euclidian distance (the length of a single segment line directly connecting the workcenter point locations) falls outside the specified maximum/minimum distance values (EAI, 1999).

  In the E-Score field, relationship weight values are not multiplied by length as with the Weighted-Score field, but rather they are simply weight values or "stepwise." The best possible score is "0", (that is, all relationship distances fall within the respective max/min distance values).

- The E% Score column shows the layout's percent of optimal quality, when all relationships would fall within respective maximum/minimum distance values.

An E% Score of 100 would correspond to an E-Score of 0. E% Score is calculated by subtracting from 100% the actual E-Score divided by the worst possible score.

$$E\%\ Score = 100\% - \left(\frac{(\ Actual\_E\text{-}Score)}{(Worst\_Possible\_E - Score)} \right)$$

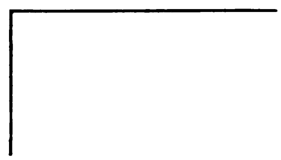
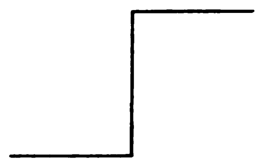
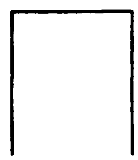
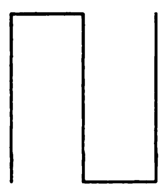
- R-Score and R% Score are similar to E-Score and E% Score, with the exception that relationship line length is calculated as rectilinear distance (the length of a two-segment line, one segment horizontal, one segment vertical) between the workcenters.

The analysis for selection of the best layout can be based on all the scores defined above. For this research, the author would like to focus the readers attention on the weighted score, E score, and E% Score only.

4.5.2.6 RESULTS

Based on the above supplied data, the author produced five different types of layout for both the Production Plants. These layouts are shown in detail in Appendix B. The different layout patterns explored by the author are displayed in Table 4.10. The existing layout in the case of Production Plant A was a U shaped layout.

Table 4.10: Layout Patterns explored

Nos.	Name	Pattern
1	Straight-line layout	
2	L Shaped layout	
3	Z Shaped layout	
4	U Shaped layout	
5	S Shaped layout	

The following section displays the score obtained for each of the layouts for Production Plant A.

4.5.2.7 PROXIMITY SCORE

After drawing the different layout options, and after several improvements, the following proximity scores were generated for production plant A and production plant B. Table 4.11 and 4.12 display a summary of these results. It can be noticed that the S-Shaped, U-shaped, and the Z-shaped layout alternatives for production plant A, and L-shaped, S-shaped and straight line layout alternatives for production plant B have relatively better proximity scores than other alternatives. The scores obtained for production plant A will be used for further analysis.

Table 4.11: Proximity scores for layouts of Production plant A

Layout	Weighted	E-Score	E%Score	R-Score	R% Score
Straight-line layout	351612	870	78.6	1320	67.5
L Shaped layout	309125	940	76.8	1480	63.5
Z Shaped layout	258139	800	80.3	1320	67.0
U Shaped layout	279823	500	87.7	1170	71.2
S Shaped layout	258608	420	89.7	810	80.0

Table 4.12: Proximity scores for layout of production plant B

Layout	Weighted	E-Score	E%Score	R-Score	R% Score
Straight-line layout	275753	485	86.6	805	77.8
L Shaped layout	240532	370	89.8	860	76.3
Z Shaped layout	242717	705	80.6	915	74.8
U Shaped layout	241501	775	78.6	1075	70.3
S Shaped layout	264605	500	86.2	1090	69.9

4.5.2.7.1 Proximity Scores For Production Plant A

As discussed earlier E% score is one of the major indicators of the quality of the layout. Though a layout can be selected on the basis of the E% scores alone, both E% score and the weighted scores have been considered as means of assessing layout alternatives. For production plant A, seen in the above table, it can be concluded that the

S shape layout is the best possible layout option, followed by a U-shaped layout, a Z-shaped option, a straight-line option, and finally the L-shaped option, based on the space information and the relationship chart provided.

As the weighted score for the Z-shaped layout and the S-shaped layout are close to each other, these layouts will be analyzed further.

As defined earlier, weighted score is the sum of relationship line values, each of which is computed using the formula: **Length × Weight.**

Though the weighted score of the S-shaped layout is more than that of the Z-shaped layout, E Score provides a reason for the S shaped layout to be considered better. The E score is the sum of all the relationship weight values whose Euclidian distance is not within the specified range. In the case of similar weighted score, the lower E score should be considered the tiebreaker (EAI, 1999).

Based on the scores shown in Table 4.11, it can be interpreted that the S-shape layout is the relatively better option, as it has the lowest E Score. Since the S-and U-shaped layout have relatively better E scores, they can be considered for further evaluation. Similarly, based on the weighted scores of the five layout options, S and Z shaped layouts can be considered as relatively better layout options, as their weighted scores are lower than those of other options.

A graph comparing the E Score and the weighted score is presented in Figure 4.21. The closer the intersection point (of the E Score value and the weighted score value) to the origin, better the layout is. Therefore, it is the S-shaped layout that is better. This S shaped layout for production plant A is presented in Figure 4.22. Similarly, it can be seen from the graph in Figure 4.23 that an L-shaped layout is the best layout in case of production plant B. The other layout design alternatives are presented in Appendix B.

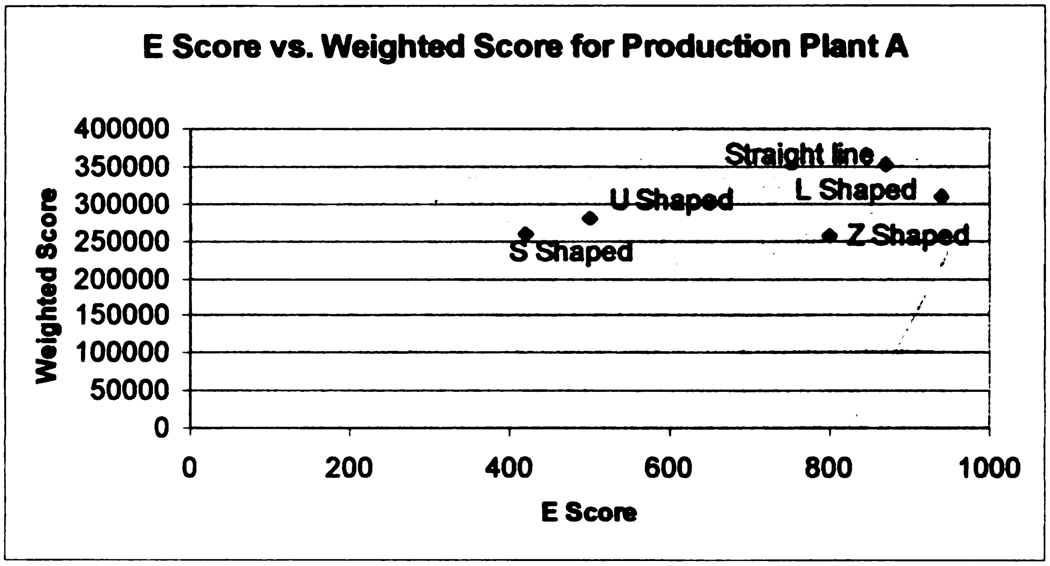
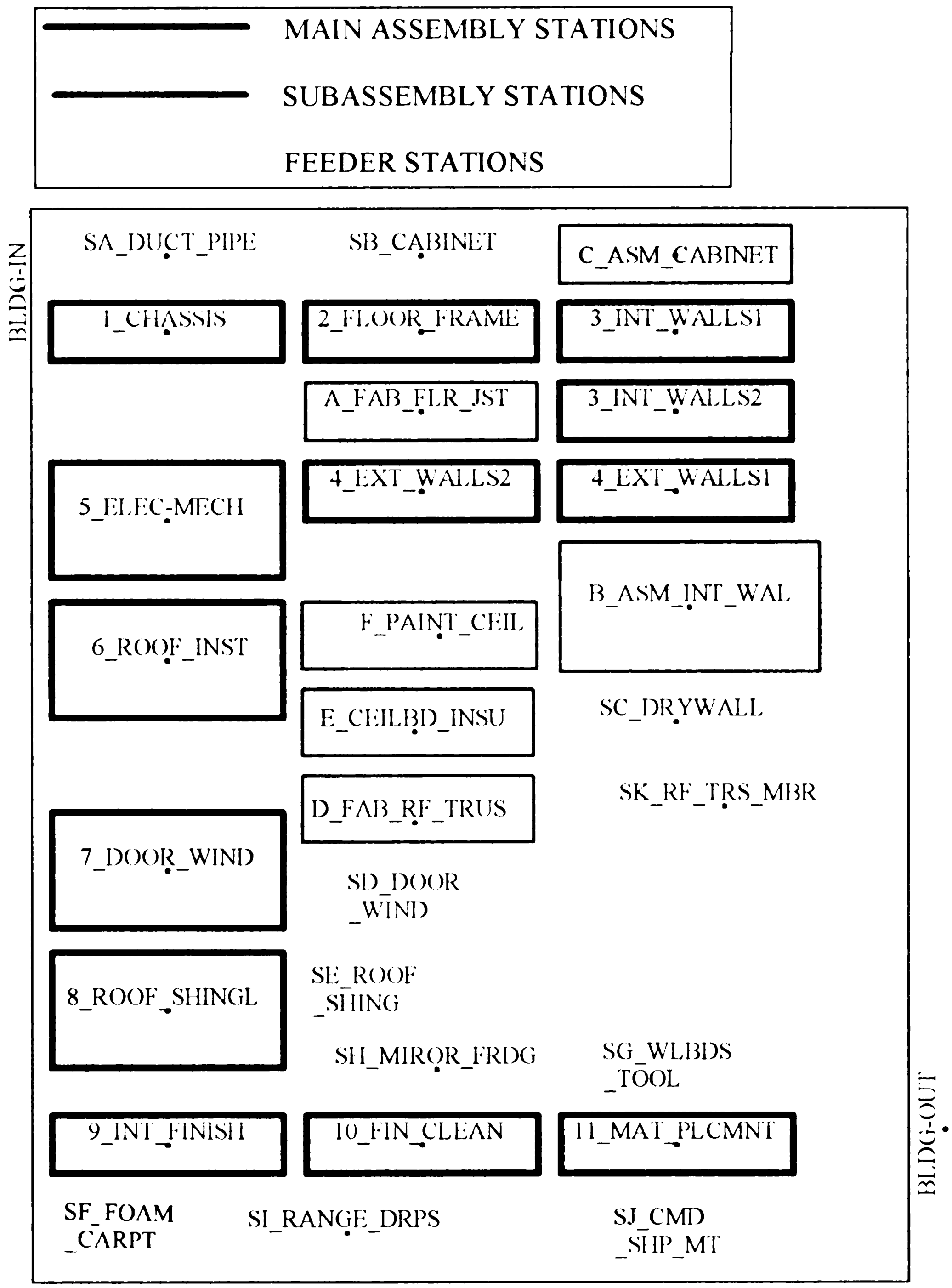


Figure 4.21: E Score Vs. Weighted Score for Production Plant A

4.5.2.8 DETAILED COMPARISION OF THE THREE LAYOUT ALTERNATIVES

From Table 4.11, it can be seen that three layouts, S-shaped layout, U-shaped layout and Z-shaped layout should be selected for further evaluation. These three layouts can be compared based on their closeness ratings. For each layout, the total number of A relationships (absolutely necessary) that have been satisfied can be calculated. Similarly, the total number of E, I, U, relationships that have been satisfied can be calculated. Hence, the total for is calculated.



S SHAPED LAYOUT
E% Score: 89.7%
PRODUCTION PLANT 'A'

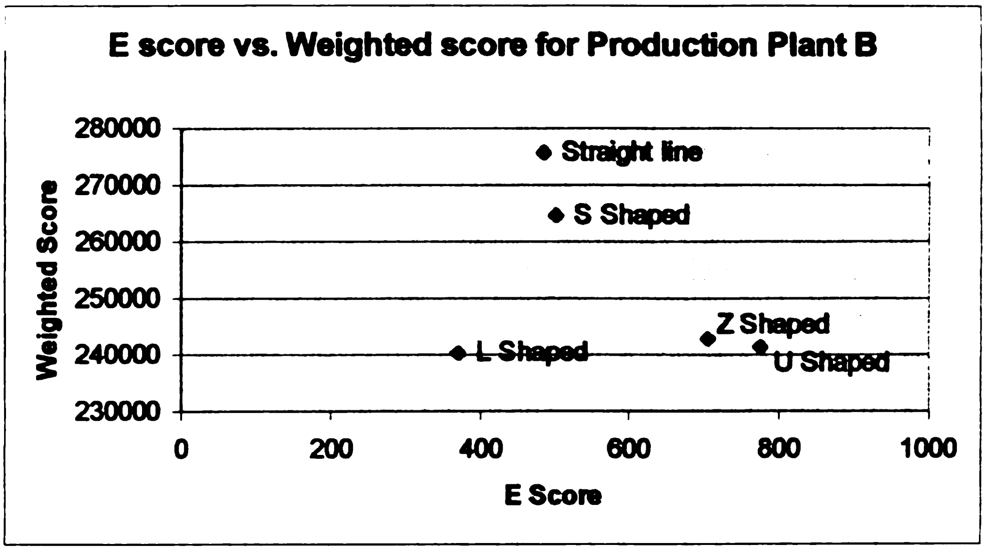


Figure 4.23: E Score Vs. Weighted Score for Production Plant B

Each of the relationships among each pair of stations was queried. Based on the values in Table 4.13. For example, for each A relationship that was satisfied, 80 points were assigned.

Table 4.13: Points based closeness ratings

Nos.	Closeness ratings	Points
1	A (Absolutely necessary)	80
2	E (Especially necessary)	60
3	I (Important)	40
4	O (Ordinary)	20
5	U (Unimportant)	0

Tables 4.14, 4.15, 4.16, 4.17, and 4.18 show the relationship charts for the five layouts. The relationship closeness ratings that have been satisfied in each layout have been depicted in red and the relationships that have not been satisfied in the layout have been presented in blue.

	1	2	3	4	5	6	7	8	9	10	11	12	13	A	B	C	D	E	F	a	b	c	d	e	f	g	h	I	j	k
1	\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
2		\ \	A 1	U 4	I 2	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
3			\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	A 1	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
4				\ \	A 1	E 3	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	A 1	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
5					\ \	A 1	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
6						\ \	A 1	U 4	I 2	U 4		U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
7							\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
8								\ \	U 4		U 4	U 4	U 4	U 4	U 4	U 4	I 2	[illegible]	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
9									\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4
10										\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4
11											\ \	A 1	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	I 2	A 1	A 1	U 4	U 4
12												\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
13													\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4
A														\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
B															\ \	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
C																\ \	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
D																	\ \	A 1	[illegible]	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	I 2
E																		\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
F																			\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
a																				\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
b																					\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
c																						\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
d																							\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4
e																								\ \	U 4	U 4	U 4	U 4	U 4	U 4
f																									\ \	U 4	U 4	U 4	U 4	U 4
g																										\ \	U 4	U 4	U 4	U 4
h																											\ \	U 4	U 4	U 4
I																												\ \	U 4	U 4
j																													\ \	U 4
k																														\ \

S shaped layout points

Total: 2800 **A points: 1740** **Effective points:2240**

Table 4.14: Relationship chart for relationships satisfied in 'S' Shaped layout at Production plant A

	1	2	3	4	5	6	7	8	9	10	11	12	13	A	B	C	D	E	F	a	b	c	d	e	f	g	h	I	i	k
1	\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
2		\ \	A 1	U 4	I 2	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
3			\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4		A 1	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
4				\ \	A 1	F 3	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	A 1	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
5					\ \	A 1	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
6						\ \	A 1	U 4	I 2	U 4	I 2	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
7							\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
8								\ \	U 4		U 4	U 4	U 4	U 4	U 4	U 4	I 2	I 2	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
9									\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4
10										\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4
11											\ \	A 1	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	I 2	A 1		U 4	U 4
12												\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
13													\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4
A														\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
B															\ \	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
C																\ \	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
D																	\ \	A 1	F 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	I 2
E																		\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
F																			\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
a																				\ 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
b																					\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
c																						\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
d																							\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4
e																								\ \	U 4	U 4	U 4	U 4	U 4	U 4
f																									\ \	U 4	U 4	U 4	U 4	U 4
g																										\ \	U 4	U 4	U 4	U 4
h																											\ \	U 4	U 4	U 4
I																												\ \	U 4	U 4
i																													\ \	U 4
k																														\ \

U shaped layout points

Total: 2740 A points: 2160 Effective points:2140

Table 4.15: Relationship chart for relationships satisfied in 'U' Shaped layout at Production plant A

	1	2	3	4	5	6	7	8	9	10	11	12	13	A	B	C	D	E	F	a	b	c	d	e	f	g	h	I	j	k
1	\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
2		\ \	A 1	U 4	I 2	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
3			\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	[illegible]		U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
4				\ \	A 1	E 3	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1		U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
5					\ \	A 1	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
6						\ \	A 1	U 4	I 2	U 4		U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
7							\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
8								\ \	U 4		U 4	U 4	U 4	U 4	U 4	U 4	I 2	[illegible] 2	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
9									\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4
10										\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4
11											\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	I 2			U 4	U 4
12												\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
13													\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4
A														\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
B															\ \	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
C																\ \	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
D																	\ \	A 1	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	I 2
E																		\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
F																			\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
a																				\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
b																					\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
c																						\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
d																							\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4
e																								\ \	U 4	U 4	U 4	U 4	U 4	U 4
f																									\ \	U 4	U 4	U 4	U 4	U 4
g																										\ \	U 4	U 4	U 4	U 4
h																											\ \	U 4	U 4	U 4
I																												\ \	U 4	U 4
j																													\ \	U 4
k																														\ \

Z spaped layout points

Total: 2660 A points:2080 Effective points:1900

Table 4.16: Relationship chart for relationships satisfied in 'Z' Shaped layout at Production plant A

	1	2	3	4	5	6	7	8	9	10	11	12	13	A	B	C	D	E	F	a	b	c	d	e	f	g	h	I	j	k
1	\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
2		\ \	A 1	U 4	I 2	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
3			\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4			U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
4				\ \	A 1	E 3	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1		U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
5					\ \	A 1	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
6						\ \	A 1	U 4	I 2	U 4		U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
7							\ \	A 1	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
8								\ \	U 4		U 4	U 4	U 4	U 4	U 4	U 4	I 2	E 2	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
9									\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4
10										\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4
11											\ \	A 1	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	I 2	A 1	A 1	U 4	U 4
12												\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
13													\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4
A														\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
B															\ \	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
C																\ \	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
D																	\ \	A 1	E 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	I 2
E																		\ \	A	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
F																			\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
a																				\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
b																					\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
c																						\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
d																							\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4
e																								\ \	U 4	U 4	U 4	U 4	U 4	U 4
f																									\ \	U 4	U 4	U 4	U 4	U 4
g																										\ \	U 4	U 4	U 4	U 4
h																											\ \	U 4	U 4	U 4
I																												\ \	U 4	U 4
j																													\ \	U 4
k																														\ \

Straight line layout points

Total: 2660 A points: 2240 Effective points:1900

Table 4.17: Relationship chart for relationships satisfied in 'Straight line layout at Production plant A

	1	2	3	4	5	6	7	8	9	10	11	12	13	A	B	C	D	E	F	a	b	c	d	e	f	g	h	I	j	k
1	\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
2		\ \	A 1	U 4	I 2	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
3			\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1		U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
4				\ \	A 1	E 3	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4		A 1	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
5					\ \	A 1	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
6						\ \	A 1	U 4	I 2	U 4	I 2	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4		U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
7							\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
8								\ \	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	I 2	I 2	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
9									\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4
10										\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4
11											\ \	A 1	U 4	U 4	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	I 2		A 1	U 4	U 4
12												\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
13													\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4
A														\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
B															\ \	U 4	U 4	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
C																\ \	U 4	U 4	U 4	U 4	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
D																	\ \	[illegible]	I 2	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	I 2
E																		\ \	A 1	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
F																			\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
a																				\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
b																					\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
c																						\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4	U 4
d																							\ \	U 4	U 4	U 4	U 4	U 4	U 4	U 4
e																								\ \	U 4	U 4	U 4	U 4	U 4	U 4
f																									\ \	U 4	U 4	U 4	U 4	U 4
g																										\ \	U 4	U 4	U 4	U 4
h																											\ \	U 4	U 4	U 4
I																												\ \	U 4	U 4
j																													\ \	U 4
k																														\ \

L shaped layout points

Total: 2580 A points: 2000 Effective points:1740

Table 4.18: Relationship chart for relationships satisfied in 'L' Shaped layout at Production plant A

Table 4.16 shows the results of the points analysis. The best layout is the one with the maximum effective points and minimal points for the relationships not met. Clearly the S-shaped layout is the best layout in the case of production plant A.

Table 4.16: Results of Point analysis

Layout type	Total for layout (A)	Max. possible points (B)	Total 'A' points for layout (C)	Max. possible 'A' points (D)	Total points of rel. not met (E)	Effective points (F=A-E)	% Effective points
S-Shaped layout	2800	3380	1740	2800	**560**	**2240**	**66.2%**
U-Shaped layout	2740	3380	2160	2800	**760**	**1980**	**58.5%**
Z-Shaped layout	2660	3380	2080	2800	**600**	**2060**	**60.9%**
Straight-line layout	2660	3380	2240	2800	**760**	**1900**	**56.2%**
L-Shaped layout	2580	3380	2000	2800	**840**	**1740**	**51.4%**

These points can assist in the process of layout selection and layout improvement. The aim is to increase the effective points and reduce the points on relationships not met.

4.6 SUMMARY

Based on the author's knowledge and visits to the two factories in Northern Indiana, the production process of a manufactured home was documented in this chapter. Also, data collection formats for both space and activity relationships were developed and documented. Two software programs BLOCPLAN and FactoryPLAN, were analyzed as possible layout design solutions for the manufactured housing production plant. After detailed analysis, FactoryPLAN was selected. The author visited the factories on a weekly basis for six weeks and collected the required data, developed relationship charts, and input this data into the FactoryPLAN software. Five layout options, based on the layout patterns, were provided and their scores were calculated. The final section of this chapter consisted of the selection of layout from the layout alternatives based on the preliminary score analysis.

CHAPTER FIVE

LAYOUT DESIGN PROCESS GUIDELINES FOR MANUFACTURED HOUSING PRODUCTION PLANTS

5.1 INTRODUCTION

The previous chapters attempt to explain the different steps involved in the process of layout design for a manufactured housing production plant. The techniques and tools used in the field of industrial engineering were applied to the design of a manufactured housing production plant. In Chapter 4, the author produced different layout alternatives for a manufactured housing production plant and analyzed various effectiveness scores to evaluate different layout alternatives. In this chapter, a set of guidelines outlining the overall layout design procedure is developed based on the work done in earlier steps.

This research is a part of a National Science Foundation (NSF) funded project, named, *Modeling of Manufactured Housing Production and Material Utilization*. As part of the data collection process for the Phase I (Production and Material Flow Process Model for Manufactured Housing), the author visited several manufactured housing production plants and found that the industry did not follow a systematic process for plant layout. Therefore, one of the outcomes of the present research work was to prepare guidelines for layout design. These guidelines can lead manufacturers through a series of steps or procedures to either design new layouts or to improve existing layouts. A basic flowchart method was adopted for the preparation of guidelines for the layout design of a manufactured housing production plant.

5.2 FLOWCHART

Flowcharting is a technique that depicts the flow of a process from its initiation to its conclusion. It can be defined as a method of graphically describing an existing process or a new process using simple symbols, lines, and terms to present pictorially the activities and progression in the process (Harrington, 1992). A flowchart can explain an entire process, while keeping various aspects of that process in perspective.

5.2.1 TYPES OF FLOWCHART (Deneba, 2002)

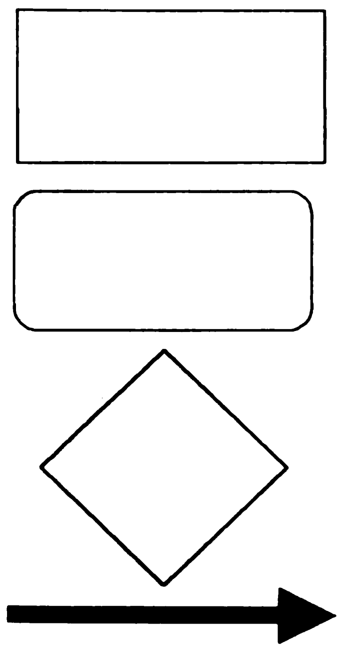
Flowcharts can be used to present information in a way that it can be easily analyzed and understood. Flowcharts can be grouped in several ways. Shown below is one of the most common approaches to classifying flowcharts:

- *Basic flowchart:* A flowchart that quickly identifies all the major steps in a process. It provides a broad overview of a process.
- *Process flowchart:* A flowchart that examines a process in great detail. It provides a comprehensive listing of all major and minor steps involved. It describes how a process works, or how data is handled by a sequence of processes.
- *Deployment flowchart:* Similar to Process flowchart, as it is very detailed, but it also indicates the people who are involved in a process. It is useful when the process involves cooperation between several functional areas.
- *Opportunity flowchart:* Highlights decision steps and check points. It is used for very complicated processes, because it highlights specific opportunities for improvement.

A process flowchart will be used for preparing guidelines in this research work.

5.2.2 FLOWCHART SYMBOLS

As flowcharts are a graphical representation of process/flow/information they require symbols for the purpose of depiction. Various types of symbols are used in flowchart. The following section presents the standard set of symbols used for the preparation of guidelines in the present research work.



Operation: Rectangle. This symbol is used whenever a change in an item occurs. The change may result from the expenditure of labor, a machine activity, or a combination of both.

Boundaries: Elongated circle. An elongated circle is used to show the beginning and end of the process. Normally, the word start,stop, or end is included within the symbol.

Decision point: Diamond. A diamond is put at the point in the process at which a decision must be made.

Direction of flow: Arrow. An arrow is used to denote the direction and order of process steps. An arrow is used to represent movement from one symbol to another

Figure 5.1:Standard Flowchart Symbols
(Harrington, 1991)

5.4 GUIDELINES FOR MANUFACTURED HOUSING LAYOUT DESIGN

Using the symbols shown above, a process flowchart was developed. It presents the guidelines for layout design of a manufactured housing production plant. The flowchart consists of five milestones. Figure 5.2 presents a basic flowchart showing these five milestones.

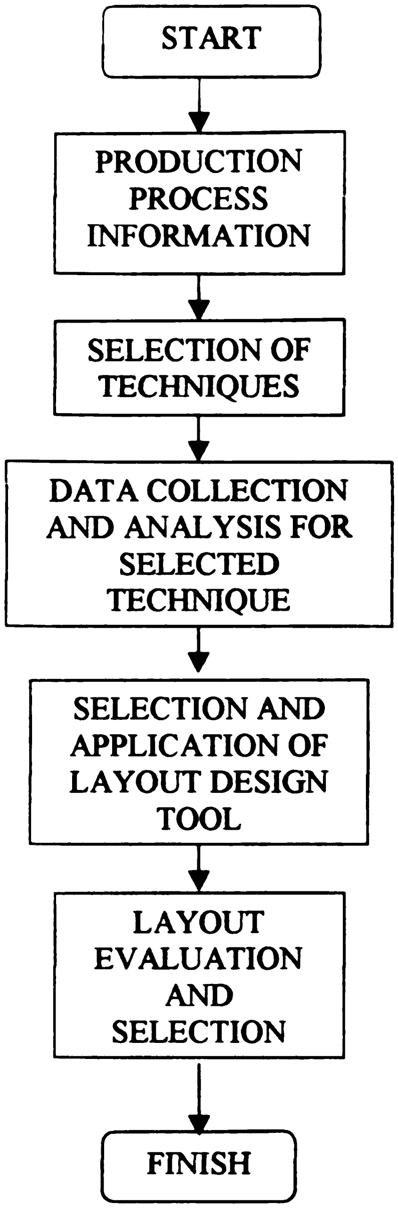
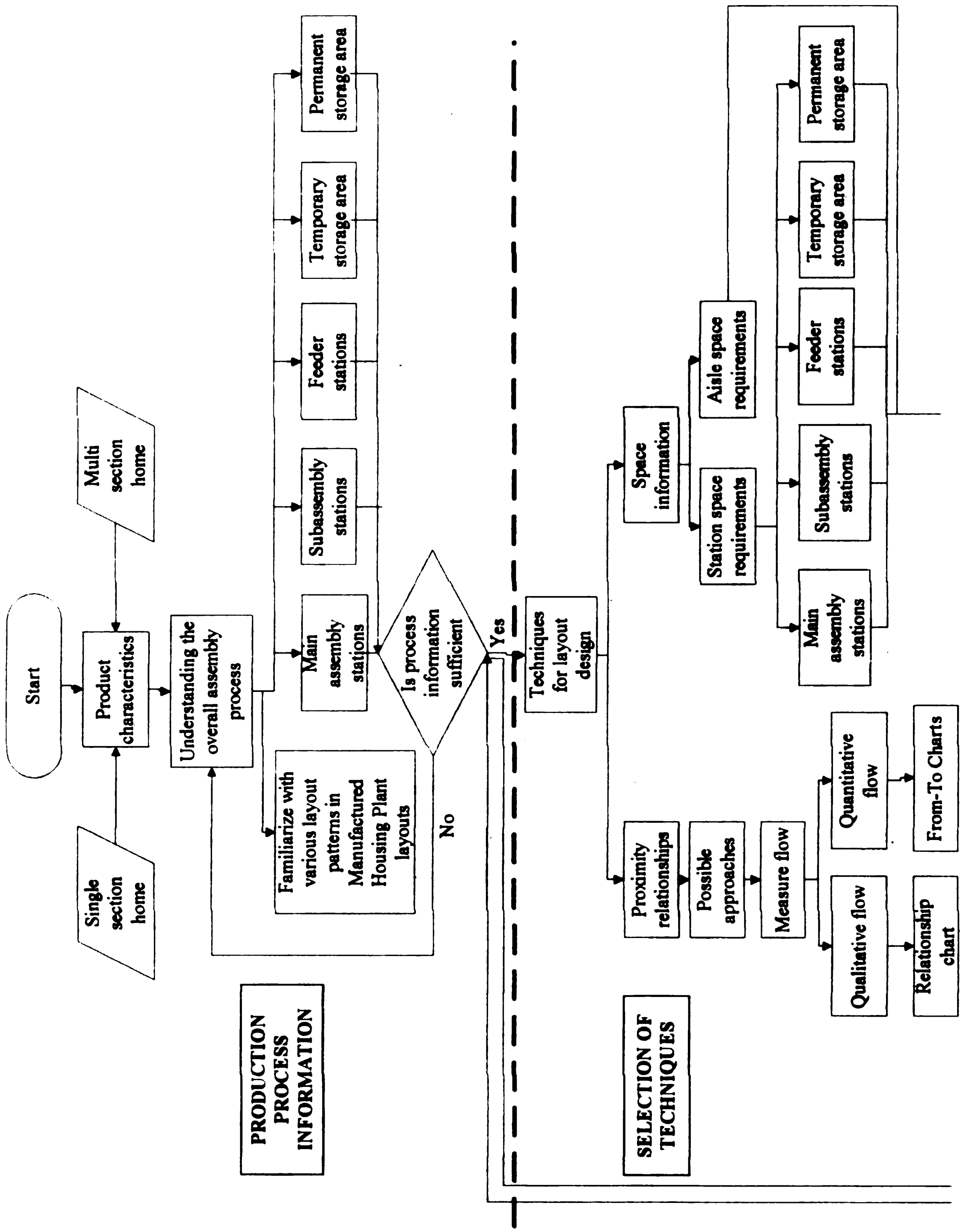
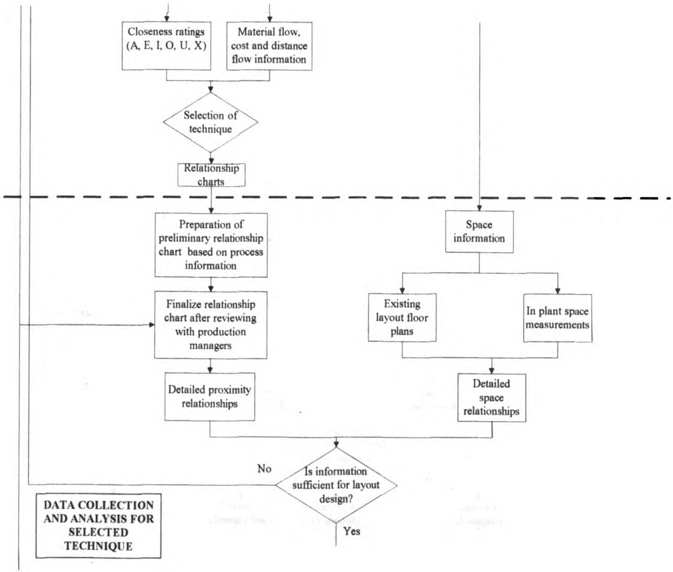


Figure 5.2: Milestones of Layout Design Guidelines

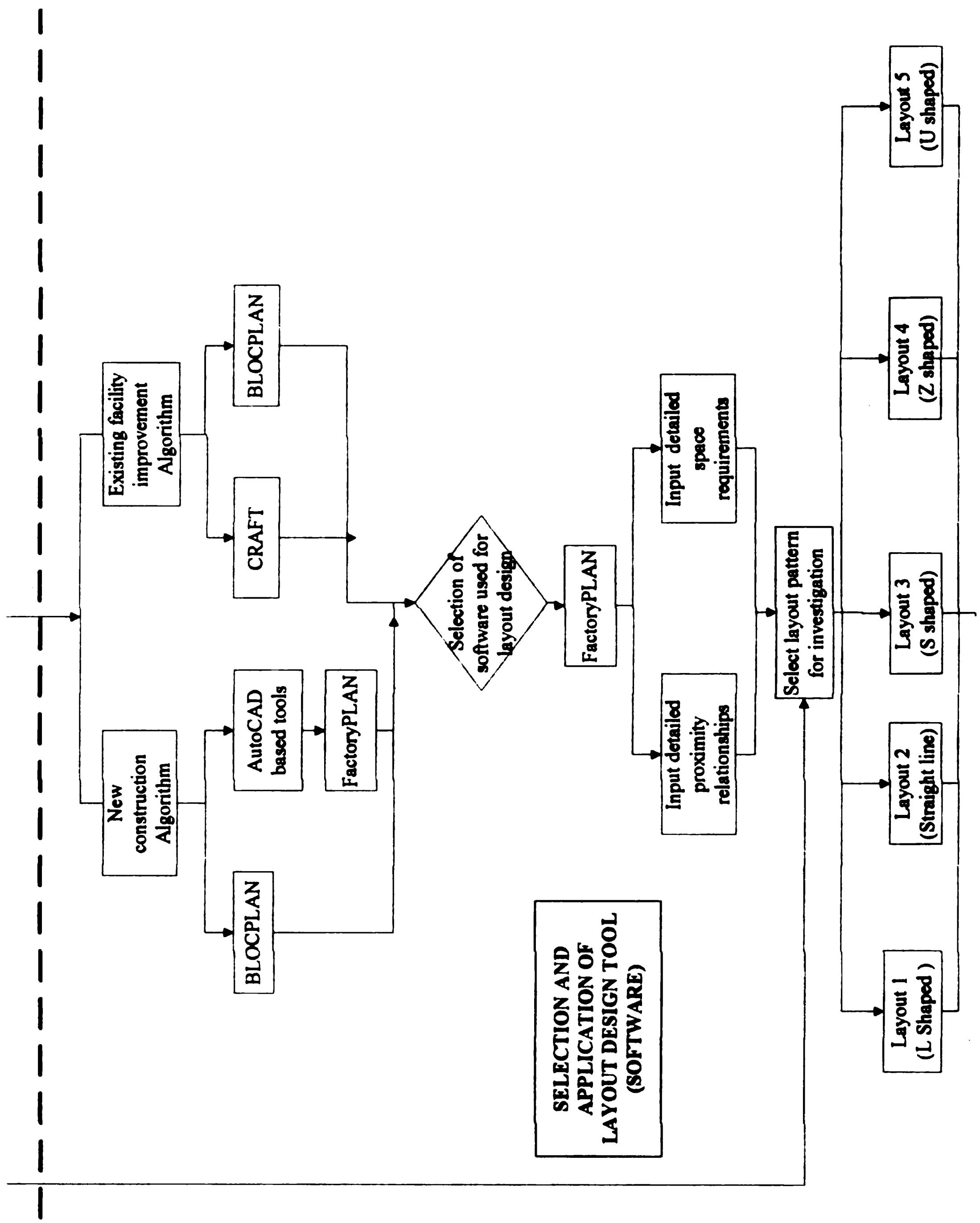
The following section describes the five milestones presented above in detail. Figure 5.3 presents a detail process flowchart showing the guidelines for developing a layout.



PRODUCTION PROCESS INFORMATION
Start
Single section home
Multi section home
Product characteristics
Understanding the overall assembly process
Familiarize with various layout patterns in Manufactured Housing Plant layouts
Main assembly stations
Subassembly stations
Feeder stations
Temporary storage area
Permanent storage area
Is process information sufficient
No
Yes
SELECTION OF TECHNIQUES
Techniques for layout design
Proximity relationships
Possible approaches
Measure flow
Qualitative flow
Quantitative flow
Relationship chart
From-To Charts
Space information
Station space requirements
Aisle space requirements
Main assembly stations
Subassembly stations
Feeder stations
Temporary storage area
Permanent storage area



Closeness ratings (A, E, I, O, U, X)
Material flow, cost and distance flow information
Selection of technique
Relationship charts
Preparation of preliminary relationship chart based on process information
Finalize relationship chart after reviewing with production managers
Detailed proximity relationships
Space information
Existing layout floor plans
In plant space measurements
Detailed space relationships
Is information sufficient for layout design?
No
Yes
DATA COLLECTION AND ANALYSIS FOR SELECTED TECHNIQUE



SELECTION AND APPLICATION OF LAYOUT DESIGN TOOL (SOFTWARE)
New construction Algorithm
Existing facility improvement Algorithm
BLOCPLAN
AutoCAD based tools
FactoryPLAN
CRAFT
BLOCPLAN
Selection of software used for layout design
FactoryPLAN
Input detailed proximity relationships
Input detailed space requirements
Select layout pattern for investigation
Layout 1 (L Shaped)
Layout 2 (Straight line)
Layout 3 (S shaped)
Layout 4 (Z shaped)
Layout 5 (U shaped)

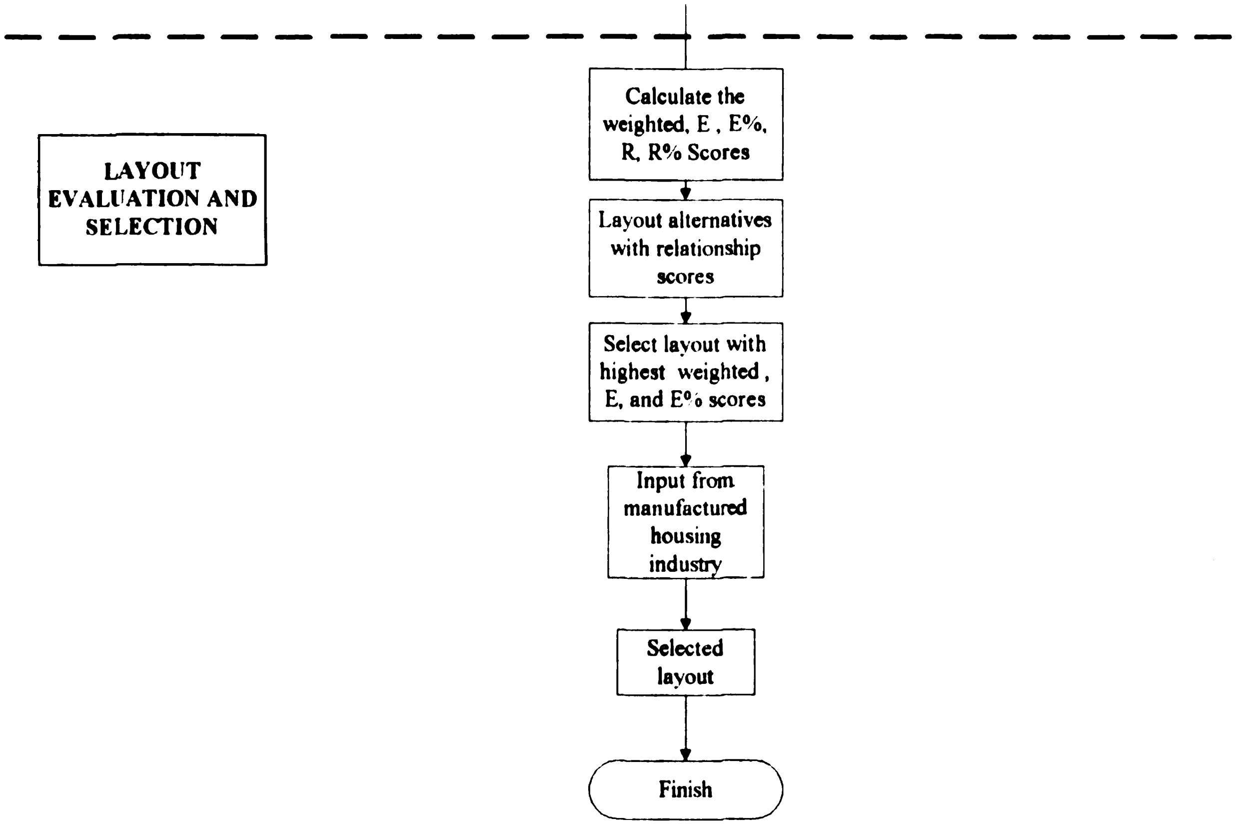


Figure 5.3: Process Flowchart guidelines for Plant Layout

Production process information: The major purpose of this section is to understand and familiarize the reader with the production and the production/assembly process of manufactured home. The designer must be familiar with the various layout patterns used in the assembly lines of manufactured home.

Selection of techniques: After the designer understands the production process of manufactured homes, he or she must determine the technique that will be used to prepare layout design. Information related to the space requirements of the stations and the aisles in the manufactured home will be needed. The designer will have to select the approach he/she wishes to use for measuring flow for developing the proximity relationships. The designer can select from two methods of measuring flow:

- *Qualitative flow:* The designer will require qualitative information for the layout design. One of the major methods used to evaluate qualitative flow is a relationship chart. This method assigns closeness ratings, in the form of A, E, I, O, and U, to describe the relationships between the stations.
- *Quantitative flow:* The designer will require detailed information of quantitative aspects of flow, like material movement from station to station, distances between the stations, overall costs of production/movement, and amount of inventory stored inside the plant.

For the purpose of this research, qualitative measurement was selected due to the following two reasons:

1. With the present infrastructure of the manufactured housing production plants, there is very limited data available that can be used for the development of From-

to charts, because From-To charts require detailed information on material flow, material movement and distance between assembly stations, and inventory of different material maintained inside the production plant.

2. The data collection required for the development of From-To charts was beyond the scope of this thesis.

Data collection and analysis for selected technique: After the technique to be used for layout design has been selected, the designer should collect data required by the selected techniques. For the development of the proximity relationships, a primary relationship chart should be prepared and finalized based on the input from the production managers. In the case of data collection for space requirements of various stations, the designer can use either floor plans of an existing plant or take in-plant measurements.

Selection and application of layout design tools: The designer should select a software tool based on the type of layout design problem. In the case of this research work, as the layout is being prepared from scratch, the software must be a new construction algorithm - based software and not an improvement algorithm - based software. The software programs used for this research were BLOCPLAN and FactoryPLAN. FactoryPLAN was selected for detailed layout design. Upon selecting the software tool, the designer should input the space information and proximity relationships. In the case of FactoryPLAN, the designer is given an opportunity to position the stations based on different patterns.

Layout evaluation and selection: The final section of the guidelines is the evaluation and selection of the optimal layout. Proximity scores are generated for each layout. The designer can then generate different layout options and calculate scores for each of them. The layout with the lowest E score is considered to be the best layout. The designer should seek input from production managers in the manufactured housing industry before selecting a final layout.

5.5 EVALUATION OF GUIDELINES

The guidelines presented in the previous section were based on the research work carried out by the author. In order to finalize the guidelines, input from leading industrial design consultants was solicited. After gathering information from two designers and one of the leading industrial design firms, the author came to the following conclusions.

The process of layout development mainly consists of steps similar to the ones followed by the author. The process details for layout designs are either developed and provided to industrial design firms by clients themselves (for example, the automobile industry develops its own details and provides them to the designer) or developed by the industrial design firm internally. Industrial design firms develop process details themselves or subcontract the process details and layout design part to a firm that specializes in preparing these details only. Presented below are the steps shown on the web page of one such specialty firm (ckgp, 2000).

- Analysis of inter-relationships between processing, machinery, and equipment facilities required to support production

- Development of material handling systems based on the manufacturing process
- Preparation of block layouts
- Development of alternative layouts for clients' consideration
- Conversion of existing plant layouts to computerized layouts. If required, field check, measure, and verify all data and information.

On its website, California Manufacturing Technology center (CMTC), presents one of its consulting services as plant layout design. It describes the following steps as part of the plant layout design process (CMTC, 2000):

- Defining the requirements of the manufacturing facility
- Specifying the activities that must be performed to meet the requirements
- Defining the process flow, space requirements, and activity relationship
- Evaluating alternative Facilities Plans and Plant Layouts
- Estimating return on investment (ROI) of proposed Plant Layout project
- Selecting and implementing a Facilities Plan and Plant Layout

Based on the information presented above, it can be concluded that the process used by the author for the development of guidelines is similar to the one actually carried out in the manufacturing facilities design industry.

5.6 SUMMARY

This chapter presented guidelines for the layout design of a manufactured housing production plant in the form of a detailed process flow chart. The first section described the purpose of the guidelines and the tool that was used to develop these guidelines. Different types of flowcharting styles and symbols were discussed. Finally, a detailed process flowchart with an explanation for each of the sections involved was presented

CHAPTER SIX

SUMMARY AND CONCLUSIONS

6.1 OVERALL SUMMARY

One of the major objectives of this research was to prepare and present different design layouts alternatives possible for a manufactured housing production plants. This objective was achieved, and five different layout options were produced based on various assembly flow patterns. Also, detailed guidelines for the layout design of a manufactured housing production plant were produced in the form of a flowchart. Chapter 2 provided a detailed literature review and an overview of the terminology used in two different areas: manufactured housing and facilities planning and design. The area of manufactured housing was further subdivided into the manufactured housing industry and manufactured housing product and process details.

In Chapter 3, a detailed description of the different techniques and tools used in the field of industrial engineering for production plant layout design was provided. This was done mainly to investigate the possible options that were available for the layout design process. A few of the popular traditional layout design techniques were presented and different layout types and flow patterns were discussed. Specific techniques applicable to this particular research work were then discussed, including the documentation of qualitative and quantitative methods of measuring flow. The qualitative measure (relationship charts) of flow was chosen for the development of layout design alternatives. The different software tools used for plant layout design were then discussed.

Two software programs, BLOCPLAN and FactoryPLAN, were acquired for use in this research. Each of these layout design software programs was then studied and its applicability in the area of manufactured housing production plant layout design was described in Chapter 4. FactoryPLAN was considered most appropriate for this research. Based on the author's knowledge and visits to the two factories, the production process of a manufactured home was then documented. Also, the data collection formats for both space and activity relationships were chosen and documented. The author visited the factories on weekly a basis and collected the required data. The data were used to develop relationship charts, and these were implemented into the FactoryPLAN and BLOCPLAN software. Five layout design options based on the layout patterns were developed and their effectiveness scores were calculated. The final section of chapter four consisted of evaluation of the layout design alternatives based on preliminary score analysis.

Based on the production process information and the process of layout design development, the author then produced step-by-step guidelines for the complete manufactured housing production plant layout design process. This includes all steps, from process information to layout selection and industry input. The purpose of these guidelines is to assist a designer/manufacturer to either design a new layout or improve an existing one.

6.2 SUMMARY BY OBJECTIVES

The overall goal of this research was to understand and develop the layout design process for manufactured housing production plants.

6.2.1 TO COMPILE THE PROCESS DETAILS OF MANUFACTURED HOUSING PRODUCTION

Manufactured homes are assembled in production facilities. Two methods were used to understand the production process better. Existing literature (Senghore, 2001; Hammad, 2001) that described the production process in detail was referred. In order to gain specific layout-related production process information, the author visited the two production plants in Northern Indiana and documented the production process. The assembly line was divided into four major areas within each major cluster (floors, walls, roof, interior and exterior finishes): main assembly stations, sub-assembly stations feeder stations and storage areas.

6.2.2 TO UNDERSTAND TECHNIQUES RELATED TO MANUFACTURING FACILITY LAYOUT DESIGN AVAILABLE IN THE FIELD OF INDUSTRIAL ENGINEERING

Based on the industrial design-related literature, the author had specified the need to develop space and proximity requirements. General layout design related tools and techniques were studied. Different types of layouts, layout problems, and flow patterns were understood. Specific techniques related to proximity relationships were identified and their applicability to the manufactured housing industry was studied. After thorough analysis, the qualitative measures of flow were chosen as the means of defining the proximity relationships. The process of identification of specific techniques for layout design was a very important step in this research. It took a lot of legwork for the author to isolate these techniques.

6.2.3 TO COLLECT SPACE AND PROXIMITY RELATED DATA, BASED ON THE LAYOUT DESIGN TECHNIQUES AND MANUFACTURED HOUSING PRODUCTION PROCESS DETAILS

In the case of space requirements the scope of the work was easy to define. The author developed a data collection table and took detailed measurements of the major station types classified under each cluster for production plant A. In the case of production plant B, most measurements were obtained from the floor plan provided by the manufacturers.

The author then developed relationship charts based on her knowledge of production process. This involved using information from the production process and the relationship chart development techniques. The production managers at the two case study production plants reviewed these charts. A relationship chart developed for production plant A is presented in Table 4.6. The process of data collection was an individual contribution of the author.

6.2.4 TO DEVELOP A LAYOUT DESIGN FOR THE MANUFACTURED HOUSING PRODUCTION PLANT

A substantial amount of research was required for attaining this objective. Two major software programs were studied for the purpose of the selection of a software tool. They were BLOCPLAN and FactoryPLAN. First, BLOCPLAN was investigated. An example layout design problem was defined and space and relationship-chart related data was developed and used as input. BLOCPLAN only accepted 18 stations, the individual length/width ratio of the stations could not be defined, and the user could not specify the layout patterns. Due to these limitations, the author searched for other layout software and found that FactoryPLAN as another possible software option. FactoryPLAN (a commercial software as part of the comprehensive FactoryCAD package) was obtained on a short-term loan basis. This software was a very good fit for the requirements of manufactured housing production plant layout design. The author spent considerable time understanding the software. The data collected from Production Plants A and B were then fed into this software, and layouts based on different patterns were generated.

FactoryPLAN provided the user with an option to attain a score based on the proximity relationships. These scores were generated for production plants A and B. Finally, a preliminary analysis of these scores was carried out to evaluate various layout design alternatives. Understanding and documenting and finally selecting the software for the purpose of layout design was an important step in this research. The author herself specifically did this. Most importantly, the author devised the process of layout analysis and selection methods.

6.2.5 TO FORMULATE LAYOUT DESIGN PROCESS GUIDELINES BASED ON OBJECTIVES 1 TO 4.

Based on knowledge of the production process, data collection (space information & proximity requirements) and layout generation, the author developed a detailed, step-by-step process model for the layout design process of the manufactured housing industry. The process model was divided into five major sections, (a) Production process information, (b) Selection of techniques, (c) Data collection and analysis for selected techniques, (d) Selection and application of layout design tool, and (e) Layout evaluation and selection. The guideline sections were further documented in details.

The guidelines developed in the previous stages were then compared to those developed by industrial design/ process design consultants. The design layouts prepared were also presented to the production managers in manufactured housing industry, who assessed their feasibility. The development of guidelines was a contribution of the author.

6.3 LIMITATIONS OF RESEARCH

One of the major limitations faced in this research was the unavailability of sufficient data to analyze proximity relationships based on quantitative measure of flow. In order to collect simple data related to material flow, an idea of the level of inventory maintained in the plant is needed. Since no proper documentation existed and the efforts required to develop this information was beyond the scope of this research, the qualitative method was selected. Specific limitations related to the layout design have been summarized in the following section.

The layout alternatives are developed based on the closeness each station shares with every other station on the assembly line or the closeness rating among the stations. Therefore, in this research, utilization of space and proximity relationships is the major consideration for the process of layout design. The reader is requested to look at these layout alternatives from the point of view of space management and not that of productivity improvement.

The layout alternatives produced in this research are two-dimensional. The layout alternatives have not been given a third dimensional perspective. Upon application of this third dimensional perspective, a necessity of review of certain parameters might arise; these issues have not been considered in this research. The cost factor associated with the actual construction of any of these layout alternatives has not been considered in this research.

During the process of data collection it was realized that both single-section homes and multi-section homes were built in the same premises. It was noticed that the process of handling this situation of mix product production is more dependent on the scheduling of these products rather than a space management issue. As both the process of construction and material required for construction for both products is similar, they follow the same path along the assembly lines. The major difference that appears is the difference in the time taken for the production of these two product types. Therefore the issue of mix product types was not addressed in this research.

6.4 CONCLUSIONS

Though manufactured homes have come a long way from recreational trailers, there has been very little effort to improve the production plants in which they are constructed. There is no standard method or procedure adopted to prepare a layout for these production plants. This industry lacks any information associated with the process of layout design of a manufactured housing production plant. There is a need to learn and adopt techniques and procedures from other disciplines that are more knowledgeable in this area. This research is the first stepping-stone to bridge the gap between the manufactured housing industry and more developed industries in the area of production plant layout design. This industry should analyze and understand the production processes of other progressive industries, like the automobile industry and based on the feasibility should learn/adopt and transfer techniques used in that field. The following section presents the major conclusions from this research work:

- The author observed that a U-shaped layout is the most common layout in manufactured housing production plants. Based on the scores obtained for the different layouts, several layout options are feasible, and manufacturers should not limit themselves to one particular layout. As this industry is a labor-intensive industry it has this opportunity to play with different options and is not tied down to the limitations of fixed machine/equipment-based layouts. One of the best ways for finding out the best solutions is to calculate the time a worker spends to get the subassembly or raw material to the main assembly station. Also, the assembly line design/ pattern should determine the building shape and not vice versa. In the latter case, the author observed that space is wasted or is under-utilized.

- The author strongly believes that manufacturers who are developing layouts should either follow a methodical guideline (like the one provided in chapter five) or a checklist in order to develop a design layout.

- All the participant parties in this industry should be educated in the area of the production process and design. Training should be provided to all members of the industry, especially the workers. As these are the people who have the maximum experience in this area, they would be the best guides to better layout design.

- In the long run, the author believes that the present production process should be studied in greater detail and certain radical changes could be made, alleviating change/improve the present layout design limitations.

- Manufactured housing industry is a labor-intensive industry. Though this allows for a lot of flexibility for design, manufacturers should consider implementing certain automation. Specific areas like interior wall fabrication and cabinets production should be mechanized to improve and speed up the production process.

This research provides insight into and an understanding of various parameters related to the manufactured housing layout design process. Manufacturers can use the different layout options and the process guideline model and tailor them to their requirements.

6.5 AREAS OF FUTURE RESEARCH

The three layout alternatives selected from the five layout alternatives can be studied from the Three-Dimensional perspective. The layouts must be analyzed and based on the changes/additions that occur, new solutions to these layouts could be provided. Also individual cost calculations must be carried out for the selected layouts.

Layout development based on quantitative measure of flow

The first obvious area of future research is the development of layouts based on the quantitative measure of flow for the proximity relationships data input. The author believes that this type of input would produce more accurate and effective layouts. But, as this form of flow requires detailed inventory management and material and cost flow analysis, documenting this process will require extensive efforts. This process will include detailed data collection related to material flow between individual stations and the costs (material, labor, and equipment) involved. Also, a detailed documentation of the inventory maintained, both temporary and permanent, is required. More effective layouts can then be developed based on both qualitative and quantitative data and can be evaluated based on the how effective they are in different spheres, like material management, labor utilization, and equipment utilization. Simulation can be used to study the efficiency of the layouts in these areas, and different "what-if" scenarios could be carried out to produce optimal solutions to plant layouts.

Optimal layout design and optimal production process integration

Extensive research has been carried in the field of manufactured housing production process development. Based on this research generic production process details can be simulated to develop an optimal production process. Once the optimal production process has been developed, the layout design techniques and tools developed in this thesis can be used to prepare an optimal layout. The detailed inventory management can be a strong input for the development of an optimal layout. This optimal layout can be then used as a template and manufacturers can then input their specific production process details and customize the layouts to their needs.

Supply chain management perspective

The complete manufactured housing industry can be studied from the supply chain point of view. The overall process, from the supplier to the consumer, can be studied and analyzed and possible optimal locations of manufactured housing production plants can be suggested. In the area of product development, radical changes can be suggested in the manufactured homes themselves. Their feasibility can be studied based on how well these changes satisfy the structural requirements, transportation limitations, and consumer demands. These changes will also affect the production process. Again, simulation can be used to assess the various options and select the most effective solution.

Total quality management in production process

Also, the area of Total Quality Management should be explored. The present production process should be studied and possible areas of quality improvements should be identified. After each cluster is installed, there should be quality checks so that rework can be avoided. The level of automation in this industry is extremely low as compared to other growing industries. Each section of the plant should be studied for possible areas of automation, not only to improve the process but also to improve the quality of the product. Also, research studies could be carried out to access consumer satisfaction in areas of space, quality, and durability of the product, and based on the results, possible changes in manufactured homes could be suggested.

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APPENDIX A

Production Plant A

Space Requirements station No. 1

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Rawmaterial supplied from
Floor	Installation of floor joist	Main assembly station	1200			
		feeder station		Bring in chassis	chassis	external storage
				Install Insulation	Rock insulation	Pipeline & ductwork subassembly station
		feeder station	1200	Install pipelines & ductwork	ductwork	Pipeline & ductwork subassembly station

Space Requirements station No: 2

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Rawmaterial supplied from
Floor	Floor decking	Main assembly station	1200			
				Installation of floor joist	Floor joist members	feeder station
				install floorboards	floor boards	Floor boards feeder station
				cut holes for ductwork		
		Subassembly station	1200	Install floor tiles in wet areas	floor tiles	Vinyl sheet rolls

Space Requirements station No: 3

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Walls (1)	Installation of interior walls	Main assembly station	1200	place interior walls.	Fabricated interior walls	
Walls (2)	Installation of interior walls	Main assembly station	1200	place interior walls, cabinets, and bathtubs	Fabricated interior walls	
		subassembly station		set studs on spacing	studs, drywall	
		subassembly station	3000	Insulate, glue & nail to wall boards	wall boards	interior walls subassembly station
		Feeder station	1200		wallboards	wall board feeder station
		Subassembly station	1200	assemble cabinets	Cabinets & bathtubs	Cabinets & bathtub feeder station

Space Requirements station No: 4

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
walls(1)	Installation of exterior walls	Main assembly station	1200	install wall board & insulation & exterior wallboards		
walls(2)	Installation of exterior walls	main activity station	1200	install wall board & insulation & exterior wallboards		
		Feeder station	1200		wallboards, insulation	

Space Requirements station No: 5

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Walls	Installation of electrical wiring & mech equipment	Main assembly station	2400			
		Feeder station	1200		wiring and piping	wall board feeder station

Space Requirements station No: 6

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Roof	Installation of roof	Main assembly station	2400			
		Subassembly station	1600	set roof truss based on spacing	trusses	truss feeder station
		Subassembly station	1600	glue & nail the ceiling boards	ceiling boards	ceiling board feeder station
		Subassembly station	1600	spray paint the ceiling & drying & loose insulation	paint	paint feeder station

Space Requirements station No: 7

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Exterior finishes	installation of door and window	Main assembly station	2400			
		Feeder station	1000	material for door & window installation	doors & windows	doors & windows feeder station
Roof	installation of roof boards	Feeder station	1000 (same as door & window feeder station)	material for roof boards installation	vinyl sidings with backer board	doors & windows feeder station

Space Requirements station No: 8

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Roof	Installation of roof shingles	Main assembly station	2400	Install roof shingles		
		feeder station	800	shingles installation	Fiberglass shingles	shingles feeder station
exterior finishes	installation of exterior sidings	Main assembly station	2400 (same as shingles installation main assembly station)	Installation of exterior siding	exterior siding	ceiling board feeder station

Space Requirements station No: 9

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Interior finishes	Installation of carpet and commode	Main assembly station	1200			
				material for installation of foam	foam	Foam feeder station
		feeder station	800	installation of carpets	carpet	carpet feeder station
		feeder station	1200 (same as material shipment for site)	installation of western commodes	commodes	feeder station

Space Requirements station No: 10

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Interior finishes	installation of interior finishes (appliances and drapes)	Main assembly station	1200			
				Checkup Electrical, plumbing, and HVAC		
		Feeder station		installation of kitchen appliances	appliances	appliances feeder station

Space Requirements station No: 11

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Interior finishes	final cleanup and testing inspection	Main assembly station	1200	clean up, testing inspection, tires, materials placement		
		Feeder station	1200	material to be placed in the home for onsite installation	onsite material package	feeder station
interior finishes	testing and cleanup operations	Main assembly station				
				installation of additional tires and testing & inspection	tires and axles	tires feeder station

Production Plant B

Space Requirements station No. 1

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Floor	Installation of floor joist	Main activity station	1330			
		feeder station	2000	Bring in chassis	chassis	external storage
		Subassembly station	770	Installation of floor joist/boxing	Floor joist members	feeder station
		Feeder station	770	Install Insulation	Rock insulation	Joist & ductwork subassembly station
				Install ductwork	ductwork	Joist & ductwork subassembly station

Space Requirements station No:2

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Floor	Floor decking	Main activity station	1330			
		Feeder station		install floorboards	floor boards	Floor boards feeder station
		Subassembly station	1330			

Space Requirements station No:3

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Floor	Rough plumbing and electrical	Main activity station	1350			
				Mark wet &dry areas		
	cut holes for ductwork/decking & stringer	Subassembly station		Install floor tiles in wet areas/	floor tiles	vinyl sheet rolls
		feeder station	400	rough plumbing & electrical	electrical and plumbing material	elec & plumb storage

Space Requirements station No:4

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Walls	Installation of interior walls	Main activity station	2700	place interior walls	Fabricated interior walls	
		subassembly station				subassembly station-1, set studs on spacing
		subassembly station	4080			subassembly station-2, glue & nail to wall boards
		Feeder station	1530	install cabinets & bathtubs	Cabinets & bathtubs	Cabinets & bathtub feeder station

Space Requirements station No:5

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
walls	Installation of exterior walls	main activity station	2700			
		Feeder station		place exterior walls	exterior walls	Feeder station
				Installation of studs and insulation	studs and insulation	studs & insulation subassembly station
		Subassembly station	3510 (2700+810)		exterior wall board	wall board feeder station
		Feeder station	400	mechanical, electrical & plumbing	wiring	Feeder station

Space Requirements station No:6

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Roof	Installation of roof	Main activity station	2700			
		Subassembly station	1350	set roof truss based on spacing	trusses	truss feeder station
				glue & nail the ceiling brds	ceiling boards	ceiling board feeder station
		Subassembly station	2700	spray paint the ceiling & drying	paint	paint feeder station

Space Requirements station No:7

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Roof	Decking and shingles placement	Main activity station	2700			
		subassembly station		loose insulation in roof	loose insulation	insulation feeder station
		feeder station	2700	installation of roof boards (OBS)	OBS	OBS feeder station
exterior finishes	installation of exterior finishes	Main activity station				
		Feeder station	1536	door & window installation	doors & windows	doors & windows feeder station

Space Requirements station No:8

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Roof			2700			
		feeder station	1000	shingles installation	Fiberglass shingles	shingles feeder station
exterior finishes						
		Feeder station	1536	exterior siding	vinyl sidings with backer board	sidings feeder station

Space Requirements station No:9

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
interior finishes	installation of interior finishes	Main activity station	1350			
				Electrical, plumbing, and HVAC		
	Installation of carpet and commode	Main activity station				
		feeder station	720	installation of foam	foam	Foam feeder station
		feeder station	400	installation of carpets	carpet	carpet feeder station
		feeder station	700	installation of western commodes	commodes	feeder station

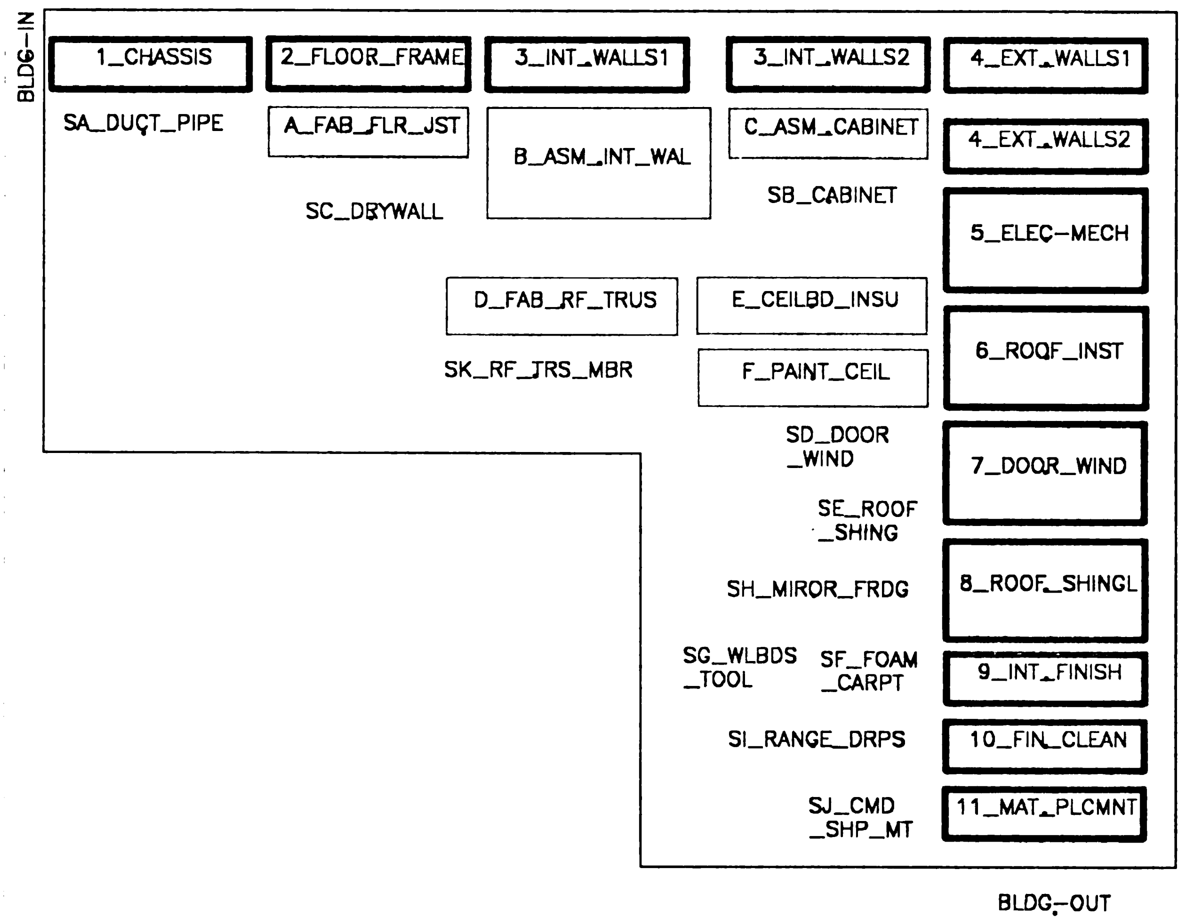
Space Requirements station No:10

Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
Interior finishes	installation of appliances	Main activity station	1350			
		Feeder station	2960	installation of kitchen appliances	appliances	appliances feeder station
		Feeder station	4240	material to be placed in the home for onsite installation	onsite material package	feeder station

Space Requirements station No:11

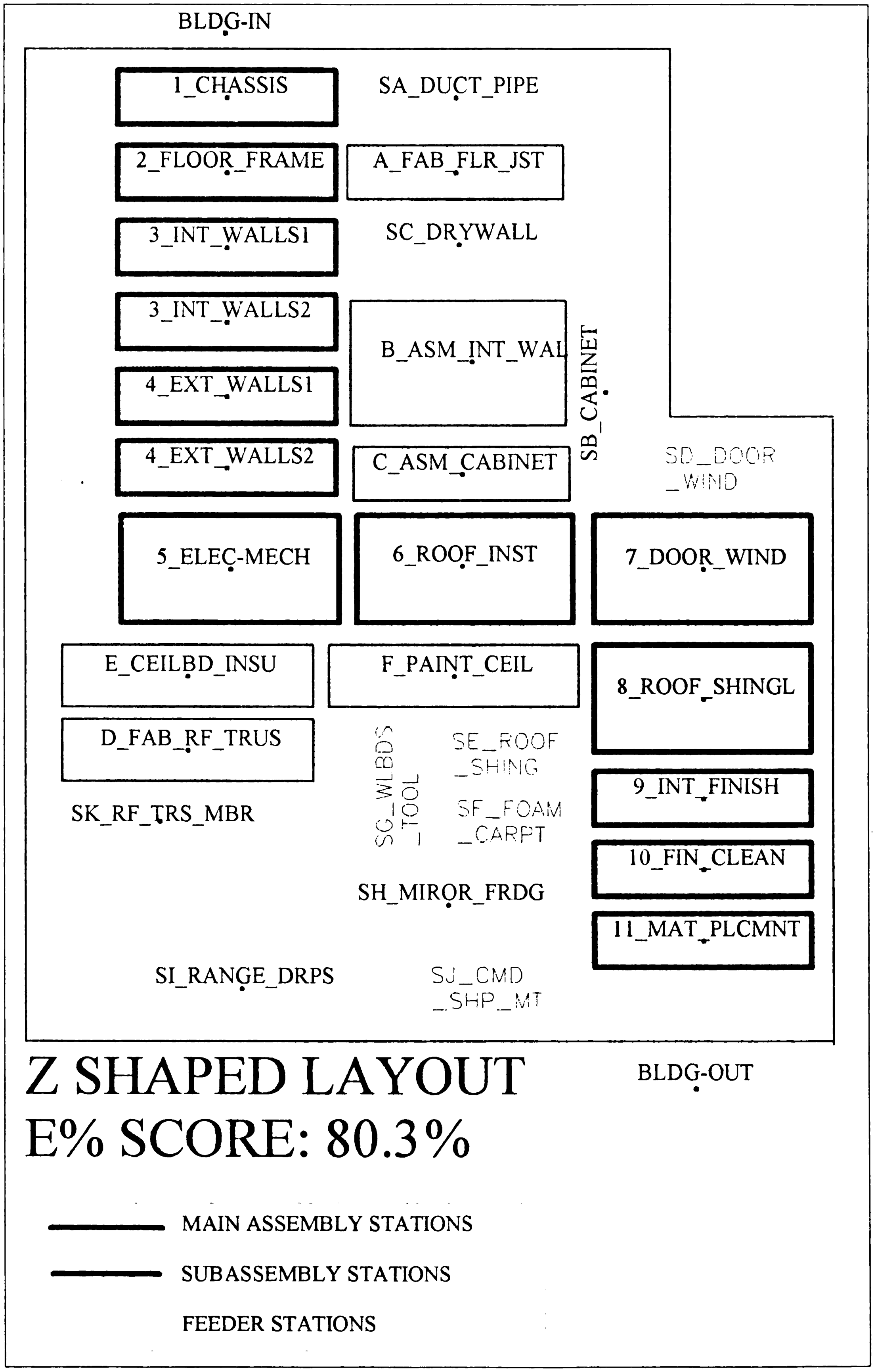
Cluster name	Description	Station Type	Area (l*b)	Major activities	Major Raw material	Raw material supplied from:
interior finishes	testing and cleanup operations	main activity station	1350			
			500	installation of additional tires	tires and axles	tires feeder station
				testing & inspection		
				final cleanup		

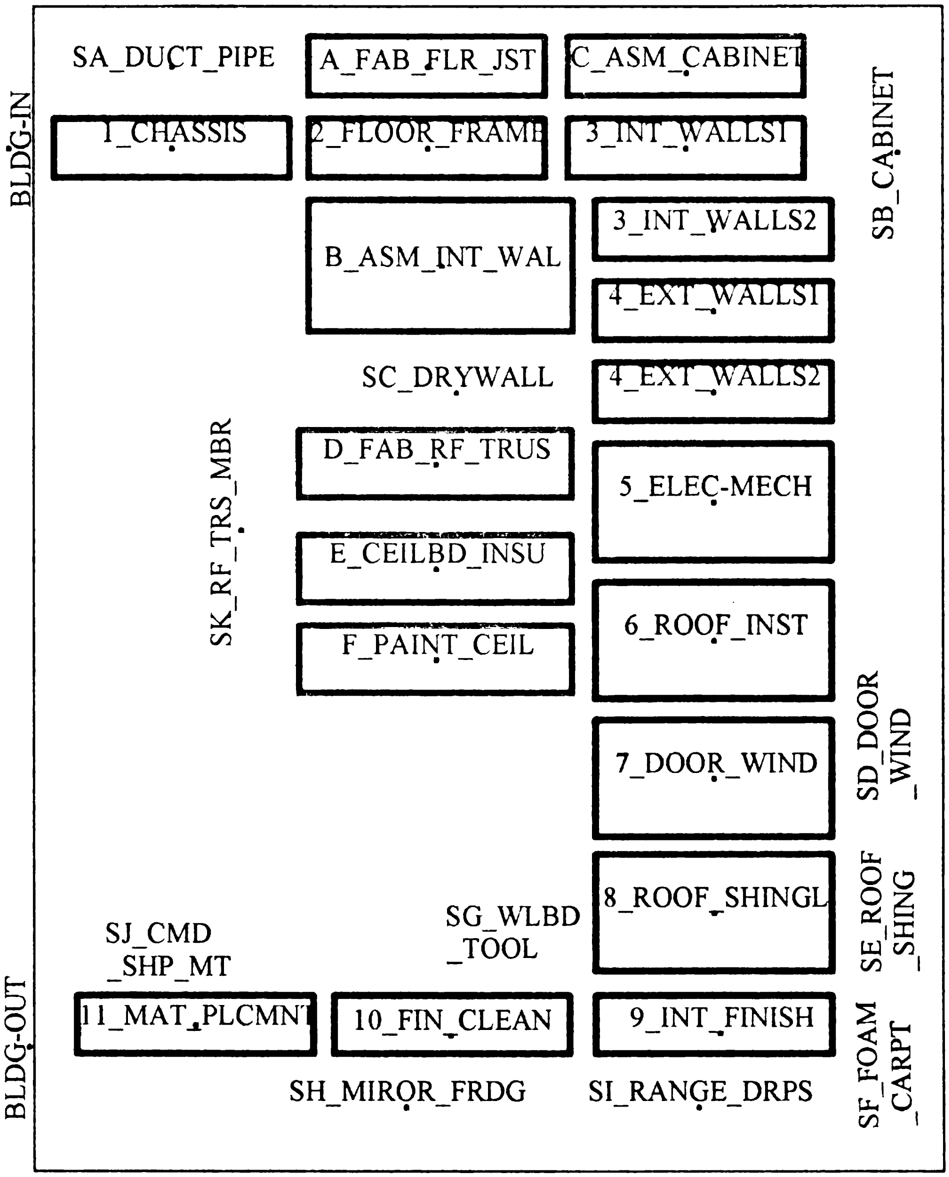
APPENDIX B



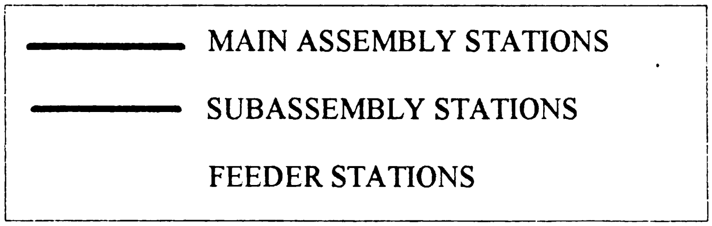
L SHAPED LAYOUT
E% Score: 76.8%

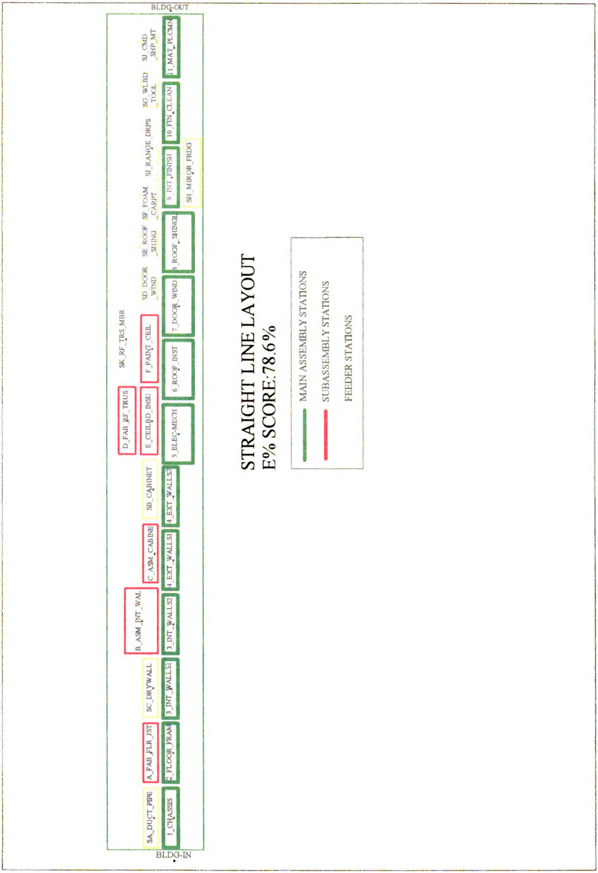
———	MAIN ASSEMBLY STATIONS
———	SUBASSEMBLY STATIONS
	FEEDER STATIONS

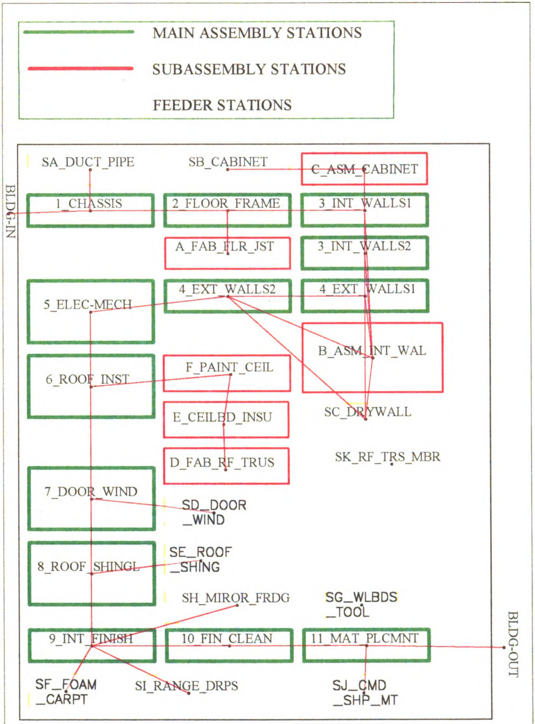

BLDG-IN
1_CHASSIS
SA_DUCT_PIPE
2_FLOOR_FRAME
A_FAB_FLR_JST
3_INT_WALLS1
SC_DRYWALL
3_INT_WALLS2
B_ASM_INT_WAL
SB_CABINET
4_EXT_WALLS1
4_EXT_WALLS2
C_ASM_CABINET
SD_DOOR
_WIND
5_ELEC-MECH
6_ROOF_INST
7_DOOR_WIND
E_CEILBD_INSU
F_PAINT_CEIL
8_ROOF_SHINGL
D_FAB_RF_TRUS
SG_WLBDS
_TOOL
SE_ROOF
_SHING
SF_FOAM
_CARPT
9_INT_FINISH
SK_RF_TRS_MBR
10_FIN_CLEAN
SH_MIROR_FRDG
11_MAT_PLCMNT
SI_RANGE_DRPS
SJ_CMD
_SHP_MT
Z SHAPED LAYOUT
E% SCORE: 80.3%
BLDG-OUT
MAIN ASSEMBLY STATIONS
SUBASSEMBLY STATIONS
FEEDER STATIONS



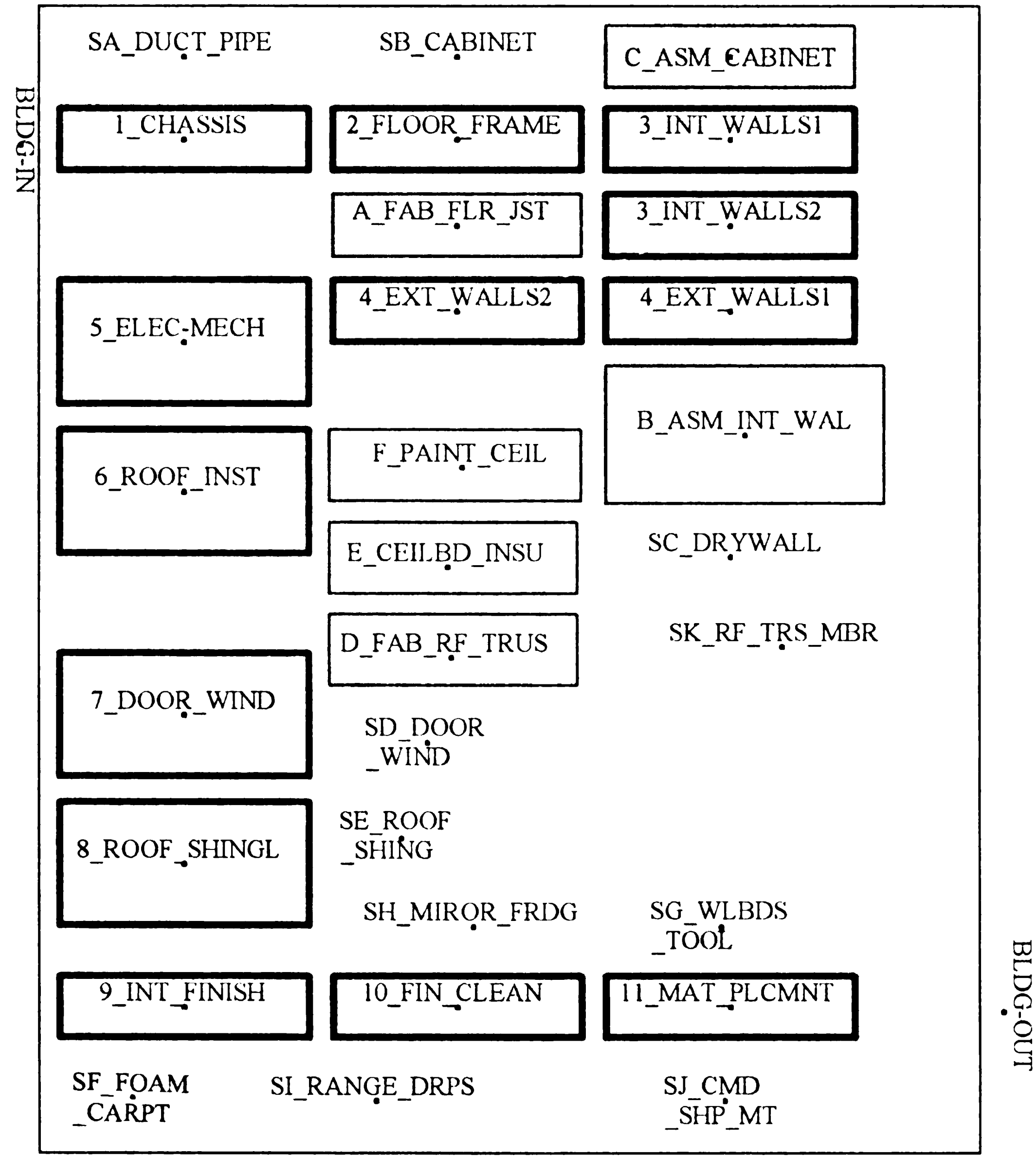
U SHAPED LAYOUT
E% SCORE: 87.7%




BLDG-OUT
BLDG-IN
1_CHASSIS
2_FLOOR_FRAM
3_INT_WALLS1
3_INT_WALLS2
4_EXT_WALLS1
4_EXT_WALLS2
5_ELEC-MECH
6_ROOF_INST
7_DOOR_WIND
8_ROOF_SHINGL
9_INT_FINISH
10_FIN_CLEAN
11_MAT_PLCMN
SA_DUCT_PIPE
A_FAB_FLR_JST
SC_DRYWALL
B_ASM_INT_WAL
C_ASM_CABINE
SB_CABINET
D_FAB_RF_TRUS
E_CEILBD_INSU
F_PAINT_CEIL
SK_RF_TRS_MBR
SD_DOOR_WIND
SE_ROOF_SHING
SF_FOAM_CARPT
SI_RANGE_DRPS
SH_MIROR_FRDG
SG_WLBD_TOOL
SJ_CMD_SHP_MT
STRAIGHT LINE LAYOUT
E% SCORE:78.6%
MAIN ASSEMBLY STATIONS
SUBASSEMBLY STATIONS
FEEDER STATIONS

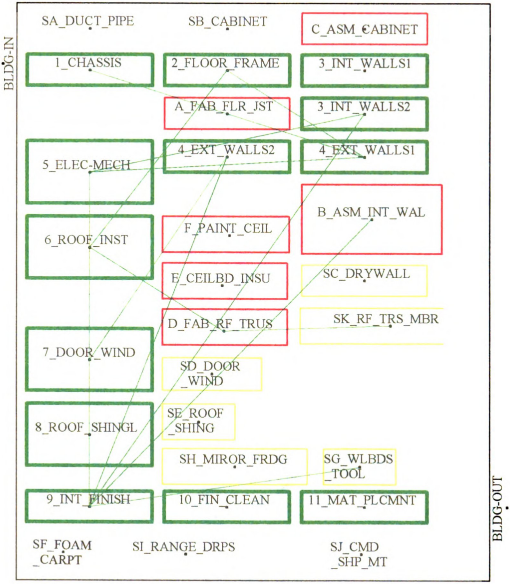


S SHAPED LAYOUT
E% Score: 89.7%
"A" Relationship



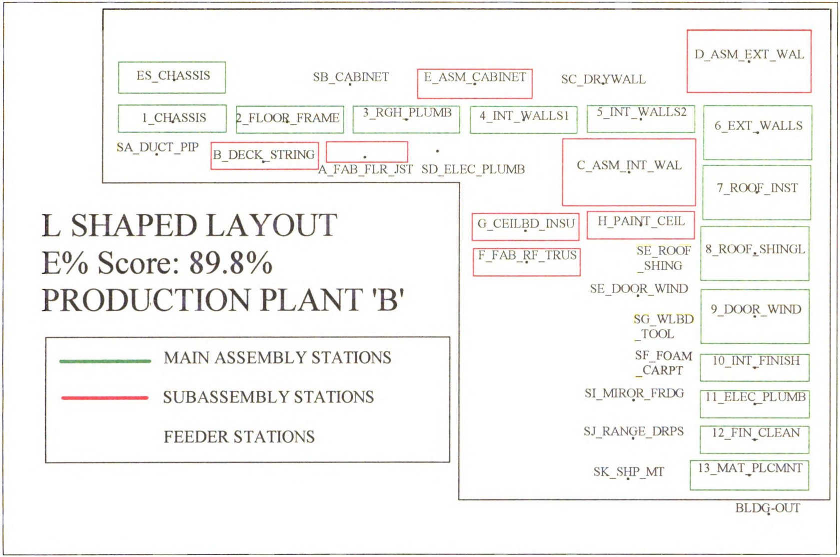
S SHAPED LAYOUT
E% Score: 89.7%
"E" Relationship

————	MAIN ASSEMBLY STATIONS
————	SUBASSEMBLY STATIONS
	FEEDER STATIONS



S SHAPED LAYOUT
E% Score: 89.7%
"I" Relationship

MAIN ASSEMBLY STATIONS
SUBASSEMBLY STATIONS
FEEDER STATIONS


ES_CHASSIS
SB_CABINET
E_ASM_CABINET
SC_DRYWALL
D_ASM_EXT_WAL
1_CHASSIS
2_FLOOR_FRAME
3_RGH_PLUMB
4_INT_WALLS1
5_INT_WALLS2
6_EXT_WALLS
SA_DUCT_PIP
B_DECK_STRING
A_FAB_FLR_JST
SD_ELEC_PLUMB
C_ASM_INT_WAL
7_ROOF_INST
G_CEILBD_INSU
H_PAINT_CEIL
F_FAB_RF_TRUS
SE_ROOF _SHING
8_ROOF_SHINGL
SE_DOOR_WIND
9_DOOR_WIND
SG_WLBD _TOOL
SF_FOAM _CARPT
10_INT_FINISH
SI_MIROR_FRDG
11_ELEC_PLUMB
SJ_RANGE_DRPS
12_FIN_CLEAN
SK_SHP_MT
13_MAT_PLCMNT
BLDG-OUT
L SHAPED LAYOUT
E% Score: 89.8%
PRODUCTION PLANT 'B'
MAIN ASSEMBLY STATIONS
SUBASSEMBLY STATIONS
FEEDER STATIONS