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REDESIGN PROCESS AND ITS IMPACT ON PRODUCTION
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MANUFACTURED HOUSING COMPONENTS ASSEMBLY REDESIGN PROCESS AND ITS IMPACT ON PRODUCTION PROCESS AND FACILITY LAYOUT

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Abhi Sabharwal

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ABSTRACT

MANUFACTURED HOUSING COMPONENTS ASSEMBLY REDESIGN PROCESS AND ITS IMPACT ON PRODUCTION PROCESS AND FACILITY LAYOUT

By

Abhi Sabharwal

The manufactured housing industry produces one of the most popular factory-built housing, and it has a great potential to meet the increasing demand for affordable housing. However, visit to a manufactured housing factory reveals that the industry's assembly procedure for assembling the manufactured house is still primitive. Therefore, there is a need to introduce advanced and futuristic techniques, and equipments currently used in other progressive manufacturing industries. The overall goal of this research is to show the effect of manufactured housing components assemblies redesign on the productivity of the production process and the material handling cost of the facility layout. In order to accomplish this goal, alternative assembly process for parts of the manufactured housing assembly is developed. The effect of the change in the assembly process is shown on the material handling cost and the productivity with help of FactoryFLOW facility layout software and Arena simulation software. In addition, this research also presents integrated information input–output model, which can be used to integrate the two software. Two approaches for data transfer between the two software are also illustrated and a demonstration example is developed to show the data exchange between the two software by one of the approach.

In loving memory of my Bauji and Bade Papa

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CHAPTER - I

INTRODUCTION

1.1 Overview

Manufactured houses are built in a controlled factory environment, in compliance with the building code specified by the U.S. Department of Housing and Urban Development, also known as the HUD code. In the early 1970s, manufactured houses were referred to as trailers and were one of the less expensive options for housing. They have grown in popularity since World War II when they served veterans returning back home (Senghore 2001). In 1980, the federal government renamed "trailers" or "mobile homes" to "manufactured houses." Initially, the manufactured housing industry comprised all types of factory-built housing, but with the passage of time other segments of factory-built housing, such as panelized and modular, started separating their products from the manufactured housing industry (Banerjee 2003). However, the terms "trailers" and "mobile homes" was still applied to manufactured houses. The following section gives a brief overview of the manufactured housing industry.

The overall share of manufactured housing in overall housing was 18.9% in 2001, the highest among all the factory-built housing. Although it had dropped from 22.7% in 1998, manufactured housing still remains the market leader in factory-built housing (Willenbrock 1998, MHI 2000, AutoB 2002).

A study conducted by Foremost Insurance Company found that almost 88% of manufactured house owners reported satisfaction with their housing choice (MHI 2004b). Manufactured houses offer good quality homes at a lower price. It is also known that a majority of manufactured houses are never moved after they have been installed and in this they are similar to site-built houses. The average square foot cost of a manufactured house is significantly less than that of a site-built house (MHI 2004a). The cost saving of manufactured houses can be attributed to the controlled factory environment and mass purchasing of material. Figure 1.1 shows the controlled factory environment.

Figure1.1: Controlled Factory Environment
(Hastak & Syal 2002)

In the year 2000, 22 million Americans (about 8% of the American population) lived in 10 million manufactured houses (MHI 2004a). In the 1990's the annual overall housing demand was around 2 million units, whereas the supply was only around 1.5 million units, leading to shortage of around 0.5 million housing units. It is quite evident from the above facts that there is not enough housing to satisfy the demand. Manufactured houses can be a very meaningful solution to this housing shortage. Out of 1.5 million units, almost 350,000 manufactured housing units were shipped in the year 1999 (Syal & Hastak 2000).

Manufactured houses generally are of two types, single-section and double-section. Multi-section houses are also available, but they are significantly less in number when compared to single- and double-sections. Mostly single-section houses are 16' wide with an average area of 1200 square feet; double-section houses are 32' wide with an average area of 1550 square feet (Banerjee 2003). Over the years, there has been a continuous growth of double-section houses and a decrease in single-section houses (MHI 2004d). The average price of a manufactured house in 2001 was $48,000; in the same year the price of a single-section house was $30,700; while a multi-section house (which includes both double-section and multi-section houses) was $55,100 (MHI 2004a).

People who live in manufactured houses come from a wide range of age groups and have varying incomes. But most people dwelling in a manufactured house are employed full time, with an annual salary range of $20,000-$29,999. The common age of the household head is 50-59 years and the house generally has two occupants (MHI 2004c). Manufactured houses have a huge impact on people and the economy. It was also estimated that in 2001, the economic impact from manufactured housing was $20.1 billion (MHI 2004a).

1.2 Need Statement

Food, clothing and shelter are three basic needs of humans. A home provides individuals with mental and emotional security. An individual's interaction with the built structure generates the recognition of its place in his or her life. People get attached to houses and come to call their house their home.

A house is a structure, but the individuals and families living in it make it a home. A home is probably one of the greatest assets of any family.

The performance and affordability is directly related to the technologies used to manufacture houses. The methods and technologies used for production of manufactured houses are still primitive (Syal & Hastak 2000). They have not progressed as compared to other manufacturing industries. They need to be refined and brought up to pace with other manufacturing industries. The National Science Foundation (NSF), Partnership for Advancing Technology in Housing (PATH) and HUD conducted a workshop "NSF Housing Research Agenda Workshop" in February 2004 with aim of compiling the current state of the art in housing technology and proposing future research directions to guide the funding in housing research. Researchers from all over the country gathered to recognize the need for research in the housing field (Syal et.al. 2003). Lack of technology was identified as one of the reasons for failure to provide adequate and affordable housing.

One of the most recent studies of the market also reveals that in spite of increasing demand for the manufactured houses, there has been a sharp drop in the production of manufactured housing units (Banerjee 2003). One possible way to combat the sharp drop is by improving and making the manufactured housing production plant more effective and the products less expensive.

Research conducted at Michigan State University, Purdue University and University of Cincinnati for NSF and PATH has shown that the manufactured housing production process and plant layout individually affect the productivity and the cost of production. Increasing productivity by making the production more efficient and reducing the material handling cost by altering the facility layout can add to the affordability factor of manufactured housing (Senghore 2001, Hammad 2001, Hammad 2003, Mehrotra 2002, Banerjee 2003). But, the effect of varying both these aspects together to get the best fit has not yet been considered. One of the possible ways of analyzing the two variables or aspects is by changing the components assembly process. Previous research has shown that the individual enhancement and improvement in the production process and the facility layout have had impressive effects. Therefore analyzing the change in manufactured housing production process and facility layout by changing the components assembly process can lead to further increase in productivity and to lowering of material handling cost. The following sections briefly explain various factors related to the need for this proposed research.

1.2.1 Increase in the Variability of Demand and Customization of Manufactured Housing

Low variation in product design, inability to adjust production to demand, and economic recession are the three main reasons for the downward trend of the manufactured housing industry today. The industrialization of housing has achieved high production levels and substantial cost reductions due to mass production and economies of scale. However, the reverse trend can be observed in terms of the design flexibility (Hammad 2003). The inability of production lines to adjust to product variability, demand and customization has always caused problems for production plants. Manufactured houses are customized, but only to a certain extent. This customization is mainly cosmetic. In author's view, manufacturers have found it hard to deal with the variation of demands and product change. Many manufacturers had to close down their plants due to the economic recession. Some manufacturers who had multiple plants decided to operate only from one plant.

The market has seen a variable trend in the nature of demand for manufactured housing. A trend has also been observed in the growing demand for double-sections and decreasing demand for single-sections. However manufactured housing production plants have not been able to adjust to this variation. There is a need for a more flexible system for manufacturing manufactured houses.

Lean manufacturing and flexible manufacturing are two new manufacturing techniques, which are being adopted by more and more manufacturers in order to survive in these difficult times. Lean manufacturing can help manufacturers identify and reduce waste. While flexible manufacturing, leads to more flexible manufacturing (BCM-891). Thus, a manufacturing production plant can reduce waste and at the same time adjust to the changes put forward by the market and other external factors.

1.2.2 Economic Recession

The manufactured housing industry has experienced a sharp decline in sales since its peak in 1998. However the demand for site-built housing has remained level. Many reasons can be given to explain the decline in demand for manufactured housing. One major reason was the repossession of homes in the late 1900's after lending firms had approved many buyers to buy new homes. This has led to strict rules for loan approval for new homes (Banerjee 2003). As a result, manufacturers are forced to concentrate more on the production of homes and their systems within the facility. The concept of adding "value" to the house has started taking its toll on manufacturers. Manufacturers focus on just producing houses; they need to produce good houses and in some cases, better ones. Research based on both production process and layout needs to be conducted and incorporated by the manufacturers for survival of these plants.

1.2.3 Need to Implement Components Assembly Redesign Techniques

One possible way to solve the above problems is by redesigning the manufactured housing components assemblies. It is possible to measure the effect of the components assemblies redesign by observing how changing the components assembly process affects the output of the production process and the material handling aspect of the facility layout. Proposal for redesigning the components assembly process is based on the hypothesis that changes in the components assembly process would affect both the production process and the facility layout.

Major problems encountered at a manufactured housing plant are idle stations; wastage of materials, manpower and equipment; inefficient use of resources; and reliance on manpower, rather than machines and smart robots.

Manufactured housing has a lot to learn from other manufacturing industries (Syal and Hastak 2000). Also it has been observed that the manufactured housing plant spends very little time and money in analyzing its facility and problems, compared to other manufacturing industries. The automobile industry, by the contrary, spends millions of dollars for analyzing and improving their facilities and processes (Banerjee 2003).

This need for analyzing the manufactured housing production plant provides a motive for the study and understanding of production process and facility layout. The work was started by Senghore (2001), in which the author developed a process model of manufactured housing production process. Hammad (2001) took the lead in simulating the production process, and identifying and removing the bottlenecks. On the other hand, developmental work on planning and design of the facility layout was initiated by Mehrotra (2002). In her work, the author proposed two ways of analyzing the facility layout - one qualitative and other, quantitative. Mehrotra's research work was limited to the qualitative aspect of facility layout, while Banerjee (2003) analyzed the quantitative aspect, based on material flow. The material handling system and the layout was analyzed and an efficient method for material handling system was proposed, as an effect the cost of material handling was greatly reduced. Although the production process was assumed to be constant, meaning the production process was not altered and the change was only in the layout and the material handling system. So far there have been no attempts to analyze the components assemblies and measure their effect on both the production process and facility layout.

By implementing the manufactured housing components assembly redesigning process, the author believes production can be increased and material handling cost, decreased. The assumption underlying this proposed study is that the manufactured housing components assembly redesign would affect both the production process and the facility layout. As a by-product of redesigning the components assembly process, new assemblies will be developed and proposed. Such new assemblies would be based on their technical feasibility, cost savings in material handling, and increase in production.

1.2.4 Manufactured Housing as an Affordable Option

Housing today is a very expensive. In 1999, HUD released a report titled "A Report on Worst-Case Housing Needs: New Opportunities Amid Continuing Challenges" (HUDUSER 1999). According to this report, 4.9 million households with 10.9 million individuals face "worst-case housing needs". These families are renters who received no government assistance, make less than 50% of the area median income; pay more than 50% of their income for rent and utilities; and / or live in housing with severe physical deficiencies such as no hot water, no electricity, no toilet or no bathtub nor shower. These 10.9 million people are barely able to fulfill their need for shelter. Also from 1997 through 1999, there was a 9% drop in the number of rental units available to low-income renters. This meant almost 1.1 million fewer rental units were available for renters whose incomes were 50 percent below the local area median. It is also estimated that 14 million people pay more than 30 percent of their monthly income for rent and utilities, and more than 6.7 million households pay more than 50 percent of their income for rent (Habitat 2004).

Providing affordable, durable and quality homes has always been one of the greatest problems facing the society. Clearly, a person cannot be a productive member of society without a decent place to live. Without adequate, safe and affordable housing individuals cannot grow, children cannot learn and families cannot thrive. Affordable housing is one of the major problems faced by many countries these days. Over the years, a fair amount of research has taken place to deal with the problem of providing enough and affordable housing. The shortage of affordable housing can be solved if houses can be constructed faster and at lower cost while not compromising on quality. In recent years, there has been a rejuvenated emphasis on housing technology research due to the PATH program initiative at the HUD and the NSF (Syal et.al. 2003).

Manufactured housing is a meaningful solution for providing affordable housing and solving the housing shortage problem. The advantages of manufactured housing are many-fold. It is a viable option for affordable housing, because it costs significantly less than a site-built house.

The manufactured housing industry is the market leader in the factory-built housing industry. The popularity of manufactured housing comes from its affordability. As manufactured houses are built in a controlled factory environment, the production process is much more efficient, as compared to building a house on a site where the construction process is exposed to such limitations as weather and poor working conditions. This gives manufactured housing an advantage over site-built housing. Also manufactured houses are more affordable for a large sector of society, as compared to site-built houses. Table 1.1 shows the cost and size comparison for a new manufactured house and a new single-family site-built house.

Table 1.1 Cost and Size Comparison for New Manufactured House and New Single-Family Site-Built House
(Source: MHI 2004e)

Year	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Manufactured House (Including installation cost)							
Single-Sections							
Average Sales Price	$27,000	$27,900	$28,800	$29,300	$30,400	$30,800	$30,700
Average Square Footage	1,165	1,200	1,240	1,120	1,130	1,115	1,120
Cost Per Square Foot	$23.18	$23.25	$23.23	$26.16	$26.73	$27.26	$27.50
Multi-Sections							
Average Sales Price	$46,200	$48,100	$49,800	$51,100	$53,600	$55,200	$56,200
Average Square Footage	1,580	1,575	1,580	1,655	1,675	1,695	1,715
Cost Per Square Foot	$29.24	$30.54	$31.52	$30.88	$32.00	$32.57	$32.77
Single-Family Site-Built House							
Average Sales Price	$166,400	$176,200	$181,900	$195,600	$207,000	$213,200	$228,600
Less Land Price	-$31,846	-$33,227	-$34,709	-$45,238	-$47,476	-$49,056	-$54,460
Price of Structure	$134,554	$142,973	$147,191	$150,362	$159,524	$164,144	$174,140
Average Square Footage	2,090	2,140	2,170	2,221	2,265	2,282	2,301
Cost Per Square Foot	$64.38	$66.81	$67.83	$67.70	$70.43	$71.93	$75.68

Shipments of manufactured houses have continually declined and sale prices have gone up. But manufactured housing still remains the least expensive housing option. The affordability of manufactured housing can be increased if adequate attention is given to the production line, facility layout and removal of waste. Waste may result from inefficient components assemblies, idle time at stations, material wastage, inefficient material handling, and rework. The cost reduction could also be achieved by reducing inventory levels, lead times, and integrating the supply chain. This reduction could be achieved through eliminating waste and all scrap forms in products. Scrap is found to be the major loss in factory resources and materials (Black 1998).

Table 1.2: New Manufactured Houses Placement
(Modified from: MHI 2004e)

Year	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*
Total Placements	363,345	353,676	372,143	348,102	250,419	193,120
Single Sections	173,557	148,809	144,608	122,575	74,919	48,924
Average Sales Price	27,000	27,900	28,800	29,300	30,400	30,800
Multi Sections	189,788	204,867	228,535	225,527	175,500	144,196
Average Sales Price	46,200	48,100	49,800	51,100	53,600	55,200
Retail Sales (billions)	$13.6	$14.1	$15.6	$15.1	$11.7	$9.5

1.3 Existing Research

Starting in 2000, collaborated research efforts have been taking place at Michigan State University, Purdue University and University of Cincinnati in Manufactured Housing. This research is funded by the National Science Foundation (NSF) through the Partnership for Advancing Technology in Housing (PATH) initiative under grants awarded in year 2000 (CMS Grant# 0080209) and

2002 (CMS Grant# 0229856). Earlier studies had the overall objectives of improving the production process, streamlining the material flow, and improving the facility layout design. The primary goal of these studies was to build better homes faster at lower cost with high quality. The overall approach of the first NSF grant (CMS Grant# 0080209) was to improve the production process by modeling the manufactured housing production and material utilization processes and exploring the facility layout design (Senghore 2001, Hammad 2001, Barriga 2003). The developmental work in facility layout initiated the research into the qualitative aspects of facility layout of a manufactured housing plant (Mehrotra 2002). The second grant (CMS Grant# 0229856) focuses on issues like optimal production process, facility layout, supply chain and developmental work in "Whole House" and "Building Redesign" (Banerjee 2003, Hastak & Syal 2002). Figure 1.2 shows the completed, on-going, and proposed research focuses of NSF funded manufactured housing research.

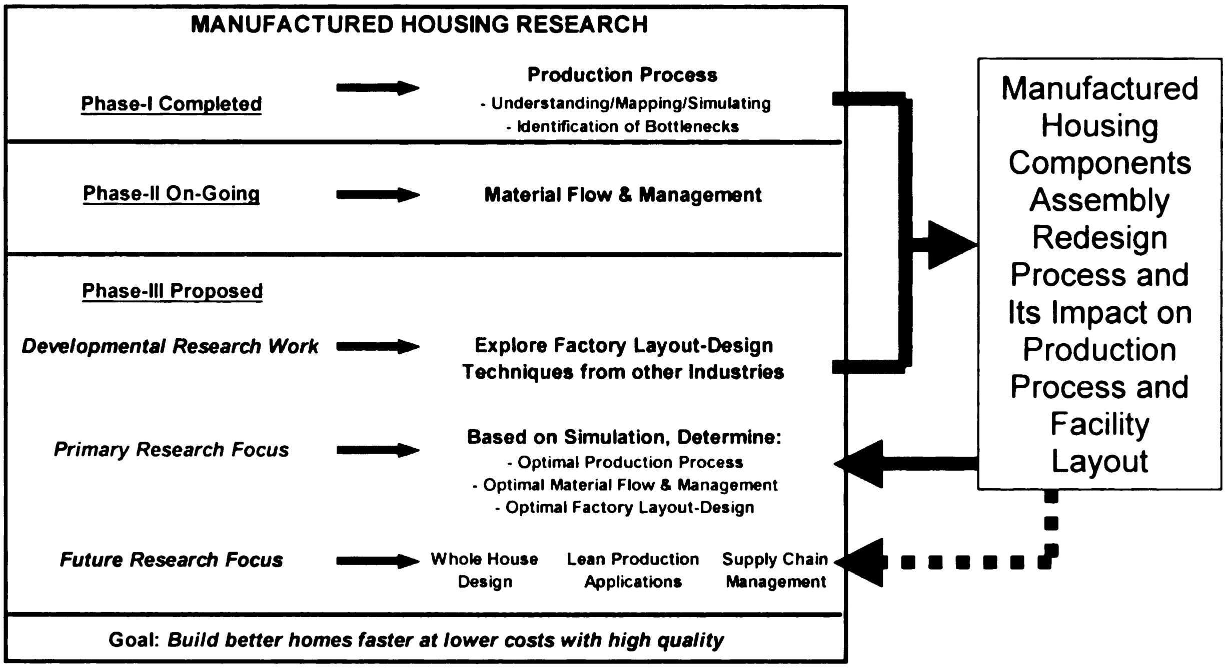


Figure 1.2: Earlier, On-Going, and Proposed Manufactured Housing Research (Modified From: Hastak & Syal 2002)

Major topics of research in manufactured housing are divided into the following categories:

- Production Process Modeling and Analysis
- Material Management
- Facility Layout Modeling and Analysis
- Supply Chain Modeling and Analysis
- Radical and Innovative changes in Whole House Design

Research on manufactured housing production process started with Senghore (2001), by investigating the manufactured housing production process and material flow. A process model was developed and with help of simulation, it led to the investigation and in-depth analysis of bottlenecks in the roofing station. Simultaneously, Hammad (2001) developed a simulation model for the overall production process and identified bottleneck stations. These bottleneck stations were resolved by a technique called line balancing. The resources were redistributed between the bottleneck and idle stations to make the production process flow smoothly. Also Barriga (2003) conducted research in material flow and management, looking into the problem causing material management systems and proposed solution as new material management system.

Developmental research work in facility layout was started by Mehrotra (2002), revealed two aspects of analyzing the facility layout. One was the qualitative aspect, which dealt with interdepartmental or station relationships and proximity. The other aspect was quantitative aspect, which dealt with the cost of material quantities, travel distances, including cost of material flow, and material handling systems (Banerjee 2003).

In addition, various other efforts have been carried out by the investigators funded by the two NSF-PATH grants. A PhD dissertation by Hammad (2003) titled “A Decision Support System for Manufactured Housing Production Process Planning and Facility Layout” is a by-product of these efforts. Currently, research in investigating inefficiencies in the supply chain (Jeong 2003) and building process redesign by “Whole-House” approach is also underway.

This research proposes to find the bridge between the production process and facility layout, since earlier studies focused only on either one of the aspects keeping the other aspect constant. This research will set the stage for accomplishing the objectives for an optimal production process and facility layout design, and developmental work in “Whole-House” design.

1.4 Research Scope and Uniqueness

The scope of the proposed research is to explore the redesign of components assembly systems by changing the existing components assembly process. This will be achieved by modifying existing and developing new assemblies, and by investigating their effect on the production process and facility layout. Components assemblies are the building blocks for an assembly. They include both individual parts as well as subassemblies. Their redesign would include, change in the product, assembly sequence and incorporation of some new assemblies.

This research focuses on the main as well as the feeder assembly stations where components are assembled. The proposed research investigates new ways of assembling components and their impact on the overall production process and on the material handling aspect of the facility layout. The production process is analyzed on the basis of the productivity and the facility layout was analyzed on the basis of the material handling cost. In addition, integrated information input–output model of simulation and facility layout software are also developed. The primary intent of this research is not to propose an optimum production process and facility layout but to see the effect of components assembly redesign on the manufactured housing production process and facility layout. The optimum design of production process and facility layout can be a future area of research carried as a continuation of author's work. Figure 1.3 depicts the research scope and methodology for the proposed research.

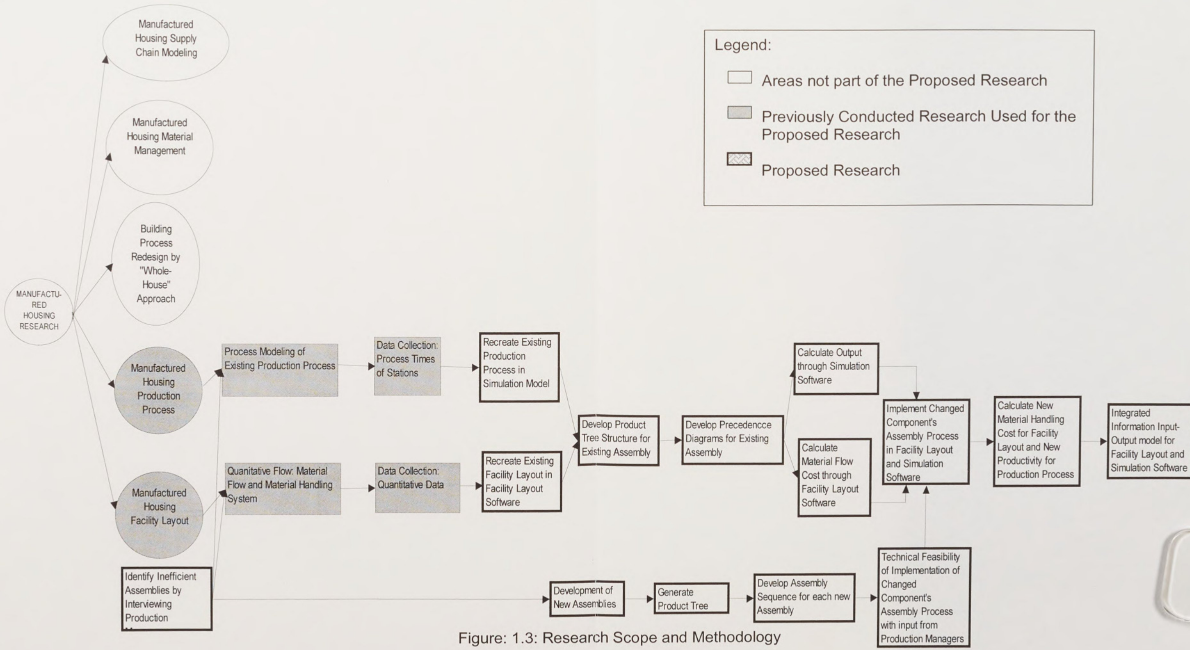


Figure: 1.3: Research Scope and Methodology

1.5 Goal & Objectives

The overall goal of this research is to demonstrate the effect of components assembly redesign on the productivity of the production process and the material handling cost of the facility layout of a manufactured housing production plant.

The primary objectives to achieve this goal are as follows:

Objective I: *To explore possible changes to the components assembly systems.*

Objective II: *To recreate the material handling analysis of the facility layout and the production process simulation models.*

Objective III: *To demonstrate the impact of the revised component assembly on the production process and the material handling aspect of the facility layout.*

Objective IV: *To explore the link between two aspects in objective III by integrating facility layout and simulation models.*

1.6 Methodology

In this thesis, the author redesigns the manufactured housing components and demonstrates their effect on the productivity of the production process and the material handling cost of the facility layout. The methodology steps have been listed under each objective.

1.6.1 Objective I: To explore possible changes to the components assembly systems

Step-1: Study and understand the manufactured housing assembly process.

Step-2: Identify clusters and parts of clusters of the manufactured housing assembly that are inefficient and can be done differently by incorporating new assemblies.

Step-3: Develop product tree structure for existing components assembly.

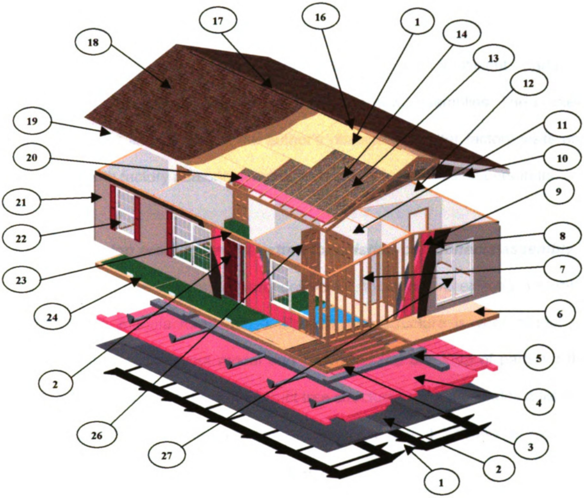
Step-4: Develop precedence diagrams for existing components assembly process.

Step-5: Develop new assemblies for these inefficient parts.

Step-1: Study and understand the manufactured housing assembly process.

The manufactured house consists of various components and subassemblies. There are thousands of components and subassemblies that come together to make a manufactured house. It is essential to study and have a detailed understanding of the assembly process, components and subassemblies and their functions, so as to propose new assemblies.

The author started by breaking down manufactured house into component parts and studying each part one by one. Specifically the author looked upon the significance and the function of the components. Figure 1.4 gives the break-up of some main components in a manufactured house.



1. Chassis	*10. Ceiling board*	*19. Soffit ventilation*
2. Bottom board	*11. Interior drywall*	*20. Eave Insulation*
3. Floor joist framework	*12. Side wall*	*21. Siding*
4. Floor Insulation	*13. Roof truss*	*22. Window*
5. HVAC Duct	*14. Roof insulation*	*23. Headers*
6. Floor Decking	*15. Roof Sheathing*	*24. Floor Covering*
7. Wall stud	*16. Ridge beam*	*25. Exterior Door*
8. Exterior Wall Sheathing	*17. Ridge vent*	*26. Interior Door*
9. Wall Insulation	*18. Roof protection*	*27. Patio/atrium door*

Figure 1.4: Components for Developing a Manufactured House
(Source: Fallcreek Homes Poster & Barshan 2003)

Step-2 Identify clusters and parts of clusters of the manufactured housing assembly that are inefficient and can be done differently by incorporating new assemblies.

Some inefficient clusters were selected and inefficient parts or components were identified for developing these new assemblies. The clusters and parts were identified from the author's observations after factory visits and interviews with factory personnel and other manufactured housing personnel.

Step-3: Develop product tree structure for existing components assembly.

Product tree structures were developed to represent existing assembly system for a manufactured house. Product tree structure is very helpful for modifying the facility layout model and conveying the break-up of parts for the product. The main advantage of product tree structure is that it provides a list and visualization of component parts of an assembly. Figure 1.5 shows an example of a product tree for a manufactured house chassis.

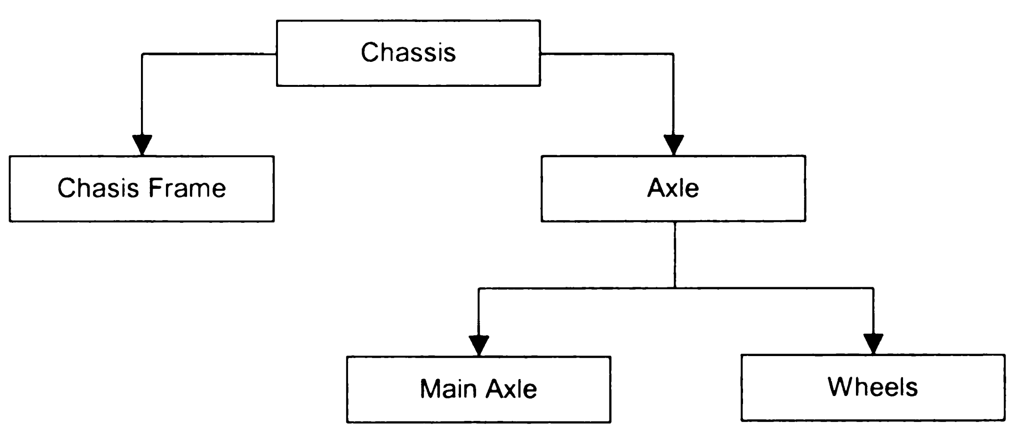
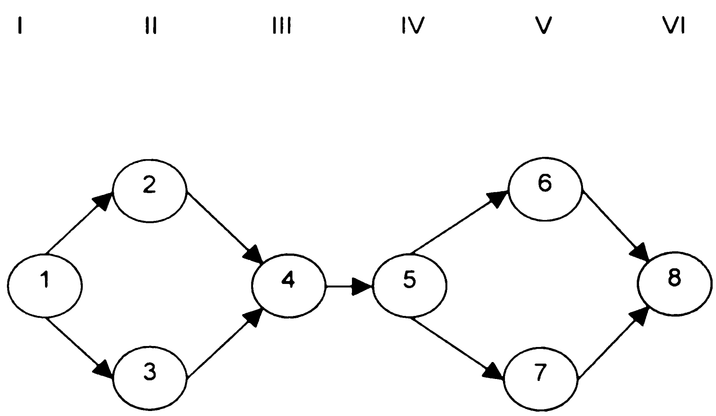


Figure 1.5: Product Tree Structure for a Manufactured House Chassis

Step-4: Develop precedence diagrams for the existing components assembly process.

It was vital for a useful assembly design to have a precedence diagram representation of an assembly process (Boothroyd et.al. 1982). There is always an order of assembling an assembly or product. It helps the manufacturers to sequence their operations and helps them understand the nature of assembly.

Once the assembly process for the assembly was studied, the next step was to develop the precedence diagram for these existing assembly processes. These precedence diagrams will further be used to explain the new assembly process and animating the procedure of assembling modified and new assemblies. Figure 1.6 is the precedence diagram for assembly of a manufactured house chassis.



1. Bring Chassis Frame in the station. 2. Load Chassis Frame on the pulley. 3. Align Main Axles with Chassis Frame 4. Lower Chassis Frame over Main Axles	5. Attach Main Axles with Chassis Frame 6. Attach Tires to Main Axles 7. Run Basic Electrical Wiring 8. Remove Chassis from Station.

Figure 1.6: Precedence Diagram for Assembly of a Manufactured House Chassis (Boothroyd et.al. 1982)

Step-5: Develop new assemblies for these inefficient parts.

The new assemblies developed were checked for technical feasibility. Factory personnel are the best candidates for taking input on feasibility due to their experience. Thus factory personnel, namely the production managers, were asked to assess the feasibility of use of modified and new assemblies. The new assembly intent was illustrated with the help of new product tree structures and new precedence diagrams. The production manager and other factory personnel at the case-study factory were interviewed and their input was taken to test the technical feasibility of the new assembly.

1.6.2 Objective II: To recreate the material handling analysis of facility layout and the production process simulation models

Step-1: Study the manufactured housing production process and facility layout.

Step-2: Explore different techniques and software of simulation and facility layout modeling.

Step-3: Recreate the existing facility layout model.

a. Study the prior developed facility layout model.
b. Verify the changes on the model based on the case study factory.
c. If necessary, collect pertinent data to depict modification in the facility layout model.
d. Modify existing layout and recreate quantitative facility layout model.

e. Compare the annual material handling cost, calculated by the facility layout model and the cost incurred by the plant.

Step-4: Recreate production simulation models.

a. Collect data for simulating the production process by visiting the case study factory.
b. Develop simulation models for inefficient clusters.
c. Verify the model as per the modeling assumptions.
d. Compare the simulation model's output to the factory's output.

Step-1: Study the manufactured housing production process and facility layout.

The author reviewed existing research, literature (Senghore 2001, Hammad 2001, Mehrotra 2002, Banerjee 2003, Hammad 2003, Barriga 2003, Jeong 2003) based on production, facility layout, material flow management, and supply chain of manufactured houses for an understanding of the details and working of the manufactured housing plant. This step involved studying the manufactured house, its assembly, its production process, and the facility layout.

The production process consists of activities to be carried out to assemble a manufactured house. The activities belong to a particular cluster that acts as a milestone or a group of activities that bring certain parts of the house together. The clusters are described briefly in the following section. Figure 1.7 shows a typical manufactured housing production process and facility layout.

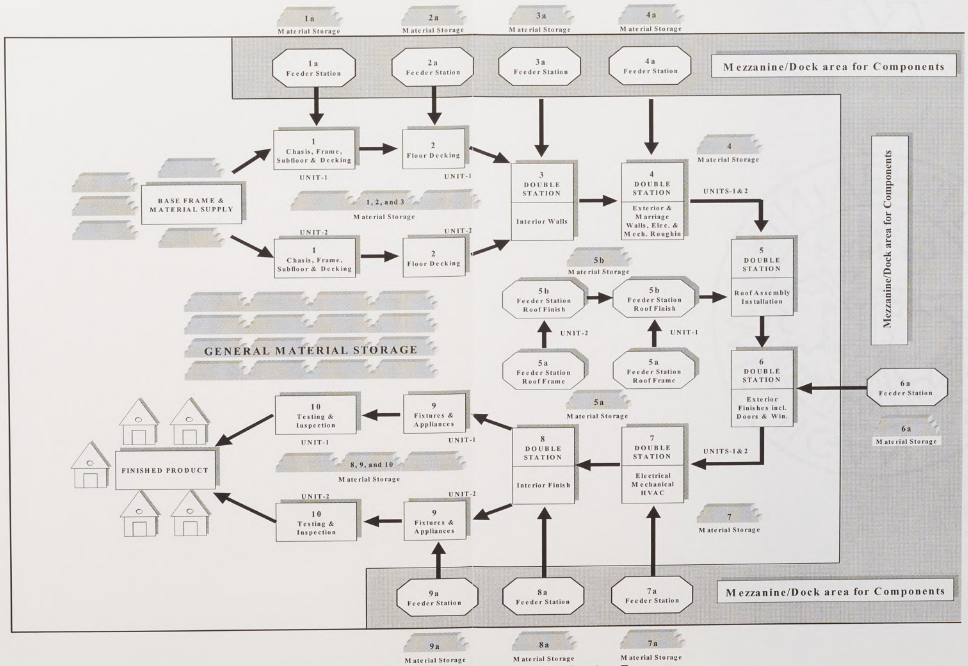


Figure 1.7: Manufactured Housing Production Process
(Source: Hastak & Syal 2002)

Floor Cluster:

The floor cluster mainly consists of three stations. The assembling of chassis, attaching of wheels and axles, installation of floor joist, floor decking, HVAC installation takes place in this cluster.

Wall Cluster:

Installation of interior and exterior walls is done in this cluster. Also bathroom fixtures and cabinets are also fixed in this cluster.

Roofing Cluster:

In this cluster, the roof is brought together and fixed to the house. Roof deck, insulation, and shingles are also installed in this cluster.

Exterior Cluster:

The major activities taking place in this cluster are installation of doors and windows, siding and exterior boards. The activities in this cluster are carried out simultaneously with roofing.

Finishes Cluster:

This is the cluster where all the finishes are applied. This is also a cluster where non-structural work is carried out. HVAC, and electrical and mechanical installations are done here. In addition, carpeting, and interior works like painting and inspection are carried out in this cluster.

Step-2: Explore different techniques and software of simulation and facility layout modeling.

In addition of exploring different techniques and software of simulation and facility layout modeling, the author has also discussed the manufacturing process and design.

The main sub-topics discussed in the literature review are manufactured housing production process; supply chain; material flow and management; facility layout research in manufacturing industries, design for manufacture; design for assembly; and design for manufacture and assembly.

Step-3: Recreate the existing facility layout model.

In this step the facility layout model was evaluated and recreated, such that it represents the existing production process, layout and material handling system. To recreate the existing facility layout model, the following steps were taken:

a. Study the prior developed facility layout model.

Previously conducted research in the facility layout was carried out by Mehrotra (2002) and Banerjee (2003). As part of this research Banerjee (2003) created and evaluated the facility layout of a case study factory. The author studied the model in detail so as to recreate the facility layout model for the proposed research.

b. Verify the changes on the model based on the case study factory.

Inputs were taken from the production manager by the author to verify if there were any modifications in the factory. Following verifications were carried out by the author:

1. Physical layout of the case study factory.
2. Changes in materials.
3. Changes in material handling quantities.
4. Changes in material handling equipment.
5. Changes in unit material handling cost.

c. Collect pertinent data to depict modifications in the facility layout model.

Data pertaining and relevant to the modifications in the facility layout model were collected. These data were in the form of frequency based "From-To" charts, distance based "From-To" charts, additions to the material handling equipment list, new quantities of materials being handled by humans and machines, and new equipment details (Banerjee 2003).

d. **Modify existing layout and recreate quantitative facility layout model.**

Depending upon the modifications, the facility layout was suitably modified. Changes were made to the product tree structure of the software and the material handling quantities and layout was modified (Banerjee 2003).

e. **Compare the annual material handling cost, calculated by the facility layout model and the cost incurred by the plant.**

The model will be verified as correct if the annual cost of material handling produced by the facility layout model is the same as the cost incurred by the manufactured housing production plant. Otherwise the model will be checked for errors and this process will continue unless the cost obtained is correct.

Step-4: Recreate production simulation models.

Simulation of the production process involved various steps. Below is a short summary of the steps that were taken to develop production simulation models of the selected manufactured housing components.

a. Collect data for simulating the production process by visiting the case study factory.

Data pertaining to the simulation of the production process are process times of activities, feeder stations cycle times, production volume etc. These data were collected and analyzed.

b. Develop simulation models for inefficient clusters.

The production simulation models are developed using Arena simulation software. The development of a simulation model involved following certain steps. Figure 1.8 depicts the methodology of developing the simulation model.

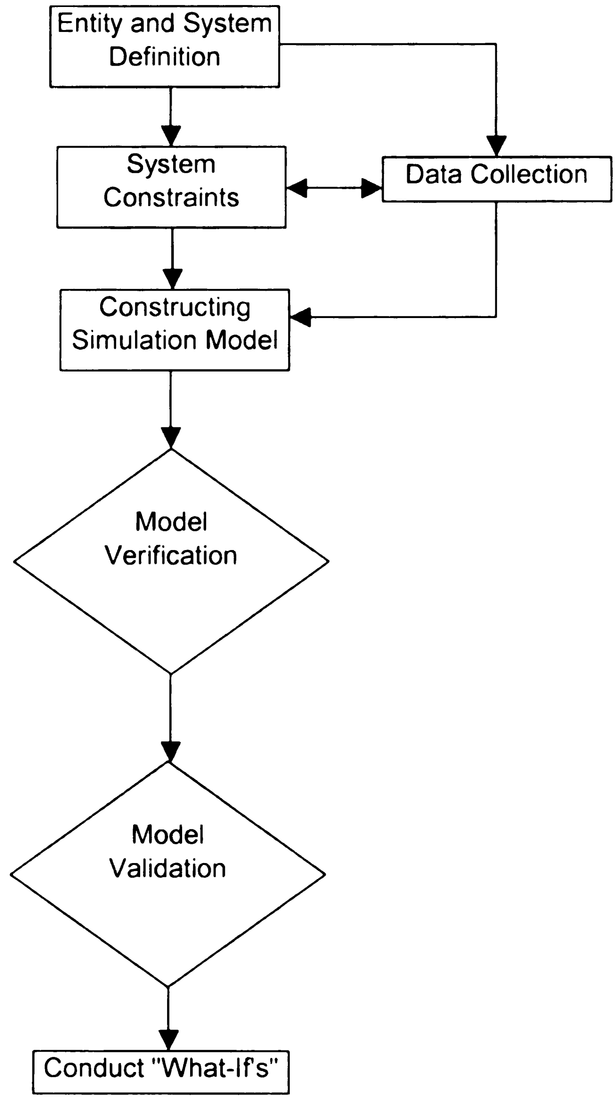


Figure 1.8: Methodology For Developing Simulation Models
(Modified from: Hammad 2003)

c. Verify the model as per the modeling assumptions.

The model was verified for its activity relationships and other relationships, so that it truly represents the existing production process.

d. ***Compare the simulation model's output to the factory's output.***

Model output can be checked in two ways. The model's output can either be checked by comparing the model's running time for a certain amount of units produced, or it can be checked for the number of units produced in a certain amount of time to the actual production. This step was important to discover any errors in the simulation model.

1.6.3 Objective III: To demonstrate the impact of the revised component assemblies on the physical layout, material handling aspect of the facility layout and the productivity of production process

Step-1: Develop new facility layout model to depict the changes made in the components assembly of the cluster.

Step-2: Develop new production simulation model for the cluster.

Step-3: Compare the physical layout, material handling cost of the facility layout and the productivity obtained from the production simulation model.

The above-mentioned steps were carried out in iterations for the clusters identified earlier. This objective involved development of new facility layout model after incorporation of the new component assembly system for the cluster, development of new production simulation models, and comparison of the outputs produced by the software.

Step-1: Develop new facility layout model to depict the changes made in the components assembly of the cluster.

The new facility layout model was created to measure the effect of change in components assembly redesign on the material handling cost. The new facility layout model was prepared after making changes to the existing facility layout model. The changes in the facility layout model were carried out in stages. These stages are:

1. Changes in assembly
2. Changes in material handling quantities
3. Changes in material handling equipment
4. Changes in routing information
5. Changes in activity points
6. Changes in physical layout

Step-2: Develop new production simulation model for the cluster.

The development of the new production simulation models for the selected clusters was based upon the changes encountered in the product tree structure and precedence diagram. The production simulation models are developed from the existing production simulation model developed earlier in this research. The changes that took place in the production simulation model were also implemented in stages. The stages that led to the development of the new floor cluster simulation models are:

1. Guess estimates for new activities

2. Data analysis for new paths
3. Eliminating unnecessary servers or stations
4. Placing the servers as per new logic and controlling paths
5. Providing new relationships to servers
6. Providing new time distribution to the servers

Step-3: Compare the physical layout, material handling cost of the facility layout and the productivity obtained from the production simulation model.

The facility layout model and the production simulation model were created solely to measure the effect of components assembly redesign. The facility layout model was used to compute the material handling cost incurred by the factory in one day, whereas the production simulation model was used to measure the time taken to produce 10 floors.

1.6.4 Objective IV: To explore the link between two aspects in obejective-3 by integrating facility layout and simulation models.

Integration of the facility layout and simulation software would be very useful in reducing the manual efforts involved in creating the production simulation model after, inputting the data once in the facility layout software. If the software integration is performed, the creation of the simulation model would be automated. Also, the changes once made in the facility layout model would not have to be made again in the simulation software. This would result in substantial timesaving and as well as reducing manual errors, which might be caused during modifications.

The methodology adopted for exploring the link between the two aspects by integrating them is presented below.

Step-1: Highlight the information requirements for the two software and the information generated by them.

Step-2: Develop information input–output models for the two software individually.

Step-3: Develop integrated information input–output models for the two software.

Step-4: Explore the data exchange in between the facility layout and simulation models.

Step-1: Highlight the information requirements for the two software and the information generated by them.

The significance of this step is to list all key information required and generated by the facility layout and simulation software. The mapped information is then used to develop the information input–output model.

Step-2: Develop information input–output models for the two software individually.

The information input–output models were prepared by using the representation technique input–output model. The input–output models for the software were prepared by linking the information requirement with the generated information on the other end.

Step-3: Develop integrated information input–output models for the two software.

The integrated information facility layout and simulation software models were developed by combining the input–output models for facility layout and simulation software. The information requirement for each software was first listed. This information was then transformed into the other software information output. Part of this output became the input for the corresponding model, but there was still some information that was missing. This information was found by comparing the output of the model with the input of the other model. The information that was missing was listed and was shown as the additional information needed for the development or modification of the other model. Finally, the comprehensive output that would be generated as a result of this integration was listed.

Also a dynamic information input–output model was developed that represents the data exchange as dynamic. In this case the software are assumed to be working in conjunction rather than separate. The data exchange in between the two software is dynamic.

Step-4: Explore the data exchange in between the facility layout and simulation models.

In this step an attempt has been made to transfer data from one spreadsheet to another required by the two software to create the models. The models were created successfully by inputting different spreadsheet files to the software and two approaches for data transfer has been highlighted. A demonstration example has been implemented to show the data transfer by one of the two approaches.

1.7 Expected Outcome & Deliverables

The author has proposed a unique way to analyze and evaluate the components assembly redesign for a manufactured housing factory. The effect of changing the component assemblies was shown on both the material handling aspect of the facility layout and the production process leading to integration of two. Therefore, the major deliverables are:

- Components assembly redesign process
- Evaluation of redesigned components assemblies
- Redesigned components assemblies that are cost-effective and provide better productivity.
- Integrated information input–output models of facility layout and simulation software
- An implemented approach to data exchange in between the facility layout and simulation models

1.8 Summary

This thesis contains colored images. Manufactured housing is one of the most affordable housing options. In spite of its affordability, the industry is experiencing a slump. Therefore, there is an immediate need to improve and make the manufactured housing assembly more effective.

The manufactured housing industry is still primitive in the design aspects of production process and facility layout. The prevalent design techniques in other manufacturing industries have not been employed by the manufacturers to design their production process and facility layout. The author believes that almost no time is spent in analyzing the manufactured housing facilities and its processes.

Although the production process and facility layout aspects have been explored, there have been no attempts to investigate components assembly redesign while designing the factory. This research attempts to propose a unique way of analyzing and evaluating the components assemblies redesign. The author strongly believes that components assembly redesign will have a much greater effect on the productivity and the material handling cost.

CHAPTER - II

LITERATURE REVIEW

2.1 Introduction

The existing literature pertaining to this research can be broadly classified into three categories. These categories are Production Process, Material Management, and Supply Chain in Manufactured Housing; Facility Layout Techniques in Manufacture Housing and Other Industries; and Design for Manufacture, Design for Assembly, and Design for Manufacture and Assembly.

2.2 Manufactured Housing Production Process, Material Management and Supply Chain

Manufactured Housing is one of the less expensive options for housing available to the society. The cost advantage of manufactured housing comes from the controlled factory environment and savings in material due to bulk purchasing. Although producing an affordable housing option, manufactured housing plants are not being analyzed for the production and supply chain bottlenecks, which tend to make the house more expensive. This section describes the existing research in manufacture housing production process, material management, and supply chain management.

2.2.1 Manufactured Housing Production Process Research

Researchers at Michigan State University, Purdue University and University of Cincinnati have conducted research on manufactured housing production process, material management, supply chain and facility layout. Their work on production process focused on resolving bottlenecks via simulation and material management.

The first research study on the production process aspect was done by Senghore (2001). The thesis titled, "Production and Material Flow Process Model for Manufactured Housing" explored the production process and material flow that takes place in a manufactured housing plant. The report gave a detailed description of production process and material flow. The primary goal of this report was to show how the production process of manufactured housing could be improved and resource utilization streamlined. The objectives fulfilled to reach this goal were to develop process flow model for multi-section houses, develop production and material flow model, and select a section of production line with 3-4 stations and transform the process into a computer simulation model. The simulation software used was EZSTROBE (Martinez 1998). The simulation identified some bottlenecks in the roofing cluster. "What-If" scenarios were developed and these bottlenecks were resolved.

Hammad (2001) took the lead in simulating and identifying the overall production process bottlenecks. The thesis titled, "Simulation Modeling of Manufactured Housing Process in Construction" dealt with simulation modeling of the overall production process of manufactured housing. This report also identified ways of improving the productivity of the manufacturing process in a plant. The overall goal was to enhance the productivity of the production process in the manufactured housing industry. The major objectives covered were to understand the production process, develop a computer simulation model, and to improve the process by manipulating the model parameters and the accompanying effects on the simulation performance measures. The simulation software used was Arena (Kelton et.al. 1998). Arena was chosen over other simulation software because it is specifically designed to model manufacturing processes.

Hammad (2003) did an extension of Hammad (2001) as a doctoral dissertation. The dissertation is titled "A Decision Support System For Manufactured Housing Production Process Planning And Facility Design". The contribution of this research was the development of a decision support system (DSS), which provides the manufactured housing industry with an efficient tool to streamline the performance of existing manufactured housing facilities. It fulfilled the following objectives: to develop a streamlined manufactured housing process, to develop optimization models to streamline the activities and predict relevant parameters, and to develop advanced layout designs employing recent theories in manufacturing like lean production. This dissertation investigated the combined impact of multiple factors on the productivity of four modules namely, market, factory, manufactured housing processes, and production system layout.

2.2.2 Manufactured Housing Material Management Research

A master's thesis, "Material Supply Management System for Manufactured Housing Industry" by Barriga (2003) was completed as a result of the material management aspect of the manufactured housing research. The research stressed the issues of material supply and proposed improving to the material supply efficiency that would be significant and would have a direct impact on production rate, cost effectiveness and quality.

The main goal of this research was to develop an efficient material supply management system that could be considered as an alternative to be applied in the Manufactured Housing Industry. Initially, the research focused and analyzed the current material management system in the manufactured housing industry to detect its shortfalls, so proper recommendations could be proposed for improvement. Also, it provided a more efficient material management system by combining different successful management techniques used in other manufacturing industries, as well as field data obtained from several visits to different factories. The proposed methodology took into account the material requirement planning (MRP) and integrated the use of available technology to make it more efficient. The methodology also recommended the use of a computer database, to replace the physical database that is primarily used in the manufactured housing industry, for improving the quality of management of information.

The very first step of this research was to standardize the material management system. It was observed that the practices used at the six factories were independent demand systems based on mathematical formulas that assumed demand of each material is not related to the demand of other materials. The literature recommended the use of dependent demand system in manufacturing industries instead of the current system. Therefore, a new material supply management system was developed based on dependent demand systems. One of the key elements of this new system was that it integrated the different parties related to material management and also used modern practices for estimating material quantities. The main advantage of the proposed system is its ability to relate demand for materials directly to the master production schedule.

2.2.3 Manufactured Housing Supply Chain Research

The supply chain adversely affects the performance of manufactured housing as a whole. The research in the supply chain aspect was initiated at Purdue University and a thesis titled, "Supply Chain Analysis and Simulation Modeling for the Manufactured Housing Industry" was completed. Jeong (2003) conducted this research with the primary goal of developing an efficient supply chain management system. The proposed supply chain management system can be an alternative to the current system in the manufactured housing industry. The objectives were to explore available supply chain management systems in other industries and their adoption in the manufactured housing industry; develop supply chain models for manufactured housing through a simulation that optimizes process time from order to installation; propose innovative design alternatives for delivery from the factory to customers based on an optimized supply chain simulation model; and investigate radical changes in the supply chain management and identify progressive avenues for future research and advancements.

In the view from supply chain management, the current network among the related parties in the manufactured housing industry is at a primitive level compared to those in other industries. Lack of coordination within the industry has made it difficult to get a competitive advantage in affordability and cost-effective quality of manufactured housing.

The purpose of this study was to investigate and analyze the supply chain management system in the manufactured housing industry. In this research, an efficient supply chain flow and supply chain management system was developed, focusing on optimal process time. The first step of the study was to identify and analyze the existing supply chain practices in the manufactured housing industry. The next step was to develop a supply chain simulation model based on the current supply chain management system. After identification of bottlenecks with the help of simulation in the current supply chain flow, a new optimized supply chain management system was proposed with regard to process time from order to installation of manufactured housing.

Currently, a PhD dissertation, "Supply Chain Management in the Manufactured Housing Industry: Supply Chain Optimization Model and Decision Support System", (Jeong 2004) is under way. This research focuses on developing an integrated optimal supply chain management system by optimizing the sub supply chain system and applying advanced technology in the entire supply chain. The proposed output of the research study is expected to be in terms of guidelines for supply chain management that supports the decision making process for the manufactured housing industry.

2.3 Facility Layout Research in Manufacturing Industries

This section will describe facility layout research in manufacturing industries. This research in manufactured housing has been broadly classified into two categories namely, the qualitative approach and the quantitative approach. Also, the existing literature on facility layout concepts in other manufacturing industries can be broadly classified into four categories namely, material flow movement and handling systems and facility layout; modeling techniques for facility layout design; advanced facility layout design techniques and theories; and computer applications in facility design (Banerjee 2003).

2.3.1 Manufactured Housing Facility Layout Research

The manufactured housing facility can be analyzed in two ways, namely, by the qualitative or quantitative approach. The qualitative approach primarily deals with the space and proximity issues, whereas the quantitative approach deals specifically with the material flow. Other aspects in the analysis of the quantitative approach can be information and personnel flow. Material flow is taken as the basis for the quantitative approach because the cost of material flow constitutes a large share in manufacturing costs. Figure 2.1 shows the aspects that are dealt with under qualitative and quantitative approach. The highlighted part shows the aspects incorporated under each approach as part of the ongoing research at MSU and Purdue University.

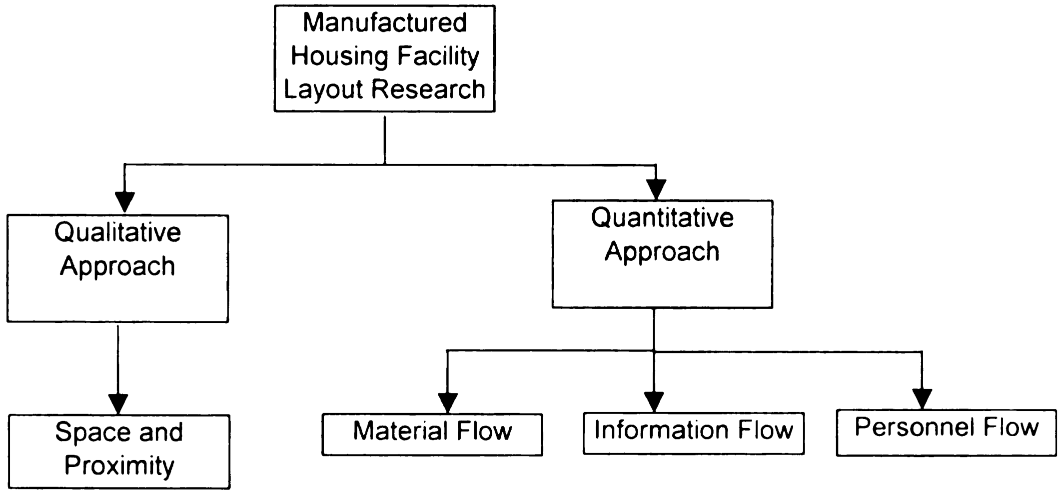


Figure 2.1: Manufactured Housing Facility Layout Approaches

2.3.1.1 Qualitative Approach

Mehrotra (2002) initiated the research in manufactured housing facility layout. The thesis was titled "Facilities Design Process of a Manufactured Housing Production Plant". The overall goal of this research was to understand and develop layout design process guidelines for a manufactured housing production plant. The research was specifically carried out with the aim of maximizing the adjacency criteria. The main objectives were to compile the process details of manufactured housing production, understand techniques related to manufacturing facility layout design available in the field of industrial engineering, collect space- and proximity-related data, based on the layout design techniques and manufactured housing production process details, develop layout design for the manufactured housing production plant, and formulate layout design process guidelines. The author performed a detailed analysis based on relationship charts for an existing manufactured housing facility and analyzed various layouts based on space and proximity. The research was mainly qualitative, because the input was taken from production managers and other facility personnel in terms of proximity. Proximity is mainly the relation between the two stations in terms of their adjacency. In addition, space requirements for each station were collected from the case study factories. Based on proximity and space data, relationship charts were developed. After analyzing relationship charts the author came up with evaluation criteria, "R% scores". Various shapes were evaluated and their R% scores were calculated. The S-shaped layout proved to be the most effective layout in terms of space and proximity, i.e., the qualitative aspect.

2.3.1.2 Quantitative Approach

The other approach that was explored in facility layout analysis was the quantitative approach (Banerjee 2003). Her masters thesis titled, "Material Flow Based Analysis of Manufactured Housing Production Plant Facility Layout" approaches the facility layout problem with a focus on the quantitative aspect of material flow. The goal of this study was to analyze the impact of material-flow on the facility layout of a manufactured housing production plant, and to outline the comprehensive process steps for evaluating the layout-design based on material-flow. The primary objectives were to develop a quantitative model for the facility layout based on the material-flow, perform computer aided analysis of the quantitative model, including development and evaluation of the alternatives, and outline the process steps required to analyze the facility layout based on the material flow for a manufactured housing production plant. A facility evaluation software FactoryFLOW (EDS 2002) was used to validate and perform "what-if" analysis of the facility layout model. The model was validated by the annual cost of material flow incurred by the factory.

The author also carried out "what-if" analyses based on the distance-intensity chart and the flow patterns. The points selected in a distance-intensity chart were the points that did not lie close to the axis intersection, these parts had high movement intensity and/or traveled a very long distance. Similarly, the flow patterns were also observed and the activity points within which the flow lines were comparatively thick representing a huge amount of flow or the length of the flow lines was comparatively long representing long travel distance, then they were selected for analysis. These points in the distance intensity chart and flow lines in a flow pattern represent distance and intensity information pertaining to a particular part. The points or flow pattern were selected for "what-if" analysis on two bases, i.e., distance covered by the part, or the travel intensity of the part. If a part had to travel a very long distance, then the part was brought closer to the station where it was needed; and if the part travel intensity was too high, then a higher capacity material handling equipment was used so as to reduce the number of trips for the part movement. It was noted that a small change in the location of stations or in material handling equipments generated a huge amount of savings in the annual material handling cost.

2.3.2 Facility Layout Techniques in Other Manufacturing Industries

Most of the material in this section comes from Banerjee (2003), in which an extensive literature review specifically on this subject was conducted. The existing literature on this subject is broadly classified into four categories: material flow movement and handling systems and facility layout; modeling techniques for facility layout; advanced facility layout techniques and theories; and computer applications in facility layout. Before understanding the various categories in facility layout techniques, it is very important to know certain concepts and definitions. These concepts and definitions have been explained and defined in Banerjee (2003). Two books titled "Facilities Design" by Heragu (1997) and "Facilities Planning" by Tompkins et al (1996) cover all the major topics in facility layout techniques. A brief overview of the two books is given below.

The book "Facilities Design" by Heragu (1997) is an attempt to introduce the reader to the concept of facility design. A good overview of the facilities and definitions has been given in the first chapter. The major contribution of this book is that it introduces the reader to the concept of facilities design, its modeling and analysis. The modeling approach comes from the decision support models. The author has concentrated on the analysis of products, equipment, process flow and material flow. The author, with help of examples, has described and implemented algorithms that can be used for the layout problems. The latter part of the book is dedicated to group technology, queuing theory, and material handling with emphasis on their implementation in facility layout problems. The author has also discussed about basic and advanced location models.

"Facilities Planning" a book by Tompkins et.al. (1996) is divided into four parts. In the first part, the author introduces the reader to various players in facility planning. Important qualitative factors, such as flow, space and activity relationships have also been discussed in this section. The author then reviews concepts and techniques for developing alternatives. This section discusses material handling, layout and computer-aided layout. In this section the author introduces the reader to commercial packages available for the analysis of facility layout. In the third part of the book, the quantitative aspect of facility layout is discussed in detail. This section covers location models and cost estimation in facility planning based on the quantitative aspect. Alternative formulations on the quantitative aspect are also an integral part in this section. In part four of the book, the author mentions various criteria for evaluating and selecting the alternatives. The book ends with a chapter written on the preparation and documentation of assembly plans.

2.4 Design for Manufacture, Design for Assembly and Design for Manufacture and Assembly

This section describes existing literature on Design for Manufacture; Design for Assembly; and Design for Manufacture and Assembly. Before proceeding to describing all the sections in detail, it is important to know the difference between the words "manufacture" and "assembly". Manufacture refers to assembly of individual component parts of a product, and assembly refers to adding or joining of these parts to form the complete product. Similarly Design for Manufacture (DFM) can be defined as "the design for ease of manufacture of the collection of parts that will form the product after assembly" and Design for Assembly (DFA) can be defined as "design of the product for ease of assembly" (Boothroyd et al 2002).

2.4.1 Design for Manufacture

The author of the book "Process and Design for Manufacturing" (Wakil 1989) has stressed product design as the crucial factor for successful manufacturing. As per this book, the conventional procedure for product design used to start with an analysis of desired components, which presented the form as well as the materials of the product to be made. The design was then sent to the manufacturing department, where the type and sequence of production operations were decided. But now, due to the integrations of activities in manufacturing, the modern design procedure involves consideration of the methods of manufacturing during the design stage itself. Wakil (1989) also highlighted certain factors that affect the constructional details. The factors are: accessibility of different parts or areas, handling of the workpiece or product, safety requirement, and appearance. The author also discusses computer-aided manufacturing (CAM) and automated manufacturing systems. The appendix of this book has been dedicated solely to automatic assembly and industrial robots.

Various manufacturing processes such as casting and foundry work; metal forming; machining of metals are explained in detail in this book.

In the book "Process Design and Process Engineering" Niebel & Draper (1974), discusses criteria for product success. The book discusses about locating ideas for new products. The authors say that the ideas mainly come from company executives, company sales force, customer suggestions, government agencies, and research laboratories. The authors also mentions that on average about 500 possibilities are required at the idea stage for every new product that appears for production. The authors put forward man-machine considerations when designing the product, its operation and manufacturing. Cost and product development are also among the topics discussed in the book. As per the book, there are two types of costs for an engineer's consideration, first being the cost incurred while developing the product, and the other one being the cost of the product itself. The cost of the product consists of the cost of each component in the product. Therefore it is even more important to make good decisions between the materials and the processes. This book mainly discusses various types of materials, their properties and the type of processes associated with these materials. The author has also given due consideration to the importance of quality control. Various quality control procedures are explained, along with steps for developing a program for reliability and quality control. This book also gets into design for assembly by discussing planning of optimum operation sequence. This can be obtained by classifying the operation sequences into primary and secondary where primary operations are critical operations and secondary operations are not critical operations. Then the rules for developing an operation sequence that should be applied are also described. Much stress is placed on the importance of good planning for product success.

2.4.2 Design for Assembly

A book titled "Design for Assembly" by Andreasen et al (1983) is a simple to understand and comprehensive book that talks about assembly, assembly processes, design for assembly and integrated product development. The author has made a successful effort in explaining and making others understand the concepts and implementation of design for assembly. The book gives differentiations of various components of assembly, namely, machine parts, components, building blocks, base components, and formless materials. The author also describes two main divisions of assembly process based on their complexity namely, sub-assembly and final assembly. The author has put a lot of stress on the ease of assembly for manufacturing. The author also notes that a series of decisions that are made during the design stage have a considerable influence on the feasibility of rationalizing a product's assembly. It is therefore very important to consider the principles of design for assembly. Some important factors highlighted that affect the product design are design factors, production factors, sales factors, destruction factors and use based factors. The author has also summarized various principles of design for ease of assembly that have been explained in detail in Redford and Chal (1994).

Redford and Chal (1994), in "Design for Assembly: Principles and Practice" place differentiated product design factors into two categories namely, factors independent of assembly methods and processes, and factors dependent on assembly process. The book also exposes two major factors that influence the production ratio to facility: the amount of assembly effort required and the effectiveness of assembly effort. It goes further in explaining the different assembly systems. The authors also discuss various methods of evaluating assemblies, some of them are the Hitachi assemblability evaluation method, the Lucas DFA evaluation method and the Boothroyd-Dewhurst DFA method. The last chapter mainly discusses alternative product design concepts. This chapter has mentioned some out-of-the-box assembly systems and these methods are explained with some easy-to-understand examples.

2.4.3 Design for Manufacture and Assembly

Design for Manufacture and Assembly (DFMA) is a combination of DFM and DFA. Before DFMA was introduced, DFM and DFA were applied at the design stage, one after another. But DFMA is a combined approach in which both DFM and DFA are looked at concurrently. DFMA is mainly used to perform three main activities (Boothroyd et al 2002):

1. To provide guidance to the design team in simplifying the product structure, to reduce manufacturing and assembling costs.
2. To study competitor's products and for measuring manufacturing and assembly difficulties.

3. As a tool for estimating cost for negotiating suppliers contracts.

In the book "Product Design for Manufacture and Assembly" by Boothroyd et al (2002), the DFMA approach has been explained from the perspective of product design. The book begins by introducing the readers to DFM, DFA and DFMA. A brief history of the development of the DFM and DFA approaches is also provided. Several industries where DFMA is being applied are discussed and difficulties in respect to the product manufacturing are also discussed. The major problem identified is that of keeping the DFM and DFA isolated and applying them one after another.

As DFM and DFA encompass a broad range of topics, from selection of materials and processes to design for various processes, they are all discussed in this book. The chapter on product design for manual assembly discusses various guidelines for part handling, insertion and fastening. This chapter also discusses criteria for assembly efficiency. Assembly efficiency can be determined by dividing the theoretical minimum assembly time by the actual assembly time. The equation for calculating the design efficiency is as follows:

$E_{ma} = N_{min} t_a / t_{ma}$

where,

E_{ma} = DFA index

N_{min} = Theoretical minimum number of parts

t_a = Basic assembly time for one part

t_{ma} = Estimated time to complete the assembly of the product

The same book, dedicates a chapter to automatic and robot assembly. Here, general rules for product design for automation and for product design for robot assembly are put forward to help designers design their parts for achieving ease in parts fitting during an automated assembly process.

The factors mentioned above (Redford & Chal 1994) affect the steps taken for assembly design. A doctoral dissertation titled, "Assembly-Oriented Design: Concepts, Algorithms and Computational Tools" by Mantripragada (1998) discusses certain steps that are essential during the early stage of design. These steps are *(a) Identify and systematically relate design requirements (key characteristics) to important datums on parts and fixtures at various assembly levels. (b) Design the dimensional and tolerance relationships among elements of an assembly from these key characteristics. (c) Identify assembly procedures that best deliver the key characteristics repeatedly without driving the costs too high.* The author developed graphical representations of the assembly to represent a hierarchical model of the assembly called "Datum Flow Chain" (DFC). These DFCs are used to drive the assembly design process. DFCs express the logical intent concerning how parts are to be related to each other geometrically to deliver the key characteristics repeatedly. Current CAD systems do not have the ability to support this approach of designing assemblies. The major contribution of this thesis is presenting a conceptual framework to model and evaluate assemblies and their assembly procedures for future CAD systems.

The first chapter mainly discusses causes of the problems encountered during the assembly of a product. The causes are classified into three categories, namely causes of problems due to design, causes of problems due to assembly and causes of problems due to manufacturing. The author narrows the scope of the thesis by concentrating on the first two causes only. The author's main goal is to make a conceptual framework for assembly oriented design. The focus is primarily on better understanding of modeling of assemblies, assembly processes and developing algorithms and computational tools to quantify the effects of different assembly procedures on the quality of final assembly.

The literature review has been carried out in two categories. The first category is assembly modeling and design, and the second one is modeling variation propagation in assemblies. The first category deals with assembly representation, analysis and assembly sequence. The second category deals with tolerance analysis and assembly process. The scope of assembly oriented design approach is laid out and the need for implementing such techniques is also highlighted. After defining the scope the Datum Flow Chain (DFC) technique is presented which is used to model and present assemblies.

Before understanding the development of DFCs it is important to know about key characteristics. Key characteristics (KC) are the properties of an assembly. For example the size of an assembly is one of the key characteristics. These key characteristics are used to establish mating conditions and also the design for the subassembly. Joints when mated together need to deliver KCs; otherwise there will be fit-up problems. The KCs are the distinctions that can be modeled with directed graph representations. These directed graph representations for dimensional transfer from part to part is one of the bases of tolerance achievement. These directed graphs are hence called Datum Flow Chains (DFC).

DFCs also assign hierarchies to the joints by defining which part or parts locates which other part or assembly. Before going into the analysis of assemblies, the author classifies the two assemblies into type-1 assembly and type-2 assembly. State transition models were developed to model variation propagation and control. The assembly processes were modeled as a discrete event linear time varying system. The author then develops algorithms to determine and control variations based on the combined effect of individual part variations and also on the choice of assembly procedures. Some software tools to implement the techniques are also described. The author concludes by highlighting the contributions and future research directions. Some major future research areas proposed by author were integration of software tools and automated design of optimal assembly features. The author concludes that the efficiency of the design activity can be improved by improving the design tools. The author believes that DFCs will play a major role in improving the design activities.

The above-mentioned dissertation introduced a completely new method i.e. DFC for representing and design assemblies, whereas a PhD dissertation, "Concurrent Product Design of Machined Parts with a Feature Based Product Representation Scheme" by Changchien (1996) proposes a combined approach by utilizing available techniques. The author identifies the main problem as that each of the design steps was done in an isolated mode. The lack of a systematic and simultaneous consideration of the impact of design decisions on manufacturing and assembly leads to repeated and excessive changes in design and processes. Concurrent engineering was presented as a solution, to foresee product design and eliminate potential design flaws by integrating design information throughout the product development life cycle. The research presented a product life cycle design framework in the context of concurrent engineering.

The major objectives of this research were to develop a concurrent design framework, implement the methodology for the framework, and to show the results by implementing the framework on a real product design. The author discusses various approaches to product development, product data modeling and representation, and multi-objective design optimization. The topics such as approaches to concurrent engineering, which covers DFM and DFA, are discussed. Also attention has also been given to axiomatic design and artificial intelligence approaches. The section on product data modeling and representation covers topics like feature-based design, various principles of product data modeling, product data models, programming in product design and STandard for the Exchange of Product model data (STEP). The author then discusses various methods in multi-objective decision making and fuzzy sets.

After having defined the building blocks of the proposed research, the author presents the concurrent product design framework (CPDF). This framework is solely developed for modeling and supporting engineering designs in this research. Concurrent consideration of design activities throughout a product development life cycle early in the design stage eliminates potential design errors and problems in subsequent design activities. It is therefore important to consider them concurrently or develop a framework that operates on an integrated approach.The framework developed is also consistent with CAD/CAM applications.

The framework is composed of various design processes: design formation, feature-based design, design optimization and STEP model data generation. After the framework was developed, it was implemented on a milling fixture design and the results were obtained. The results showed that the average fitness increased after implementing the framework. The author concluded that the concurrent product design framework provides a formal model for representing key design activities. The author also recommended following areas of future research: completing this framework by adding more considerations in the framework and integration of various CAD/CAM software with the framework.

Component integration also plays a major role in design or redesign of a manufacture process. Chou (2002), defined component integration as a redesign process of combining several components into single one, which is made of a single material and still satisfies the requirements of the original components. In the author's PhD dissertation titled “A Methodology for Component Integration in Product Design”, the author says that the concepts of component integration has been employed in several product design methods such as DFM, DFA and Function Sharing to reduce the number of components and to improve manufacturing quality in efficiency. But, none of existing methods provide the critical information needed to identify the appropriate components integration. This research is capable of providing designers with two types of critical information that are important but are generally ignored in the existing component integration methodologies. The two types of information are: identifying groups of components that could be feasibly integrated and deciding which of them should be implemented first in the redesign stage. The various objectives were to create a search procedure to identify feasible component integration sets (FCIS) and to develop an evaluation method to select the best FCIS.

The literature review comprised of summaries of two major categories. The first category was product design methodologies that dealt with DFA, Design for Disassembly (DFD), Function Sharing and Axiomatic Design. The second category was assembly representation schemes that cover topics like AND/OR graph, geometric modeler and assembly modeler. The methodology adopted for this research was first to identify and define the constraints in component integration. After the constraint identification, FCIS were developed. The FCIS constitutes the part numbers that needs to be integrated in a sets form. These sets became the basis for manipulating the existing assembly representation schemes. Basically a representation scheme consisted of AND/OR graphs.

The methodology described above was applied to a case study. The case study was the hair dryer assembly. The author started by representing the assembly in AND/OR graph, then a search was carried out to identify possible

FCIS. These FCIS were then used to perform component integration. Once integrated, the overall assembly cost index was evaluated. The author concluded by identifying FCIS as an important contribution to component integration methodologies. Some of the future areas of research that were recommended were development of a knowledge-based system for component integration and development of functional relationships factors.

There are other theses and dissertations that relate to the topics of DFM, DFA and DFMA. These theses mostly focuses on the issues of product complexity, critical manufacturing characteristics, process selection, assembly planning, assembly representations, and integration of assembly planning and material handling (Angster 1996, Bartolomei-Suarez 1996, Doggett 1999, Drsikill 1997, Fagade 1999, Hu 1996, Ko 1989, Laperriere 1992, Peplinski 1994, Vo 2000).

2.5 Summary

This chapter introduced the reader to the existing research that has been carried out in the various fields relevant to this research. The chapter gave a short overview of existing research in the field of manufactured housing production process, material management and supply chain management. It also introduced the reader to the work carried out in the field of facility layout both in manufactured housing and other manufacturing industries. A new category DFMA was also introduced in this chapter, which will be the basis for this research. This chapter described various state of the art works in DFM, DFA and

DFMA. The DFM, DFA and DFMA that are the basis for redesigning components assemblies have been described in chapter-3. After reviewing all the literature it can be concluded that manufactured housing production process; facility layout; and DFM, DFA and DFMA are important aspects to be considered during the product design stage and they also play a major role in determining the quality and manufacturing cost of a product.

CHAPTER - III

TOOLS AND TECHNIQUES OF DESIGN FOR MANUFACTURE AND ASSEMBLY

3.1 Introduction

The manufactured housing industry can benefit tremendously from research done in the production process, facility layout, material management and supply chain. Previously, research has been carried out in the above mentioned aspects of manufactured housing, but not on the manufacturing and assembly of a manufactured house. The purpose of this research is to incorporate some concepts of other manufacturing industries in the area of manufacturing and assembly, and apply them in manufactured housing industry. This chapter will introduce some concepts and methods in a new arena, i.e., design for manufacture and assembly.

3.2 Design for Manufacture and Assembly

Design for Manufacture and Assembly (DFMA); Design for Manufacture (DFM); and Design for Assembly (DFA) covers a broad range of topics. DFMA is a combination of DFM and DFA. DFM and DFA although classified into two categories are interrelated. DFM mainly deals with ease of manufacturing of the collection of parts that come together to make an assembly or a product. The design for ease of assembling this assembly or product comes under DFA. This section will describe DFMA, DFM, and DFA.

3.2.1 Overview of DFMA

Design for Manufacture and Assembly (DFMA) is a combination of Design for Manufacture (DFM) and Design for Assembly (DFA). It deals with the manufacturing processes needed for manufacturing the individual parts of the assembly or the product and also the assembly sequences. To make an assembly more effective, DFMA also considers whether two or more individual components can be integrated into one and can be joined to the main assembly as one component. This is also known as component integration.

3.2.1.1 Objective of DFMA

There are three main objectives for applying DFMA. These objectives or activities are considered to be the primary driver of DFMA. These three objectives are (Boothroyd et al 2002):

1. To provide guidance to the design team in simplifying the product structure, to reduce manufacturing and assembling costs.
2. To study competitor's products and for measuring manufacturing and assembly difficulties.
3. As a tool for estimating cost for negotiating suppliers contracts.

3.2.1.2 Procedure for Applying DFMA

As DFMA is a combination of DFM and DFA, they are applied one after another and many iterations are carried out. The DFA analysis is first carried out to simplify the product structure, and then DFM is applied for estimating costs for the parts. After applying DFM, both the original design and the new design are compared to make trade-off decisions in terms of ease of manufacturing, assembly and manufacturing cost. During this stage various processes and materials to be used are also considered. This leads to the application of DFA and DFM again for the new design of the product and the parts. It is very important to know that as per the DFMA methodology the DFA and DFM are applied many times, while keeping in mind the effect of one on another. This is what makes DFMA superior to the traditional way of approaching the product design problem. Figure 3.1 summarizes the typical steps taken in DFMA during the design stage.

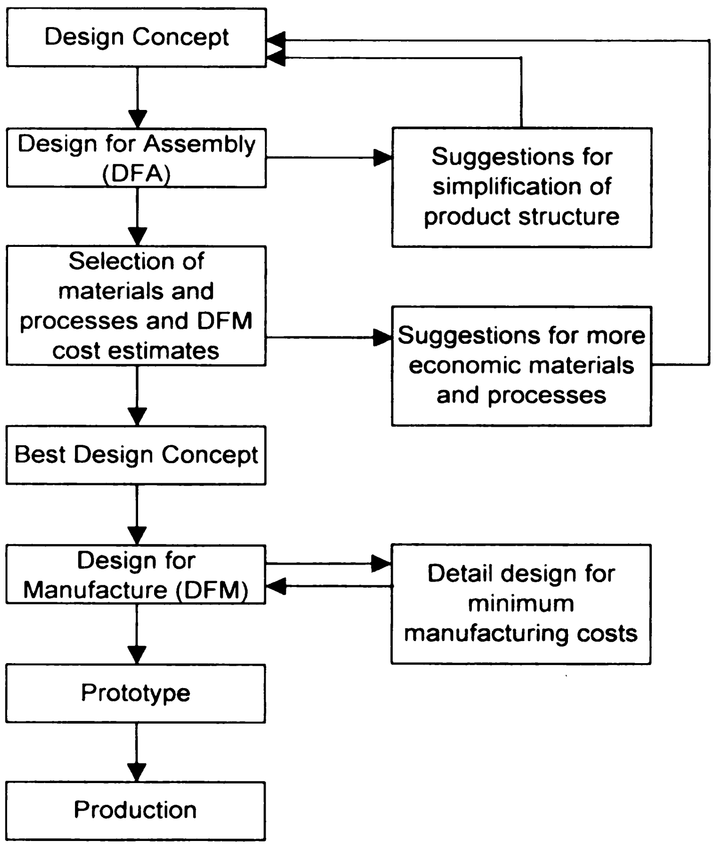


Figure 3.1: Procedure for Applying DFMA
(Source: Boothroyd et al 2002)

3.2.2 Overview of DFM

DFM stands for Design for Manufacture and it is used to design the individual components that will be put together to form an assembly or the final product. DFM starts by process and material selection and goes into details of design for each process. Some of the processes that are carried out for fabricating the components are casting, forging and machining. The cost and selection of these processes varies from material to material. Therefore it is initially very important to choose the right processes and appropriate materials for fabricating the individual components.

3.2.2.1 Objective of DFM

The objective of applying DFM is to do detailed design for minimum manufacturing costs. There are two approaches of applying DFM, the traditional approach and the modern approach. In the traditional approach, the manufacturing costs depend on the function of the component. The function of the components defines the material to be used and also the process. These all are interrelated, but at the design stage, the function of the component is the primary driver for determining the material and process (Wakil 1989). It is in this approach that the selection of manufacturing methods is dependent on form and materials. In modern approach to DFM all three aspects of DFM, i.e., the form of the component, material of component, and the manufacturing process for fabricating the component are considered concurrently. Some researchers also call it the concurrent approach to DFM.

3.2.2.2 Procedure for Applying DFM

As discussed in the above section, the DFM can be applied in two ways, the traditional approach to product design and the modern approach to product design. The two approaches are explained below.

3.2.2.2.1 Traditional Approach for Applying DFM

In the conventional way of applying DFM, the procedure starts with an analysis of the desired function of the component. This desired function dictates the form as well as the material of the component. The procedure is shown in figure 3.2.

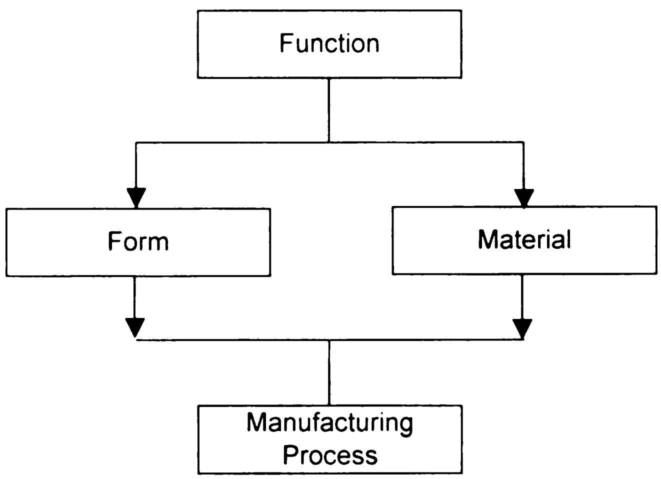


Figure 3.2: Traditional Approach for Applying DFM
(Modified From: Wakil 1989)

There are certain disadvantages when applying this procedure. Some of the disadvantages are (Wakil 1989):

1. The designs for certain products are impossible to make; therefore the design always needs to be modified.

2. Modification leads to increase in production costs as the machining or manufacturing process for some designs might require special tools.
3. In this procedure the process of manufacturing is ignored in the design phase hence resulting in poor or undesired characteristics of the component.

3.2.2.2.2 Modern Approach for Applying DFM

It was because of the above mentioned reasons that the modern approach of applying DFM evolved. The modern design procedure involves considering all the aspects, i.e. form, material, and process, concurrently. All three aspects are interactive and interrelated. Figure 3.3 shows the modern procedure for applying DFM.

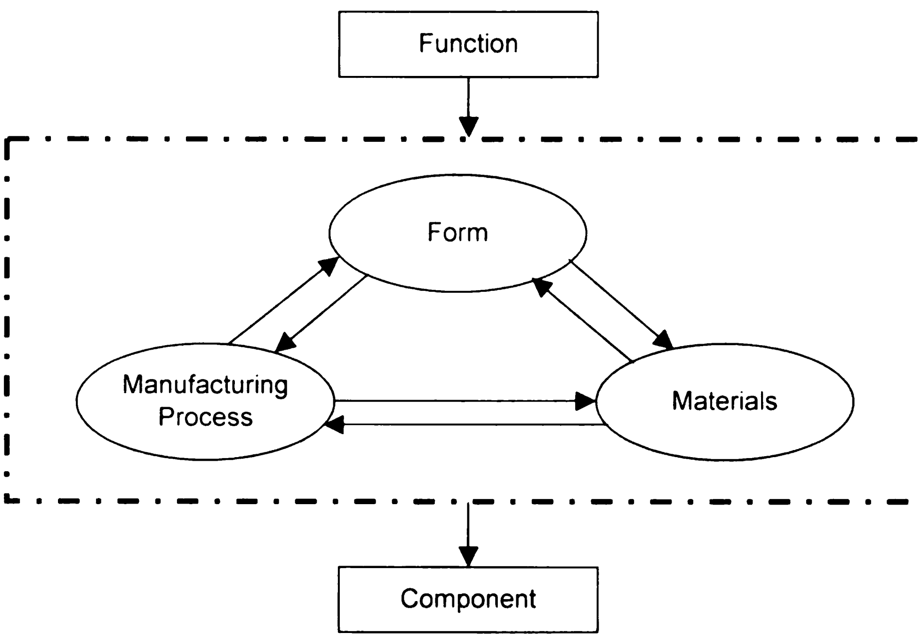


Figure 3.3: Modern Procedure for Applying DFM
(Modified From: Wakil 1989)

3.2.3 Overview of DFA

DFA is defined as the "design of the product for ease of assembly" (Boothroyd et al 2002). DFA is an effective approach to improve quality and production efficiency. The primary goal of DFA is to reduce the cost of the product by simplifying its design and hence assembly. This goal is generally achieved in two stages. The first stage is the conceptual design stage (at the initial design attempt), and the second stage is the later design stage (improving an existing design). Most researchers suggest the use of DFA in the early design stage before any production starts in order to reduce the iterations of the design process due to unacceptable outcomes in later stages. These unacceptable outcomes are assembly difficulties, unmatched mating conditions or key characteristics, wrong sequence of assembly of components, etc.

3.2.3.1 DFA Principles and Rules

As per Andreasen et al (1983) there are three DFA principles. They are: Design an Optimal Assembly; Systemize the Product Structure; Design the Components as Suited by Assembly. All the three principles are interdependent and therefore some rules under the principles are common and repetitive. The rules and sub-rules for each principle are described as below:

1. Design an / Criteria for Optimal Assembly
    a. Constant and high product quality
        i. Apply quality control techniques
        ii. Evaluate quality for automatic assembly

iii. Consider assembly as a management problem

b. High productivity

i. Design for mechanized assembly

ii. Design for automatic assembly

iii. Design for flexible automatic assembly

iv. Consider all aspects of manual assembly

c. High profitability

i. Eliminate assembly

ii. Design for standard equipment

iii. Design for special equipment

iv. Avoid variants

v. Make the variants uniform in assembly

d. Good working environment

i. Consider automation

ii. Avoid dangerous assembly methods

2. Systemize the product structure

a. General Rule

i. Design Simply

ii. Avoid designing complex assemblies

b. Choose correct structural principle

i. Integrate components wherever possible

ii. Differentiate between components

iii. Design good base for assembly

iv. Design a stacked assembly
v. Consider compound assembly
vi. Design good basis components
vii. Construct the product of building blocks
viii. Construct the product using correct specifications
ix. Avoid tolerance demands on components
x. Avoid surface demands on components

c. Choose correct joining methods
  i. Prefer joining over assembly
  ii. Avoid separate composing elements
  iii. Use integrating production methods

3. Design the components as suited by assembly
  a. Avoid assembly operation
    i. Integrate one component with another
    ii. Use integrating production methods
  b. Avoid orientation
    i. Use magazines to hold the product
    ii. Use components in the form of band
    iii. Integrate production in assembly
  c. Facilitate Orientation
    i. Avoid tangling / nesting
    ii. Design special orientation surfaces
    iii. Avoid bad-quality components

iv. Make the components symmetrical

v. Increase asymmetry

d. Facilitate Transportation

i. Make the components transports suitable

ii. Design a base component

e. Facilitate Insertion

i. Choose simple moving pattern

ii. Make insertion ambiguous

iii. Fir the components with guide surfaces

f. Choose correct joining methods

i. Avoids joins

ii. Avoid separate joining elements

iii. Use integrating production methods

3.2.3.2 Methods for Evaluation of DFA

It is very important to evaluate the designed assembly as it provides the measure of effectiveness or helps quantify the DFA. There are various evaluation methods for evaluating the assemblability of the product designs. There are two measures of measuring assemblability, qualitative measure and the quantitative measure. In qualitative measures, information is obtained from cost structures, design rules and relative costs. Qualitative measures are obtained to find the cost, the least expensive solution and the influencing factors. In case of quantitative assemblability, measures are used to quantify the assembly quality in terms of global assembly costs, detailed assembly costs, assembly indices, assembly pointers and information. Some of the quantitative assembly evaluation methods are discussed below (Redford & Chal 1994).

3.2.3.2.1 The Hitachi Assemblability Evaluation Method

Hitachi Ltd has developed their Assemblability Evaluation Method (AEM) as an effective and efficient tool to improve quality for better assemblability. The work on AEM was started in 1976, and since then many improvements and modules have been added. These later versions of AEM include many elements or modules. One of the most effective modules that have been added is the evaluation procedures for the assembly costs of individual parts. The main objective of AEM is to facilitate design improvements by identifying weaknesses in the design at the earliest possible stage in the design process. This is done with help of two indicators. The two indicators are the assembly evaluation score (E), that is used to assess design quality by determining difficulty of operation; and the assembly cost ration (K), which is used to estimate assembly costs.

AEM evaluation procedure consists of four stages. Stage 1 is where preparatory work for identifying the various tasks is carried out. In stage 2, part attaching sequences and attaching operations are matched to the elementary task symbols. Next in stage 3 the evaluation indices are calculated and in stage 4a, a decision is made for effectiveness of the design. If the design is not of acceptable level either because the evaluation score ratio (E), for a particular part is less than 80 or the assembly cost ratio (K), is greater than 0.7, then the design improvement is carried out. Figure 3.4 shows a flow chart for Hitachi assemblability evaluation and design improvement procedure (Redford & Chal 1994).

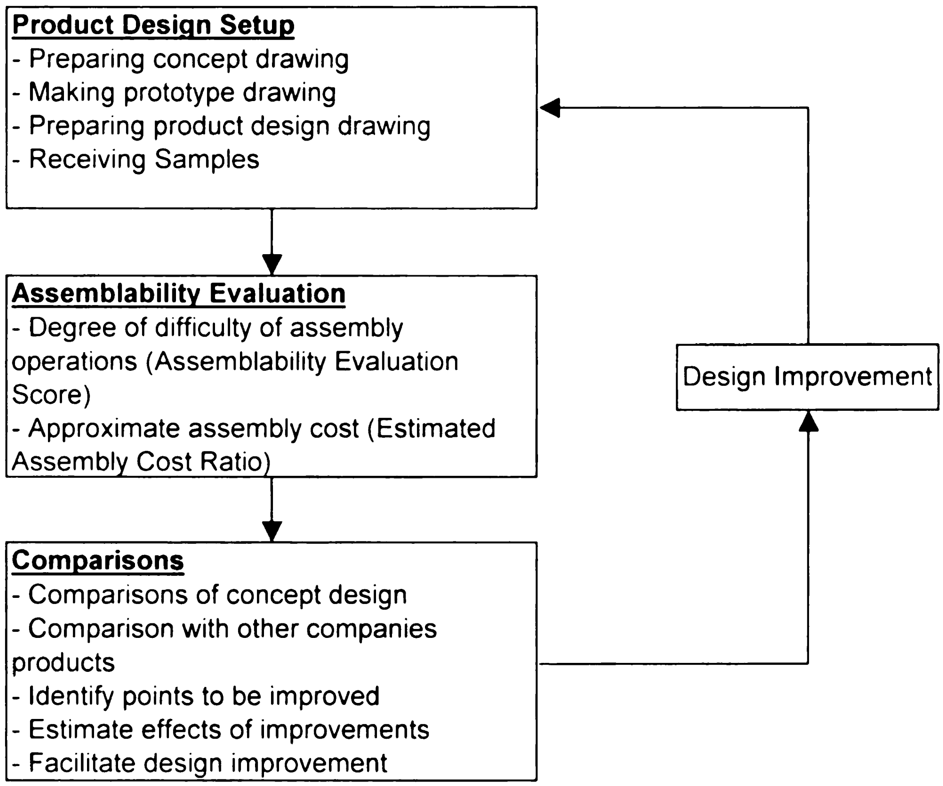


Figure 3.4: Hitachi Assemblability Evaluation and Design Improvement Procedure
(Modified from: Redford & Chal 1994)

3.2.3.2.2 The Lucas DFA Evaluation Method

This method is a result of work between the Lucas organization and University of Hull. This method employs the "assembly sequence flowchart" and is basically a knowledge based evaluation technique. The system is meant to be integrated with the CAD system to employ most of the information required for the analysis work in a short amount of time. The strategy and detailed rules are implemented by using the programming language Prolog (Redford & Chal 1994).

Figure 3.5 depicts the procedure for Lucas Design for Mechanical Assembly procedure.

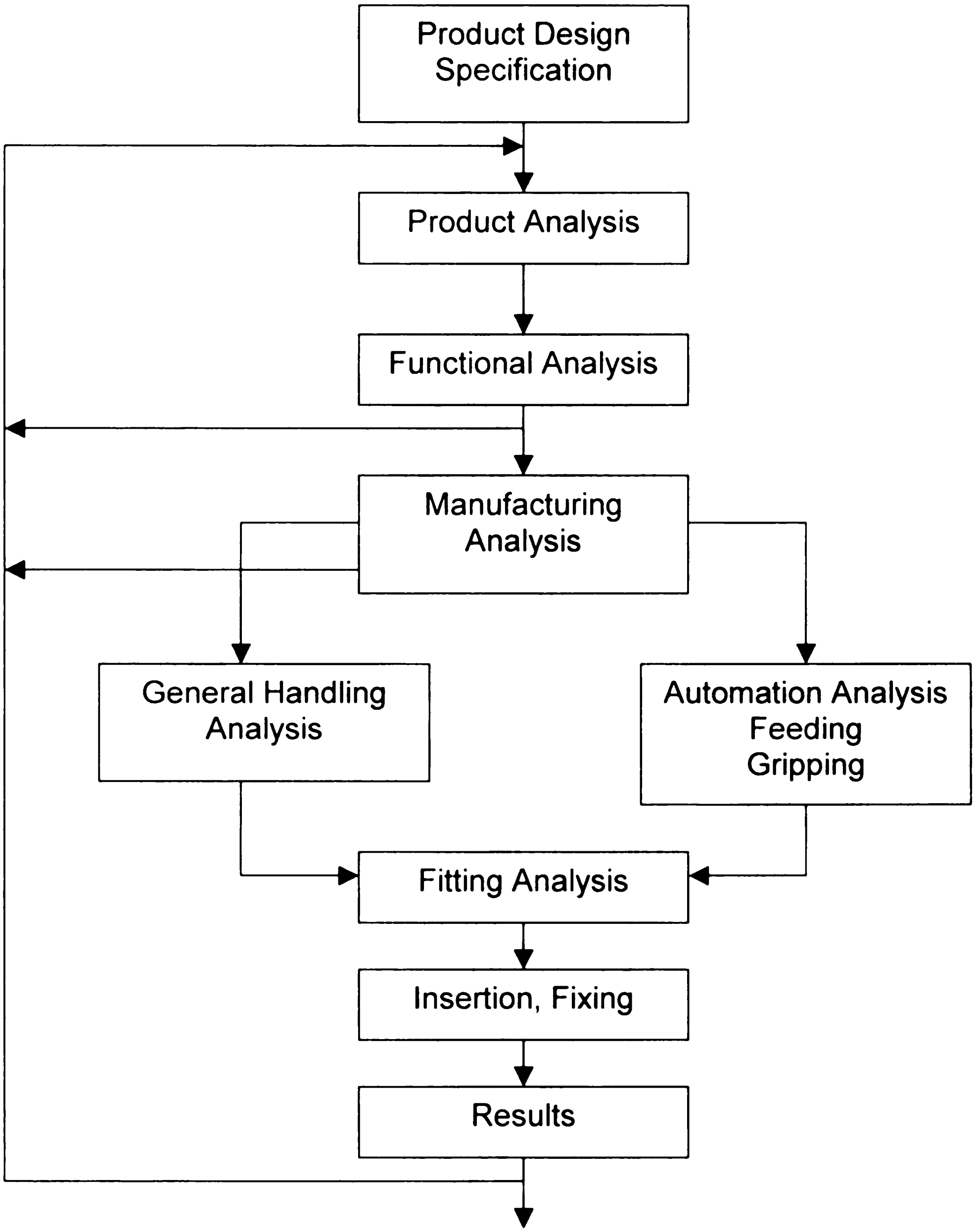


Figure 3.5: Lucas Design for Mechanical Assembly Procedure
(Source: Redford and Chal 1994)

3.2.3.2.3 The Boothroyd-Dewhurst DFA Method

Boothroyd-Dewhurst Inc. have developed methodologies for both DFA and DFM. Apart from having a handbook, a software has also been developed which is known as DFMA.

The objectives of Boothroyd-Dewhurst DFA method are to:

- Determine the appropriate assembly method
- Reduce the number of individual parts that must be assembled
- Ensure that the remaining parts are easy to assemble

The procedure for this method is carried out in two stages:

1. Determination of type of assembly method to be used
2. Analysis of design, estimating assembly costs, identifying assembly difficulties is also done in this stage.

The most powerful feature of this method is the reduction of parts. This is one of the most helpful features for designers, who use it to reduce the number of parts of a product and simplify their design. This method is also very effectively used for the redesign of a product (Redford & Chal 1994).

3.2.3.2.4 The IPA Stuttgart Method

The Fraunhofer Research Institute, Stuttgart developed the IPA Stuttgart method. It is an assembly oriented design process. The basis of this method are, evaluation of assemblability of product and product improvement during the design process. Design rules are most important while developing a design for assembly. In this approach, design rules are separated into four categories. They are:

- Measures for the product structure
- Measures for sub-assemblies
- Measures for individual parts
- Measures of joining techniques

In order to evaluate each stage it is important to determine the products suitability for assembly. The IPA method allows an evaluation of those factors that are significantly important, both in the conceptual and the preliminary design stages. This evaluation is done with the help of checklists. Below are the main steps of the IPA method (Redford & Chal 1994):

1. The setting up of a functional structure
2. The weighting of functions and the determination of the functional content
3. The setting up of a sub-assembly structure
4. The allocation of functional contents to the different parts
5. The determination of assembly sequence
6. The determination of assembly expenditure
7. The determination of values measuring the suitability for assembly
8. The identification of technical problems concerning assembly expenditure

3.3 Product Breakup and Assembly Sequence Representation

A designer represents the assemblies with help of some tools and drawings. The design intent can be conveyed by three main representations. The three representations are product tree structures, precedence diagrams, and exploded views. The breakup of components of a product is represented by assembly trees. The precedence diagrams are used to show the sequence of assembly operations. In this research product trees, which is one of the type of assembly trees, have been used. Also exploded views of the assemblies are used to show the shape, size, and other physical properties of the assembly and its components. Exploded views are not used in this research, as every manufactured house is customized, also, the specifications are provided in the product tree of the assembly and the product tree of the facility layout software.

3.3.1 Product Tree Structures

The manufacturing department of a factory requires information from the design department for manufacturing a product. Among the key information required is the order in which assembly is being carried out, as well as the breakup of components of various sub-assemblies of the final product. This representation of parts can itself be achieved in many ways. The most common way of doing it is by employing the product tree representation techniques. One of the product tree representation techniques is the product tree structure. This technique is used for representation of parts / subassemblies for a group of products and their development. It was preferred over others, as this technique has been customized for this research, due to shortcomings of other assembly tree structure technique.

The product tree represents the break-up of an assembly into its sub-assembly and components depending upon the relationships of sub-assemblies and components and not on the assembly sequence. This technique is almost similar to the Work Breakdown Structure technique used in the construction industry but the representation pattern is graphical. Although the other assembly tree structure reveals the break-up of parts, it fails to identify the cluster where the particular components belong. Therefore the product tree structure representation technique was preferred. Using this technique, the components are placed in levels in a sub-assembly. It does not depend on the sequence of assembly of components but depends on the nature of the sub-assembly. Another reason for adoption of this technique in manufactured housing research is that the products produced by the factory are customized and, although different, they happen to have the same basic structure.

3.3.2 Precedence Diagrams

The precedence diagrams are used to show all the possible assembly sequences of a product. To develop the precedence diagrams for a product, each assembly operation is represented by a circle and a number is assigned to that operation. The precedence diagram is usually organized into columns and follow the order from left to right. In drawing a precedence diagram, the operations are first listed in the form of a table alongside with their activity or operation number. Then the precedence ordering and precedence constraints are established. After having established general conditions and restraints, the precedence diagram is drawn. The nodes are placed one after another or parallel, depending upon the relationships among the activities and the restraints in putting assemblies together. This precedence diagram when completed will give the sequence of assembly operations being carried out to the manufacturing department (Fox & Kempf 1985, Harris 1978).

3.4 Overview of Facility Layout Modeling and Techniques

The facility layout modeling and techniques can be divided into four categories. The four categories are (1) Techniques and Procedures used for Manufacturing Facilities Design; (2) Types of Layout Problems, Data Requirements and Data Analysis; (3) Generic Models for Facility Layout Problems; and (4) Computer Aided Layout and Algorithmic Approach. These categories are discussed briefly below, detailed description for these can found in Banerjee (2003).

The first category, "Techniques and Procedures used for Manufacturing Facilities Design" mostly deals with various techniques and procures used by manufacturing industries for designing their facilities. The product design, process design, schedule design and facility layout design are all interrelated. The process starts out with the planning of manufacturing facilities. The planning of manufacturing is sub-divided into the plant location and plant design problems.

The plant location problem deals with the physical location of the plant and is mostly affected by the supply chain's demand and supply. Plant design is further sub-divided into plant facility system, plant layout design, and material handling design. There are various traditional procedures for the layout problem, some of the common ones are Apple's layout procedure and Leed's layout procedure (Banerjee 2003).

The category "Types of Layout Problems; Data Requirements and Data Analysis" provides a general overview of different types of layout problems, their data requirements and their analysis. The various types of layouts and layout problems can be found in Banerjee (2003) where they are thoroughly described and explained. Some of the major data requirement problems relating to flow are: frequency of trips, shape and sizes of the facilities, floor space available, location restrictions for facilities, adjacency requirements between pairs of facilities, and relationship data (Banerjee 2003). The data requirements also differ from problem to problem and on their analysis.

The third category in this section is "Generic Models for Facility Layout Problems." Before going into the details of this category it is important to know the difference between models and algorithms. Models are imitations of the real world and algorithms are the techniques developed to solve the models (Heragu 1997). This section mainly discusses various types of models, their development and their solutions in terms of algorithms (Banerjee 2003). First, a distinction between various models is made and, depending upon the type of model, solutions are proposed in terms of algorithms.

The category "Computer Aided Layout and Algorithmic Approach" focuses on computer applications for providing solutions to algorithms and facility problems. The section discusses various software like BLOCPLAN, FactoryCAD etc., available for analyzing the factory. The selection of the software package depends upon the type of analysis and the level of detail required for modeling.

3.4.1 Overview of FactoryFLOW Facility Layout Evaluation Software

FactoryFLOW (EDS 2002) is a tool that can be used to analyze and evaluate an existing layout. Therefore this software is not considered a planning or drafting tool (Banerjee 2003). It works in conjunction with AutoCAD, by integrating 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 (EDS 2002). FactoryFLOW produces flow diagrams, aisle congestion reports, and material-cost reports that are very helpful to identify critical points for analysis and to propose alternatives.

FactoryFLOW requires information on each move for each part in the form of the quantity moved, material-handling device used, and unit load. The information for these factors is provided by using spreadsheets or word processing software. Based on the data entered and the AutoCAD layout file, the software calculates total move distance and cost (Heragu 1997). The AutoCAD plays the role of giving out distances and for graphical representation of the factory and the flow taking place within it. These representations of flow and material handling provide good understanding of the production system (Banerjee 2003).

The major objectives for FactoryFLOW analysis are (EDS 2002):

1. Evaluating material handling requirements
2. Eliminating non-value-adding material handling
3. Reducing total product travel
4. Improving product throughput
5. Reducing work-in-process inventories
6. Redesigning material flow for Just-In-Time or Group Technology
7. Identifying storage space requirements
8. Analyzing layout feasibility for operator walk paths

3.4.1.1 Data Requirements for FactoryFLOW Software

The basic data that are required by FactoryFLOW for carrying out an analysis are (1) an AutoCAD layout drawing, (2) production quantity information, (3) parts routing information, (4) material handling equipment information, and (5) material handling activity information (Banerjee 2003). The AutoCAD drawing is required for setting activity points and distances. Production quantity information is necessary for validation purpose and model development. Parts routing information provides information relating to the paths followed by the parts. Material handling equipment information is used to attach a specific material handling equipment with a part. Material handling activity information provides information regarding the material handling activity.

3.4.1.2 Stages in FactoryFLOW Analysis

There are six stages in FactoryFLOW analysis as described by "FactoryFLOW Class Guide Manual" (EDS 2002). A brief overview of these stages has been provided below.

1. Identify the goal(s) of the study and determine areas or products affected

   FactoryFLOW can be used for numerous purposes. If the objective is not identified the limits for modeling level cannot be identified. It is therefore necessary to define the objective, collect and analyze data only relevant to the objective.

2. Determine the level of detail

   The analysis should be done taking one level at a time. It is necessary to know whether the analysis is carried out on a macro level, i.e., station-to-station basis, or on a micro level, i.e., flow within the station.

3. Adopt Data Naming Conditions

   The names assigned to products, parts, material handling devices and activity points should be easily recognizable for the ease of analysis.

4. Gather And Organize Input Data

    The type of analysis puts restrictions on the type of data to be collected. FactoryFLOW stores all data in a single database file, which is named with a .FLO filename extension.

5. Produce an AutoCAD plant layout drawing

    FactoryFLOW uses an AutoCAD drawing of the facility to compute travel distances.

6. Produce Reports and Diagrams For Analysis

    The FactoryFLOW diagrams, charts, and reports are used to identify problem areas. FactoryFLOW can also perform "what-if" analysis by changing activity locations, editing paths, or input data and immediately calculating the impact of the change. Alternate layouts and material handling systems can be compared, and the output reports can be used for measuring the impact of change in layout or material handling systems.

3.5 Overview of Simulation

Simulation refers to a broad range of methods of modeling reality. Simulation is used for a variety of purposes. The most common are to measure the effectiveness and efficiency of a system, trace bottlenecks, manipulate the system and make improvements. It could also be used for defining a completely new system and to carry out all the above mentioned activities. Simulation can be used for both existing and new systems.

There are various kinds of simulations. Some of the common types are static and dynamic simulation; continuous and discrete simulation; and deterministic and stochastic simulation.

1. Static and Dynamic Simulation

In static simulation, time doesn't play a major role, whereas time plays a major role in dynamic simulation. An example of a static simulation would be estimating how far a stick can be thrown, with a certain amount of force. An example of dynamic simulation is calculation of time taken to produce a certain number of units in a manufacturing facility.

2. Continuous and Discrete Simulation

The state of the system can continuously change in continuous simulation, but not in discrete simulation. In discrete simulation, the state of the system changes at certain periods of time.

3. Deterministic and Stochastic Simulation

The input provided to model the system can either be random or uniform. In a deterministic simulation the inputs are not random but the inputs are random in a stochastic simulation. There is no requirement that a model have only one type of input; it could also have both deterministic and random inputs (Kelton et al 1998).

Simulation can be performed with help of simulation software on a computer. Simulation can be performed by using general programming languages, simulation programming languages, and simulation packages (Hammad 2001). The choice of choosing a simulation language or package depends on the modeler. The choice of packages should be made after defining the requirements of the model and determining what activities need to be carried out after a system has been modeled. Two things need to be kept in mind while choosing a simulation package: the amount of flexibility, i.e. the depth of modeling offered and the user-friendly environment, i.e. easiness in modeling. It has generally been observed that programming languages and simulation programming languages offer very high flexibility but as a model becomes more complex, the program also starts to get complicated. By contrast, in the case of simulation packages predefined modules can be used to perform a particular activity, and as the model becomes more complex, the simulation model seem to be less complex than the model represented in a programming or simulation language. Simulation packages turn out to be very user friendly but have some restrictions in performing certain customized tasks; therefore, they are considered to be less flexible.

3.5.1 Overview of Arena Simulation Software

Arena simulation software (Kelton et al 1998) has been designed specifically for manufacturing and business processes. The software has two editions, the professional edition and the educational edition. The professional edition is an enhanced version of the educational edition. The professional edition has the capability of customizing the simulation objects, process logic, data distributions, performance measures, and animation. The entity number is also unlimited, and so is for the number of modules, whereas the customization, unlimited entities, and modules are limited in the educational edition (Hammad 2001).

Arena stands somewhere in between the simulation programming languages and simulation packages based on its flexibility and ease of modeling. This is because Arena has access to SIMAN simulation language. This provides high flexibility while programming, by providing the modeler with access to mix and match modules or construct entirely new modules. The easiness is maintained by providing pre-defined modules and templates for the standard process (Kelton et al 1998).

Arena also has a built-in tool called Input Analyzer, which assists in assigning best-fit probability distribution for the data. The Input Analyzer recommends distribution based on minimum mean square error. If the distribution selected by the Input analyzer is not preferred by the modeler, then other distributions could also be selected and the distribution's parameters found with help of this tool (Kelton et al 1998).

3.5.1.1 Data Requirements for Arena Simulation Software

The data requirements remain almost the same for developing different models. But the level of data requirement depends on the detail of modeling and data available. The basic data requirements are (1) relationships between various processes; (2) number of entities and types; (3) flow of entities associated with various processes; and (4) process times. Also secondary data like breakage of machinery and delays can also be added to make the process more realistic.

3.5.1.2 Stages in Arena Simulation Analysis

Arena simulation analysis can be divided into three stages. They are (1) data collection, (2) development of model, (3) producing and interpreting run results.

The very first stage of the analysis begins with the collection of data. Data relevant for model development are collected. Data such as process relationships, process times, number of entities, machine failure etc. are examples of data needed for the development of the model and analysis. The second stage of the analysis is the actual development of the simulation model. Once the data necessary for the model development are ready, the model is developed. The modules representing the processes are laid out. The relationships and process times are then assigned. Now the model is ready to run. But this model run would go on forever, as the restrictions for simulation have not been specified. The simulation can be controlled in two ways, the first option is to limit the number of entities and find out the simulation running time; the second option is to limit the time and note the number of entities produced. Once this is done, the model is verified depending upon the system relationships and output produced.

After having run the model with a limiting condition, the run report for the model is produced. The run report provides information such as number of entities produced, standard process run time, percentage time the resource is busy, etc. The report is divided into three sections. The first section is the tally variables that have information related to the average queue time and flow time. The second section, known as the discrete-change variable section, provides us with the number of entities present in the station when the simulation ended, percentage busy time for the station, etc. The last section also known as counters, provide the number of entities produced. Also simulation run time is provided at the beginning of the report. This report is used to identify simulation bottlenecks and design solutions for them. The bottlenecks are identified on the basis of queue times and percentage busy time provided by the report.

3.6 Facility Layout and Simulation Software Integration

Facility layout design often needs to be dynamically simulated to prove the concept and to determine if the required output can be achieved. This requires duplication of the CAD drawing in the simulation environment before it can be modeled. This is not a one-time duplication as the facility layout could go through numerous revisions before it is finalized (Moorthy 1999). Therefore it is very important to integrate simulation and facility layout software. There are many advantages to integrating the simulation and facility layout software. The main advantage is that manual duplication can be avoided if this integration is implemented. The automated duplication further leads to reduced efforts in creating models as well as reduction in errors. Although there are many advantages to simulation and facility layout software integration, so far not much work has been done in this field. One approach is described for possible simulation and facility layout software integration below.

Most of the material in this section comes from two papers Moorthy (1999) and Sly & Moorthy (2001). Intelligent CAD objects have been developed for facilities design. These objects allow the facilities designer to design and modify the facility layout with minimum efforts. FactoryCAD (UGS 2004) has certain layout objects in it. These layout objects are embedded with data relevant to simulation such as cycle times, machine failure probability, etc. Facility layouts design often needs to be dynamically simulated to prove the concept and to determine if the required output can be achieved or not. This generally requires duplication of the CAD drawing in the simulation environment. Moreover, the duplication is not a one time duplication; it goes through a number of iterations (Moorthy 1999).

It is therefore proposed that the information embedded in the FactoryCAD objects are transferred to the simulation package. This data transfer is achieved by creating a common data format (Simulation Data Exchange - SDX). This SDX file will serve as an automatic generation of discrete event simulation models (Moorthy 1999). Figure 3.6 shows Simulation Data Exchange Architecture.

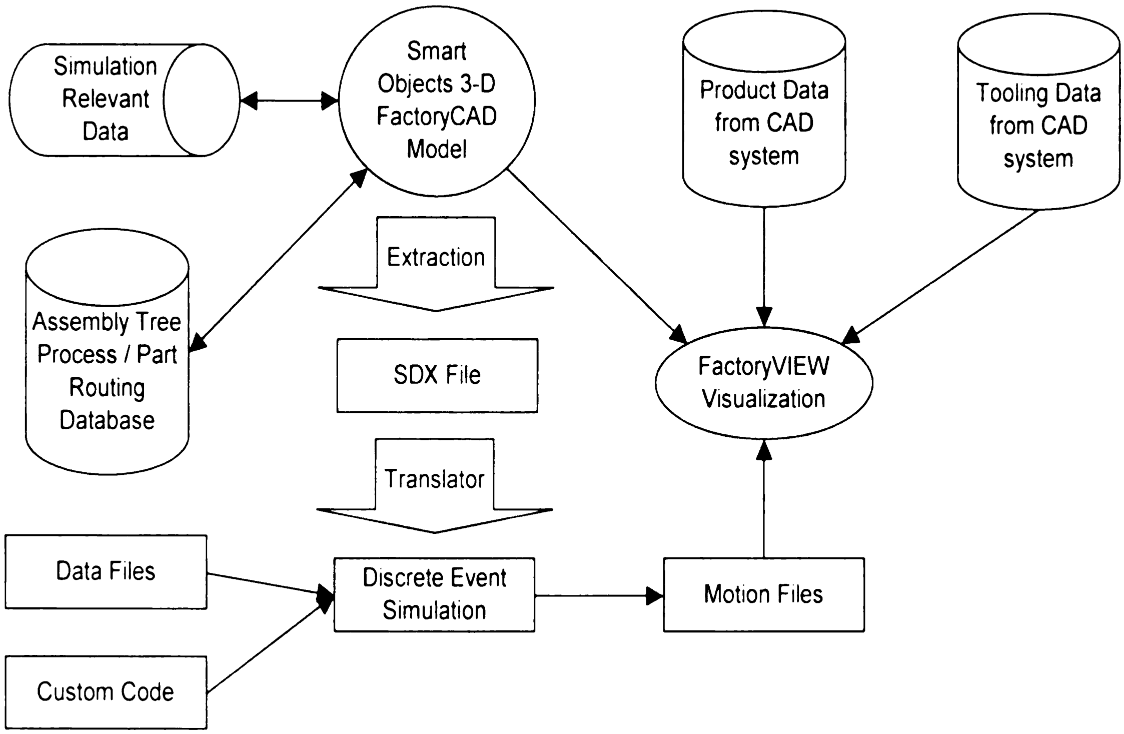


Figure 3.6: Simulation Data Exchange Architecture
(Source: Moorthy 1999)

SDX information can be inputted manually, imported, or derived from a default file into the SDX file. After extraction, the facility model is to be translated into a simulation model or modified from an existing model. Appropriate changes in the data can be made and also recommendations in the form of a newly extracted SDX file then can again be imported into the FactoryCAD layout model. Figure 3.7 shows a base level SDX process (Sly & Moorthy 2001).

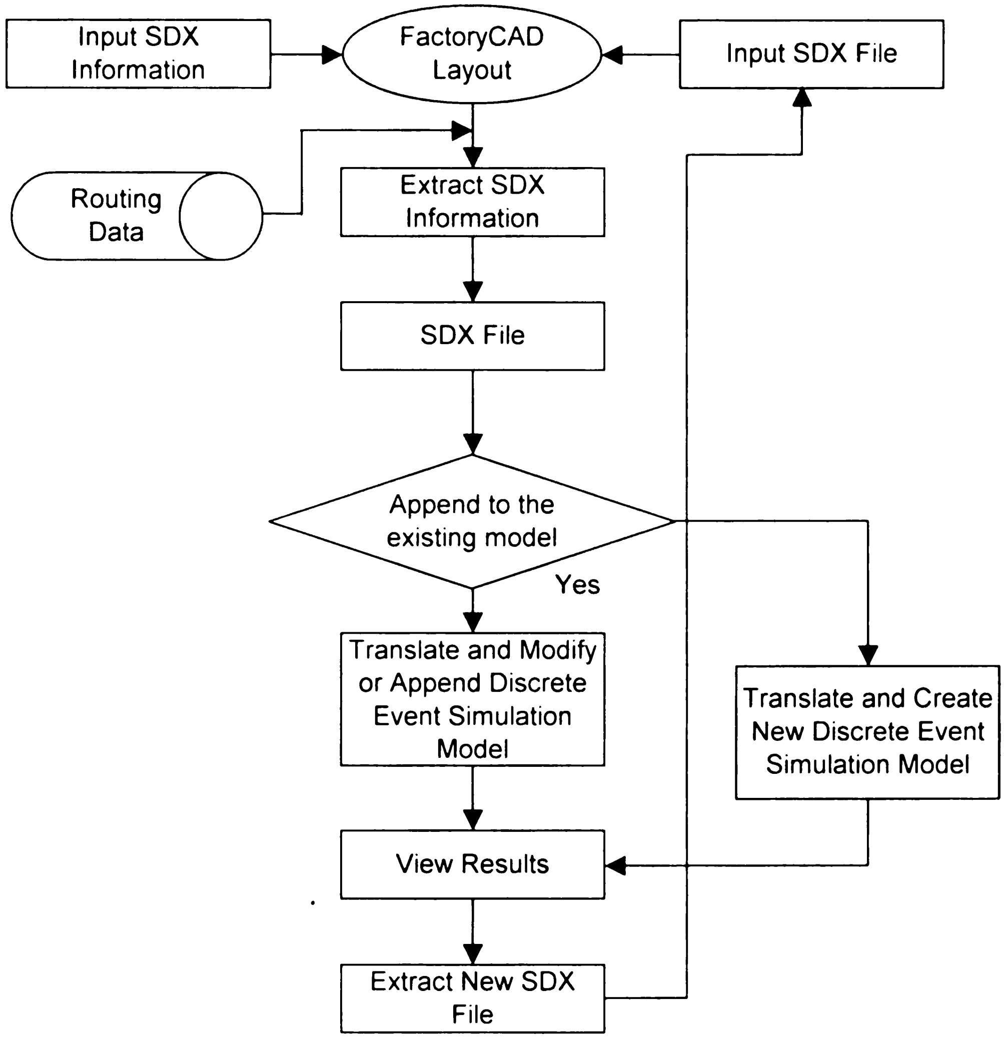


Figure 3.7: A Base Level SDX Process
(Source: Sly & Moorthy 2001)

3.7 Summary

This chapter presents an outline of all the tools and techniques that will be used by the author for this research. The objectives and procedure for applying DFMA, DFM and DFA have been described with special emphasis on DFA. In addition, some techniques like the product tree structure and precedence diagram have been presented, since these techniques will be used by the author for developing new assemblies. Some tools that will be used for quantifying the effects of change in components assembly; namely, FactoryFLOW facility layout and Arena simulation software have also been described.

CHAPTER - IV

MODELING OF MANUFACTURED HOUSING COMPONENTS ASSEMBLY

4.1 Introduction

This chapter presents the development of models that represent the existing assembly process of manufactured housing components. The methodology adopted for development of these models starts by identifying the inefficient clusters and those parts in the clusters that require comparatively more time and labor input. Second, the breakup of parts as well as the assembly procedure represented by product tree structure and precedence diagrams for these clusters with inefficient parts are developed. Finally, models representing these clusters are developed.

The identification procedure is significant, as it is important to know what components need to be improved and which are considered to be labor and time intensive. Further, the product tree structures and precedence diagrams are important to convey the breakup of parts that form an assembly and also the sequence of assembly operations that depict how and when these parts come together to form an assembly. The models are significant in showing the current assembly procedure, and the cost of material handling of the manufactured housing components. The models are also developed to show the effects of the alternatives for manufactured housing components assembly redesign.

The breakup of parts and assembly operation sequencing are conveyed by two techniques, namely, product tree structure and precedence diagram. The two software tools used to develop the model are Arena simulation software (Kelton et.al. 1998) and FactoryFLOW facility layout software (EDS 2002). These tools and techniques are described in Chapter III, this chapter emphasizes their use for manufactured housing components assembly representation and models development.

4.2 Identification of Clusters and Inefficient Parts in the Cluster

The manufactured housing factory is usually divided into 5 clusters. Activities in each cluster are carried out to assemble a complete manufactured house. The clusters and the activities carried out under each cluster are described below.

Floor Cluster

The floor cluster is divided into 3 different stations. These 3 stations are chassis preparation, sub-floor preparation and floor decking preparation. Further, a number of activities are carried out at these stations.

Wall Cluster

In the wall cluster, there are 2 sets of activities. These sets of activities depend on the type of section of the manufactured house. A manufactured house is generally a single section or double section. In a single section, the house consists of only one section that contains all the parts of a house. In a double section, the house is made of 2 sections, one section consists of kitchen cabinets and the other section consists of bathroom fixtures. First the activities related to assembling cabinets and fixtures are carried out. Then activities related to interior walls are carried out in interior wall main station. Then the section is moved to an exterior wall main station, where exterior walls are attached to the floor. Then the two sections that form a house are brought together to see if the walls match. Now the two sections are attached together and moved as one house, rather than sections. After the walls are assembled on the floor, exterior activities are carried out on the house that runs along with the roofing activities.

Roof Cluster

The roof activities are carried out while the windows and wall sheathing are being put up. The roof structure is built in a feeder station similar to the feeder station that is used for building interior and exterior walls. Then it is brought to the main station where it is attached to the walls. Once the roof is attached to the walls, rough electrical is installed, and roof decking follows.

Exterior Cluster

The exterior cluster mainly consists of exterior activities on walls and roof. Once the wall sheathing is installed, wall siding follows. Shingles are installed on the roof as part of the roof exterior work. This activity is carried out while the windows and siding are being installed.

Finishes Cluster

Before the house enters the finishes cluster, it is separated into two sections. Finishes activities mainly consists of finishing drywalls, installing carpet, installing electrical appliances and electrical fixtures, and installation of the fireplace. The walls are finished either with trims or by drywall finishing. The choice of drywall finishing depends on the manufacturer. Once the electrical appliances, electrical fixtures, and carpet are installed, cleaning and testing is carried out. This finishes the manufactured housing production process, and now the house is ready to be shipped.

Some of the clusters and the activities in the clusters overlap with each other i.e. they run in parallel. The identification of inefficient clusters and inefficient parts or activities is carried out based on 3 criteria. These criteria are: (1) based on the understanding that the activities can be done differently, (2) based on the interviews with the production managers, other factory personnel and other manufactured housing industry personnel, (3) based on time and labor consumption.

4.2.1 Identification of Clusters

The interviews were used as a mean for identifying clusters and inefficient parts in the cluster that were causing delays, based on the understanding that their redesign would lead to time and cost savings. Several interviews were used as the basis for identification of clusters and their inefficient parts. Sample interviews have been provided in Appendix-A.

Based on the interviews, the clusters were identified are floors, walls and roof clusters. These clusters seem to consume comparatively more time and labor and also caused delays to the adjoining clusters affecting the overall production of the factory. One of the important observations was that there were a lot of activities on the main station, as compared with the feeder stations.

Hence, the feeder stations were far ahead in production and sometimes had to wait for the section to move, because there was no more space for storage of the components produced in the feeder station.

4.2.2 Identification of Inefficient Parts in the Cluster

The interviews were also used as a mean for identifying inefficient parts in a cluster. This was significant, as it was important to pinpoint the activities that were causing delays and also to know what activities could be performed in a different way. Clusters identified and chosen for analysis were the floor cluster and the wall cluster. The roof cluster was also one that needed to be redesigned but the options explored did not seem to be practically feasible. The parts of floor cluster that identified as inefficient, and which could be done differently, are described below.

The floor cluster consists of 3 stations. The 3 stations are the chassis station, sub-floor station and floor decking station. In the chassis station, the chassis was being lifted twice in order to attach, first, the axles, and then, the tires. This seemed to add an extra activity to the station. Additionally, at the sub-floor station, the sub-floor was being built on the chassis. After conducting the interviews it was also found that it is not necessary to build the sub-floor on the chassis. The sub-floor could be built before the chassis entered the station, and activities in chassis station and sub-floor station could be completed in parallel.

The wall cluster has a number of feeder stations and main stations. In this cluster the walls are first assembled at their respective feeder stations; then they are brought to the main stations and attached to the floor. The interior walls are attached to the floor first and then the exterior walls are brought from the feeder station and attached on the main station to the floor. The two house sections are then attached together and checked for any dislocation of the walls. Once the sections are attached together, the outside of walls is covered by sheathing and then the windows are installed. At the same time, the roofing activities are also going on. After the windows are installed, the external walls are covered by wall sheathing. The house is then separated into two sections, the drywalls are finished at this point. Once the drywalls are finished they are sanding with sand paper and then the section is cleaned for finishes. It was observed that the drywall finishing was consuming a considerable amount of time, and the feeder stations were further ahead in production than the wall installation at the main station. Also the wall siding activity was being held up, as the windows were not installed. Therefore, drywall finishing and windows installation were selected as activities for analysis.

4.3 Development of Existing Components Assembly Models

The models' development took place in conjunction with the data collection process. The models were developed and validated by industry personnel. The models recreated were the facility layout model, the floor cluster simulation model and the wall cluster simulation model. The model redevelopment is referred to as model recreation, since previous research has been used as a basis for the present research. The simulation model formulation is only a partial recreation, as simulation models for the activity levels have not been developed before.

4.3.1 Development of Product Tree Structures

As discussed in Chapter-III, product tree structures are graphical representations of the parts and sub-assemblies of a larger assembly. The development of product tree structure is vital for this research as it provides a visual representation when changes are made to the assembly. Major changes that could take place include changing the sub-assembly into a component part, also known as component integration, the change of group of assembly. The change of group of assembly can be explained with the following example: if the drywall finishing is an altogether a different activity carried out at a different main station it would be represented as a different group, however, if the drywall finishing activity is moved to the feeder stations, then the drywall would become a sub-group of walls. Below, the product tree structures for floor and wall cluster are described and illustrated.

4.3.1.1 Data Collection for Developing Product Tree Structures

Data on part content for the floor assembly and the section assembly before the appliance hook-up and carpet installation were collected. The strategy adopted for this data collection was first to observe the part assembly at a station; and then the larger assembly was broken down into its component parts. They were then shown below the parent assembly. The sub-assembly was then taken as the larger assembly and broken down into its component parts and sub-assemblies.

The procedure was applied in iterations until a complete break-up of parts at various stations was complete. This break-up of parts was then joined together to form a complete product tree structure for the component. The product tree structures for smaller assemblies were developed and then they were combined to form the product tree structure for a larger assembly.

4.3.1.2 Product Tree Structure for Floor Cluster

A product tree structure for the floor cluster was developed in order to understand the assemblies, sub-assemblies and component parts of the floor. The floor cluster is generally built in 3 parts; the first part is the chassis, the second part is the sub-floor, and the third part is the floor decking. These are three integral floor components that come together to form the complete floor. All the other minor sub-assemblies and components are placed below each head. PVC linoleum is placed as a separate component, as it is carried out at a separate station, but this completes the work done on the floor. This is just a single-component and a one-person activity where a person places, spreads and attaches the PVC linoleum to the floor decking. A sheet of PVC spread on the floor serves the purpose of tiling below the carpets.

The chassis consists of various parts such as axles, bolt shakle, frame, lock nut, tires and wiring. All these parts are assembled at the chassis station in a particular sequence. Similarly there are various sub-assemblies and parts at the sub-floor station and decking station where more sub-assemblies and component parts come together to form the larger floor assembly. Figure 4.1 shows the product tree structure for the floor.

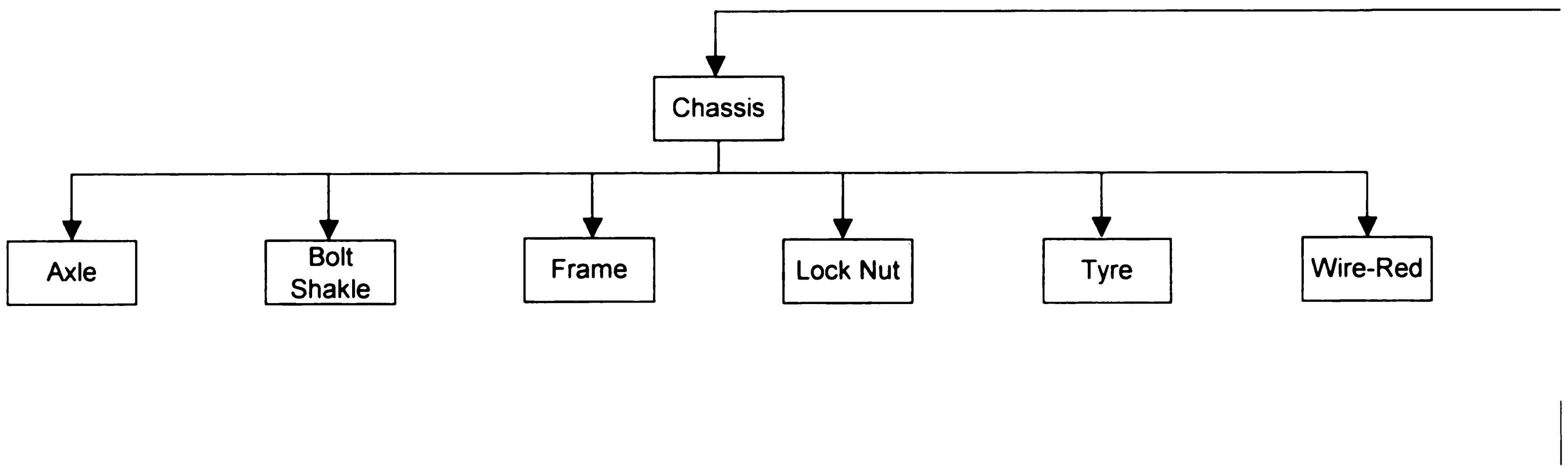


Figure 4.1a: Product Tree Structure for Floor Cluster

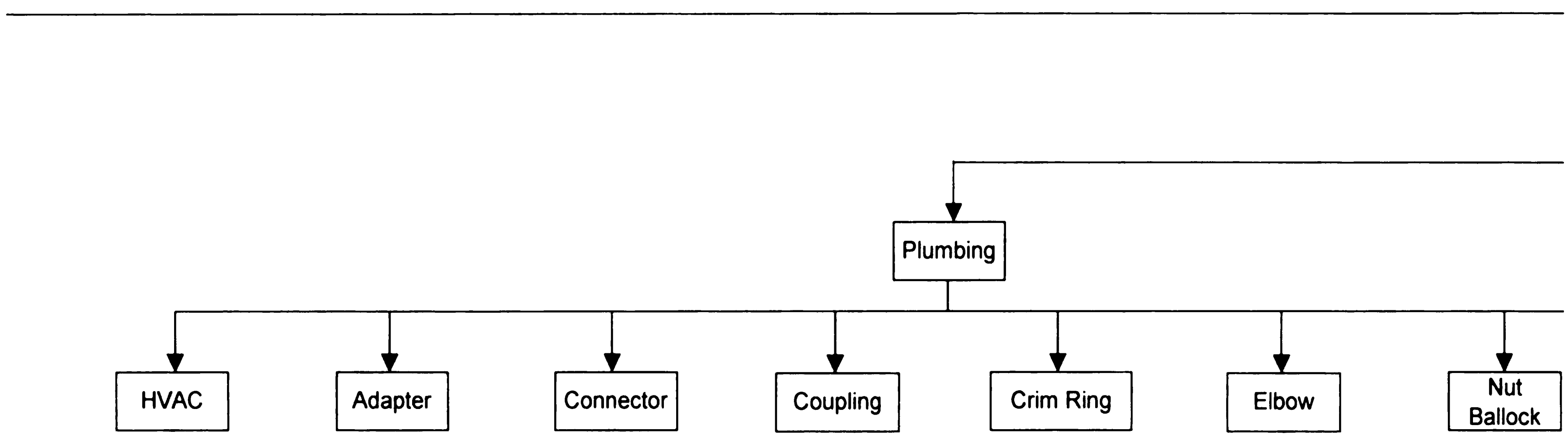


Figure 4.1b: Product Tree Structure for Floor Cluster

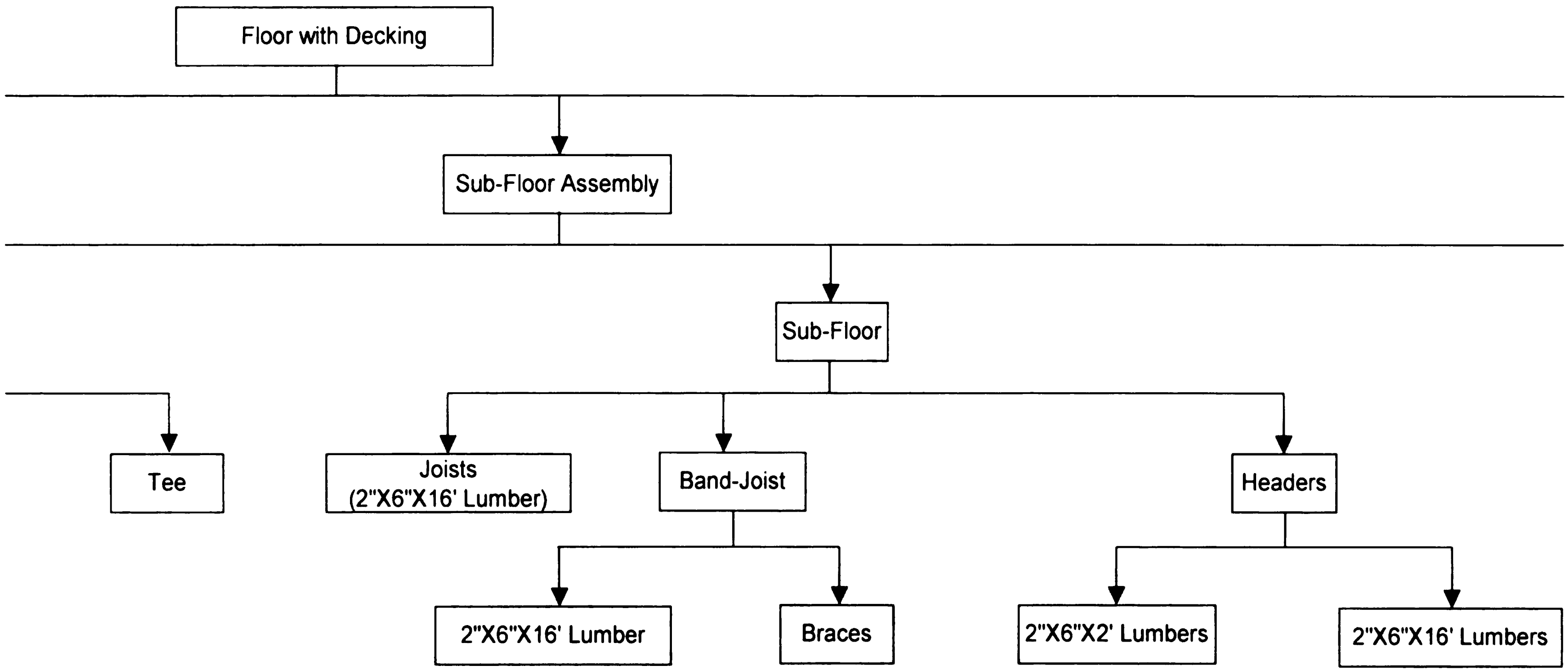


Figure 4.1c: Product Tree Structure for Floor Cluster

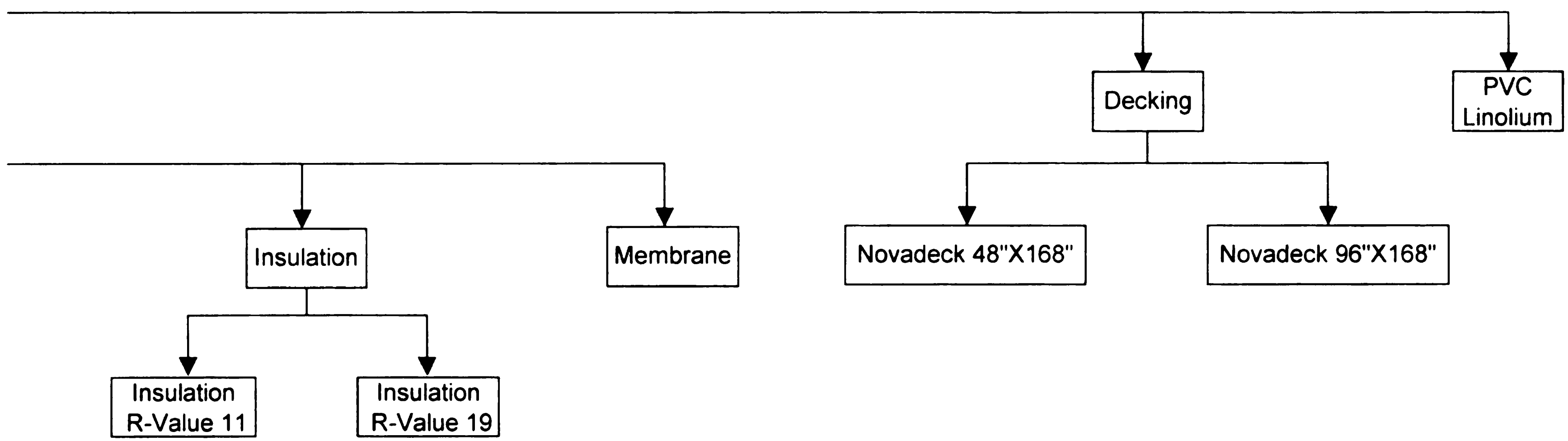


Figure 4.1d: Product Tree Structure for Floor Cluster

4.3.1.3 Product Tree Structure for Wall Cluster

The product tree structure for the walls is comparatively more complex and has more components than the floor cluster. This is because more components have been added down the assembly line. The parent assembly is the manufactured house section after drywall finishing which is almost the end of the assembly line. In this product tree structure, floor assembly becomes a sub-assembly. The sub-assemblies that come together to form the larger manufactured housing section after drywall finishing are interior walls, exterior walls, rough electrical, cabinets, bathroom fixtures, windows, sheathing, siding, drywall finishing, roof and floor. These sub-assemblies are further divided into sub-assemblies and component parts.

The wall cluster also consists of floor assembly, which has not been expanded and has only been shown up to the first level of detail, as the details of floor assembly has been provided in the earlier section. The detailed floor assembly product tree structure can be seen in Figure 4.1. The product tree structure for the walls cluster has been provided in Appendix-B.

4.3.2 Development of Precedence Diagrams

The factory personnel assembling manufactured houses generally need two pieces of information. The first is the break-up of parts, i.e., what parts come together to form a larger assembly, and second is the sequence of assembly operations taking place, i.e., when do these parts come together. Precedence diagrams are one of the means used to convey the sequence of operations. It was therefore decided that the precedence diagrams would be used to depict the sequence of assembly operations taking place. The precedence diagrams were prepared for the activities taking place at the floor and wall cluster. Based on these precedence diagrams, the data relevant for developing simulation models were collected and simulation models developed. The precedence diagrams are very helpful when a modeler needs to decide which activities of the system will be modeled and which activities will be controlling the sequence.

4.3.2.1 Data Collection for Developing Precedence Diagrams

Two types of information were needed to develop the precedence diagrams. These pieces of information are: a list of activities and the relationships in-between the activities. The list of activities was prepared for overall clusters i.e. the floor cluster and the walls cluster. The relationships were assigned in two steps. The first step was to assign the relationships for the activities taking place within a station, and the second was to find out the relative relationships within the stations and link them. Thus, the precedence diagrams were prepared for both the floor and walls clusters.

4.3.2.2 Precedence Diagram for Floor Cluster

The precedence diagram for the floor cluster consists of 37 activities. In developing the precedence diagram, the floor cluster was studied closely and a list of activities was then prepared for each station individually, namely, the chassis station, sub-floor station and the decking station. After the lists were prepared of activities for each station, they were assigned relationships, i.e., which activity is a successor and which activity is a predecessor to the activity in consideration. Similarly the relationships for the stations were also developed.

It was observed that the chassis station activities were carried out first, and then the chassis was passed on to the sub-floor station where the sub-floor was built, then it was moved to the decking station. At the chassis station, the frame is first brought into the station with help of a truck. Once inside the station, the frame is first loaded on the electric hoist and then it is lifted up. While it is being lifted up the axles are aligned below. Once the axles are placed below the frame, it is lowered and the axles are attached to the frame. After the axles have been attached, the whole assembly is again lifted, and then the tires are attached to the axles. Now the chassis is lowered, a red wire is spread for the taillight connection, and the chassis is now moved out of the chassis station.

Before the chassis is brought into the sub-floor station, the band joists are built and aligned at the extremes of the station. Once the chassis enters the sub-floor station, a black membrane is spread over the chassis that acts as a moisture shield and insulation of R-value 11. Now the plumbing system and HVAC ducts that were being prepared at the feeder station are brought into the main station and placed on the chassis. After placing the HVAC ducts, the personnel move to the header feeder station where the lumbers are attached to make the floor headers. These headers are then placed at the extreme ends of the chassis. Next, an elevated platform where floor joists are placed is brought into the station and then the floor joists are spread over the chassis. Band joists, floor joists, and headers are attached to each other. Next, insulation of R-value 19 is placed on chassis's edges and at the same time the HVAC ducts are attached to each other to form a HVAC grid. The plastic membrane is then attached to the band joist and the sub-floor is moved to the floor decking station.

The floor is then brought into the decking station; insulation is set, i.e., it is properly placed between the joists if it is emerging out. Glue is then spread over both band joists and floor joists, and floor decking, which is novadeck, is spread over the floor. Holes are then marked and cut over the novadeck and the pipes are brought out through these holes. The floor decking is then attached to the floor. Once the decking is attached, the open HVAC ducts are taken out and along with it the chassis is attached to the sub-floor with help of 6-inch long bolts. The floor is now moved to the flooring station where the PVC linoleum is spread over the floor decking and then attached. This completes the activities taking place in the floor cluster. Table 4.1 shows the list of activities in the floor cluster and Figure 4.2 shows the precedence diagram for the floor cluster.

Table 4.1: List of Activities in the Floor Cluster

Activity Number	Activity
1	Bring Chassis into the Station
2	Load Chassis Frame on Electric Hoist
3	Move the Electric Hoist Up
4	Allign Main Axle Below Chassis Frame
5	Lower Chassis Frame over Main Axle
6	Attach Main Axle with Chassis Frame
7	Move the Electric Hoist Up with Axle Attached
8	Attach Tires to Main Axle
9	Lower the Chassis Frame with Complete Assembly
10	Run Basic Electrical
11	Remove Chassis from Station
12	Attach Lumber with Braces to Build Band Joist
13	Allign Band Joists at the Extremes of Station
14	Bring Chassis into the Station
15	Spread Plastic Membrane over Chassis
16	Spread Insulation
17	Put Rough Plumbing System and Rough HVAC
18	Attach Lumber to Build Headers
19	Put Headers onto the Chassis
20	Spread Joists over Chassis
21	Attach Band Joists and Joists & Headers
22	Put Insulation on Sides
23	Atach HVAC ducts to form HVAC System
24	Attach Plastic Membrane with Band Joist
25	Remove Sub-Floor from Station
26	Bring Sub-Floor into the Station
27	Set Insulation
28	Put Glue over Band Joist
29	Spread Glue over Joists
30	Spread Floor Decking on the Sub-Floor
31	Mark and Cut Holes for HVAC and Plumbing
32	Get the Plumbing out
33	Attach Floor Decking to Sub-Floor
34	Bring out HVAC
35	Attach Chassis to Sub-Floor
36	Move the Floor to the next Station
37	Attach PVC Linolium to Floor Decking

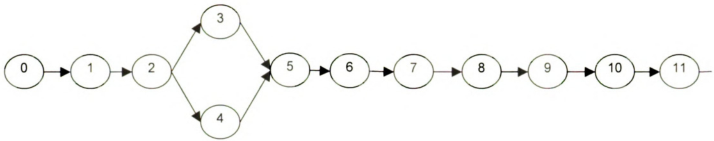


Figure 4.2a: Precedence Diagram for Floor Cluster

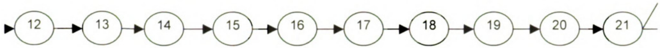


Figure 4.2b: Precedence Diagram for Floor Cluster

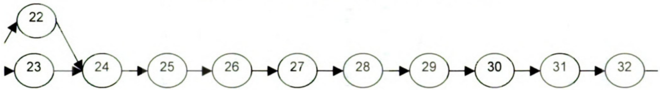


Figure 4.2c: Precedence Diagram for Floor Cluster

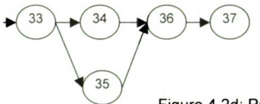


Figure 4.2d: Precedence Diagram for Floor Cluster

4.3.2.3 Precedence Diagram for Wall Cluster

The precedence diagram for the wall cluster consists of 55 activities. These activities are those that take place on the house section after the cabinets and bathroom fixtures are installed and before the house section is sent to the finishes cluster for appliances and carpet installation. The development of the wall cluster was similar to that of floor cluster. First, a list of activities for all the stations was prepared, then relationships were assigned to the activities within the stations and then relationships were assigned to the stations relative to each other.

The house section with cabinets and bathroom fixtures is first brought into the interior wall station. The interior walls are built at a feeder station, by joining lumbers to make frames, and then the drywall is spread and attached to the frame. The drywall is then cut for doors and other openings. The interior wall once ready is transferred to an electric hoist and from there it gets transferred over to the interior wall main station. Holes for pipes and wiring are cut and then the walls are attached to the floor. The walls are then attached to each other.

While the activities at the interior wall main station are taking place, walls are being assembled at the exterior wall feeder stations. There are 3 types of exterior walls namely, side walls, end walls and marriage walls. Side walls are the longer exterior wall that are placed on the longer side of the house, whereas end walls are placed at the shorter side. The marriage wall is where the two sections meet to make a complete house. The exterior walls are built in the same way as the interior walls. The only difference is that the side walls and end walls are insulated, whereas marriage wall and interior walls are not, since they only act as partition and do not serve as enclosure partitions.

The house section with interior walls is brought into the exterior wall main station. The exterior walls are then brought in one by one and attached to the floor. Once attached to the floor, the exterior walls are attached to each other. The section is then moved to the marriage wall main station. Here, at this station, the two sections of the house are brought together and attached. The two sections are temporarily attached to each other, in order to move through the roofing station as a single unit. At the marriage wall station, these sections are primarily brought together so that the walls could be checked for their placement and then they are passed on to the roofing station.

Once in the roofing station, the electrical work for the walls is carried out, and after which wall sheathing is attached to the outside of the walls. Simultaneously, the roofing activities are also taking place. The roof assembly is brought into the main station and attached to the walls. Then the blow-in insulation is spread on to the roof and eventually the roof decking is installed. The windows activities will only start when the sheathing on the walls is installed and the roof decking is attached to the roof. The windows are then installed on to the side and end walls. The wall siding activity and the roof shingle installation follow the windows activity. After the shingles and wall siding have been installed, the house is separated into two sections. The two sections are then passed on to the drywall finishing area.

The drywall finishing is carried out in 3 stages. In the primary drywall finishing, tape mesh is spread over the joints, and plaster is spread over the joints, and screw/nail grooves using a 6-inch knife. The section is then left with fans and heat bulbs in it so that the drywalls can dry. The secondary drywall finishing is carried out on the section by spreading the plaster on the joints and grooves, using a 12-inch knife, and also a thick coat of plaster is applied this time. Again the section is left for drying. Now the walls are sanded using sand paper and then paint is applied to the walls. Before the section leaves the drywall finishing part, the section is cleaned. The list of activities and precedence diagram for the wall cluster is shown in Appendix-C.

4.3.3 Recreating Facility Layout Model

The facility model was recreated from the model prepared by Banerjee (2003). The model was thoroughly studied and checked for changes. This required being very familiar with the product structure in the software, the physical layout, and in the production.

The FactoryFLOW software is primarily used to analyze the factory layout based on the material handing cost which contributes to one of the major costs incurred by the factory. Moreover, based on the review of all available software in this field, research team at Michigan State University and Purdue University decided to use FactoryFLOW software for analyzing the facilities based on material handling cost.

The verifications were carried out as described in the data collection procedure. As a result of these verifications, the new model that was created was slightly different from the one developed by Banerjee (2003).

4.3.3.1 Data Collection Process for Recreation of Facility Layout Model

Model recreation was necessary so that the assembly alternatives could be evaluated. The facility layout model used for this research was recreated from the one used by Banerjee (2003), and it will be used to evaluate results for this research.

Certain practices as depicted by Banerjee's (2003) facility model have changed in the case study factory, therefore recreation and verifications for the facility layout model was important. The model was first completely recreated and then verified for changes. The model creation process and data requirements have been thoroughly explained in Banerjee (2003). The following verifications were carried out:

1. Changes in physical layout of the factory
2. Changes in materials
3. Changes in material handling quantities
4. Changes in material handling equipment
5. Changes in unit material handling cost

The verifications were carried out, first by conducting interviews with the factory personnel specifically in the material procurement and maintenance department. Then the concerns highlighted during the interviews were studied closely and data pertaining to them were collected. The data collected included material handling equipment, material handling quantity, space and proximity, and the current manufacturing process at the specific points. The following changes were identified after the verifications were carried out:

1. Change in the production volume from 8 sections or 4 houses per day to 10 sections or 5 houses per day.
2. Addition of header feeder station besides sub-floor feeder station.

4.3.3.2 Facility Layout Model Recreation

The model recreation took place in steps, first to re-develop the model and second, to modify the model as per the verifications. First, the production for the overall factory was changed to 5 houses or 10 sections per day from 4 houses or 8 sections per day. This was done by changing the number of products in the house properties window as shown in Figure 4.3.

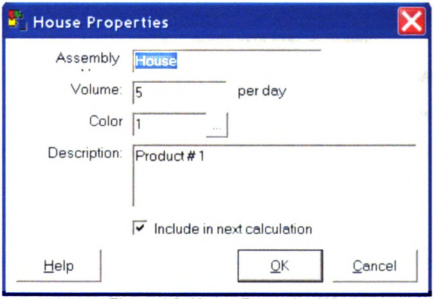


Figure 4.3: House Properties Window

The headers in the previous model were assembled on the sub-floor main station on the chassis, whereas right now the headers are built on the feeder station. Therefore, it was necessary to add a feeder station near the sub-floor feeder station. Figure 4.4 shows the addition of the activity point.

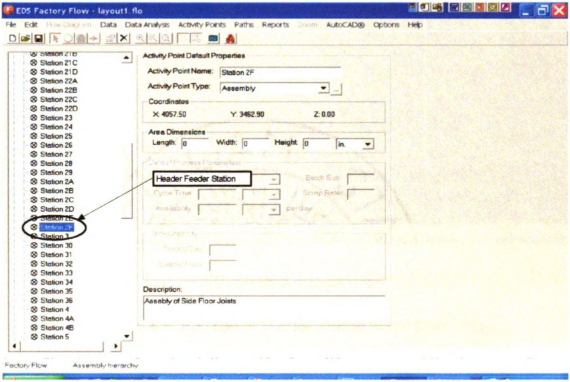


Figure 4.4: Addition of Feeder Station

Following this, it was necessary to make the changes in the CAD drawing. Therefore the header feeder station was also added in the CAD drawing. Figure 4.5 shows the addition of header feeder station in the CAD drawing.

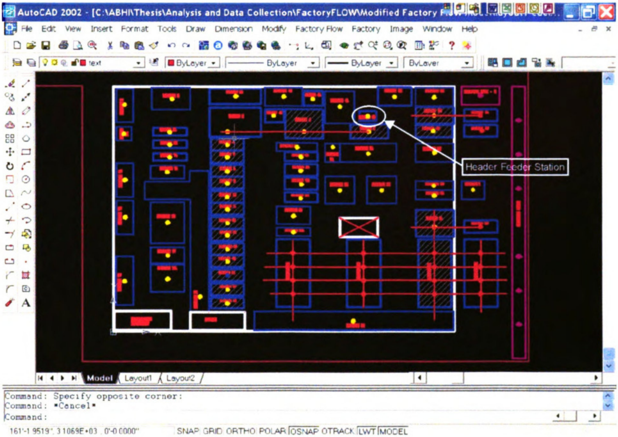


Figure 4.5: Addition of Feeder Station in the CAD Drawing

The header feeder station was placed based on the data collected in terms of space and dimensions of the station. Relative distances were taken for the sub-floor feeder station and then it was positioned in the drawing. This also required redefining the materials, material handling equipment, and quantities. This redefining was carried out based on the actual process taking place in the factory right now.

The restructuring of the headers or side-floor joists was carried out in the product structure of the house and also the routing information was updated. The material handling equipment for transporting headers were humans and therefore

2 humans for one header was assigned, and two headers were required per section. This information was added on both part-a and part-b of the house that represents two different sections of a house. Figure 4.6 shows restructuring the headers or side-floor joists in the product structure and addition of routing information of the FactoryFLOW software.

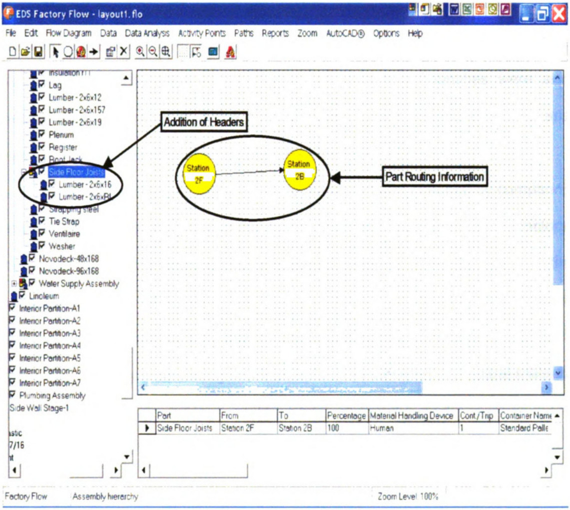


Figure 4.6: Addition of Headers in Product Structure and Part Routing Information in FactoryFLOW Software

The recreation of facility layout quantitative model is now complete and the model is ready for analysis. The product tree structure developed in this research played a vital role when recreating the facility layout quantitative model. The break-up of parts was useful as the product tree modifications were defined based on the product tree structure.

4.3.3.3 Facility Layout Model Results

The recreated facility layout quantitative model verification was carried out by going through the product structure in the software and checking the assembly logic. The material handling equipments and quantities were also checked and compared with the factory. After having verified the logic and assembly sequence the model's output was checked.

The recreated facility layout quantitative model was checked by comparing the daily material handling cost of the model and that encountered by the factory. The factory personnel agreed that the model represents the factory and the material handling cost is what the factory is encountering. The daily material handling cost as computed by the recreated facility layout model is $1,385.08, whereas the factory is spending $1,384.62. As the estimated and actual material handling costs are very close, it could be inferred that the model represents the case study factory facility layout.

4.3.4 Recreating Production Simulation Models

The simulation models recreation was carried out for the floor and wall cluster. The simulation software used was Arena Simulation Software. Arena was preferred over others as it is specifically meant for the manufacturing industry.

Arena has efficient modeling tools such as the input analyzer and the output analyzer. The animation interface provides a continuous display of the modeling logic during the development phases of the model.

The simulation model development takes place in steps. The steps are as follows:

1. Entity and System Definition
2. Defining system constraints and doing data collection
3. Constructing the simulation model
4. Model verification
5. Model output comparison
6. Conducting "What-If" analysis

Entity in this study is the manufactured house section. System is the manufactured housing factory. Systems constraints and data collection go hand in hand. Both the system constraints and data collection process define each other. For example, in the walls cluster there were some activities that dealt with roof assembly; these activities were not modeled and were a system constraint. This system constraint defined the data collection process i.e. data for the roof activities were not collected. Construction of simulation model in the software requires the modeler to be comfortable and well acquainted with the software. This is the step where the actual model building is constructed. Once the model is built, model verification is carried out. These steps are important in making sure that the model truly represents the cluster being modeled.

Another point to be noted in this simulation is that the cycle time distributions are not deterministic but are probabilistic. This means that the time related data collected in the factory will have variation. The time distribution obtained by the software based on least mean square error takes the variability into account. The time chosen the software at any iteration during the simulation may or may not be the same when running the simulation.

The above reason also contributed to the need for carrying out simulation. As the times are probabilistic and can vary with respect to time, a forward pass and backward pass calculation will not help in portraying the real picture. Therefore, to be more realistic, simulations were carried out.

4.3.4.1 Data Collection for Recreation of Simulation Models

The data collection for the recreation of simulation models was carried out over a period of 3 months. The primary data collected were the cycle times for the activities. These data were collected by videotaping and also with help of stopwatch and time sheets. The time sheets have been provided in Appendix-D. The time sheet was prepared by listing activities for each station, and the time pertaining to a particular activity was noted in the columns.

Nine data points were collected for each activity. Data were collected with respect to the station cycle times and activity cycle times at each station for the floor and wall cluster. The start of the predecessor activity and the start of the next successor activity defined the cycle time for that particular activity.

A major constraint encountered at the factory was that the workers did not follow the order of the activities during the middle of the day, and sometimes the activities were running haphazardly. This caused confusion in the start and finish for some activities, and therefore some readings were eliminated. Another major constraint was that the activities on the section would be continued even when the section had moved out. The data collection strategy was to maintain the relationships that were generally followed in the factory and follow the start rather than the end of the activities.

Data were collected over several one-day trips and some two-day trips. An ideal strategy for collecting the cycle times would have been to follow one particular floor through the course of its assembly line. Nine floors would have to be followed, but since this would have consumed a great deal of time, this strategy was not followed. Due to the limitations of available time for collecting the data, activity points were selected and cycle times were collected.

4.3.4.2 Floor Cluster Simulation Model Recreation

Before actually modeling the simulation model in the software, first the data was analyzed in a spreadsheet. The primary purpose was to learn what activities would control the process, so these controlling activities could be modeled. The controlling activities were found by averaging out the durations over 9 cycles of that particular activity. For example, one has to choose between activities number 3 and 4 to model. So the averages over nine cycles for these activities are found. It was found that activity 3 had an average of 2.17 minutes and activity 4 had an average of 1.36 minutes, therefore activity 3 was chosen for modeling and is the controlling activity in production process. Table 4.7 shows the time sheet for the Figure 4.7 shows the floor cluster simulation model and Figure 4.8 shows the details of chassis station in the simulation model.

Table 4.2: Partial Chassis Station Time Sheet

Activity Number	Activity	1	2	3	4	5	6	7	8	9	Average
1	Bring Chassis into the Station	3.77	2.2	3.23	3.08	2.93	2.78	2.17	2.82	6.93	3.323333
2	Load Chassis Frame on Electric Hoist	3.69	3.88	5.2	2.05	2.3	1.12	1.25	0.78	5.57	2.871111
3	Move the Electric Hoist Up	2.35	0.52	4.13	4.12	3.8	1.01	0.63	0.87	2.1	2.17
4	Allign Main Axle Below Chassis Frame	2.58	0.78	1.7	0.43	1.4	1.13	0.52	0.7	3.02	1.362222
5	Lower Chassis Frame over Main Axle	2.83	1	3.53	1.17	2.17	1.75	0.38	1.35	2.53	1.856667
6	Attach Main Axle with Chassis Frame	9.38	3.9	15.67	3.17	20.15	4.38	3.77	5.18	18.65	9.361111
7	Move the Electric Hoist Up with Axle Attached	0.52	4.25	11.53	6.8	0.57	1.03	0.42	1.05	1.77	3.104444
8	Attach Tires to Main Axle	9.98	9.83	8.72	11.4	9.08	6.01	5.22	11.68	11.45	9.263333
9	Lower the Chassis Frame with Complete Assembly	0.65	4.33	1.68	5.97	0.43	1.6	0.32	0.47	5.33	2.308889
10	Run Basic Electrical	10.62	2.2	1.43	1.03	2.12	3.67	5.45	1.75	2.27	3.393333
11	Remove Chassis from Station	15.42	3.03	3.62	4.4	3.78	0.48	1.45	6.48	2.58	4.582222

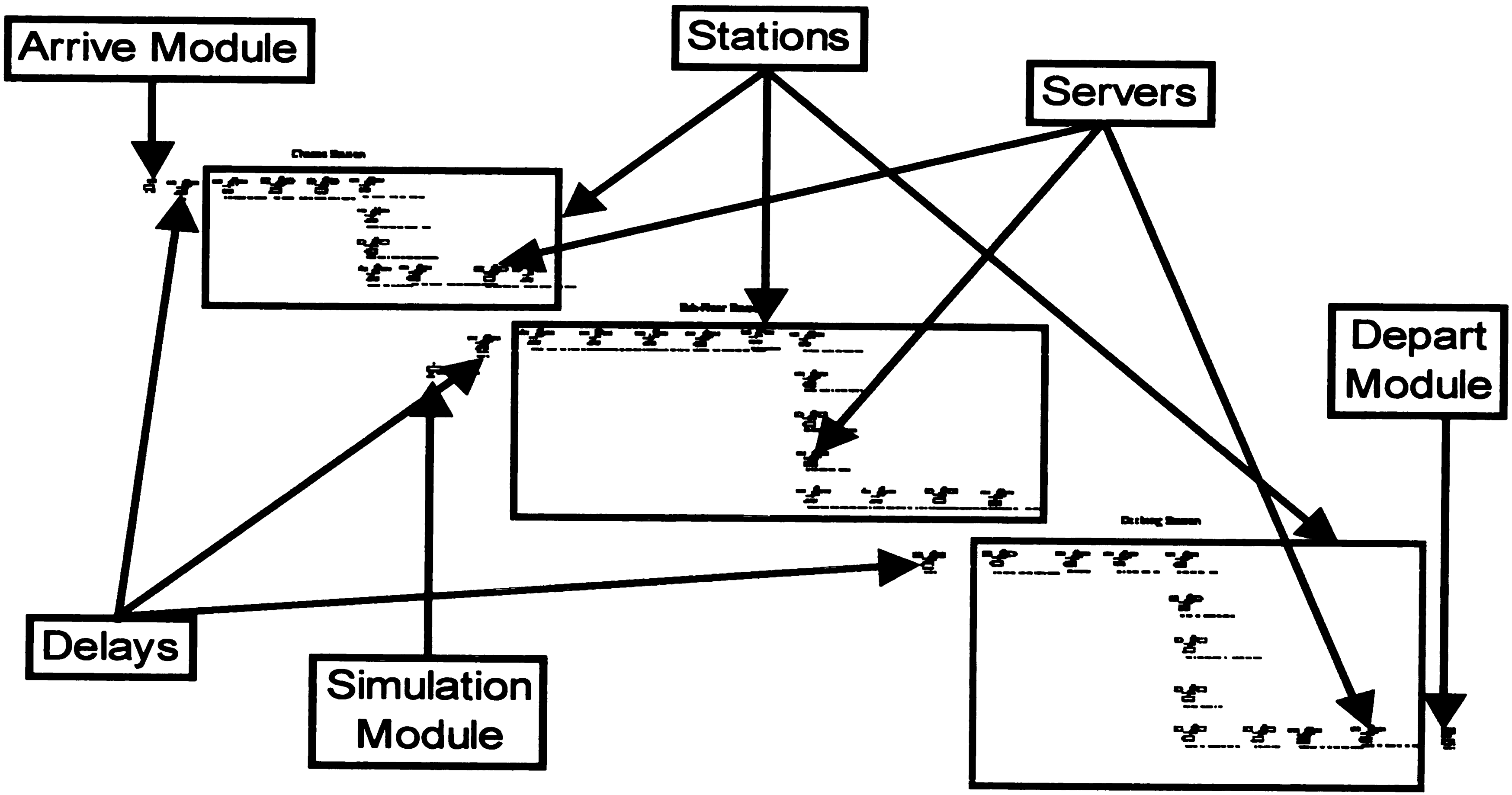


Figure 4.7: Floor Cluster Simulation Model

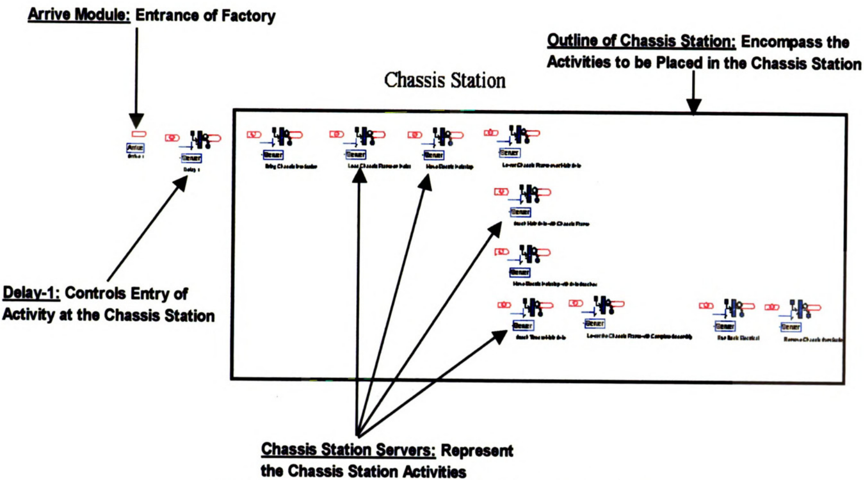


Figure 4.8: Details of Chassis Station in the Simulation Model

The rectangles represent the different stations and the servers inside the rectangles are the activities. The three rectangles are the chassis station, sub-floor station and the decking station. Distributions of cycle times were obtained by using the input analyzer tool. A brief description of the modules is provided below. In addition, the development of the floor cluster simulation model is discussed.

The arrive module was placed first by choosing it from the left panel and dropping it in the model window. Similarly, other activities were placed by placing servers. They were then all assigned relationships, as shown in the precedence diagrams. Servers were also placed outside the stations and were given fixed times. These times were the total of the average cycle times of all the activities in the preceding station. They were labeled as delays, which would serve as the purpose of holding off the entities outside the station until the entity that is inside the station is processed. This was done to demonstrate the logic that only one entity or house section can occupy the station at one single time. Once the servers were placed and the relationships were assigned to them, then the depart module was placed outside the decking station to collect the entities coming out of the process and record their statistics. Figure 4.9 shows a server module window where the activity name, cycle time distribution, and the relationship for this activity is entered.

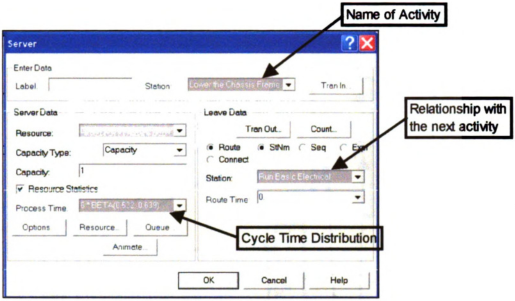


Figure 4.9: Server Module Window

4.3.4.3 Wall Cluster Simulation Model Recreation

The wall cluster simulation model was recreated the same way, as was the floor cluster simulation model. This model had to be slightly modified, and some advanced modeling technique was used. At the marriage wall station, 2 house sections come together; therefore the capacity of the servers was increased to 2 from there on. The server capacity was kept as 2 until the house was separated into 2 sections. Then, again, the server capacities of the following activities were changed. Also a spreadsheet was used for finding the controlling paths. The roof activities were not modeled, as data were not collected on them and the model was for the walls cluster. Figure 4.10 shows the wall cluster simulation model.

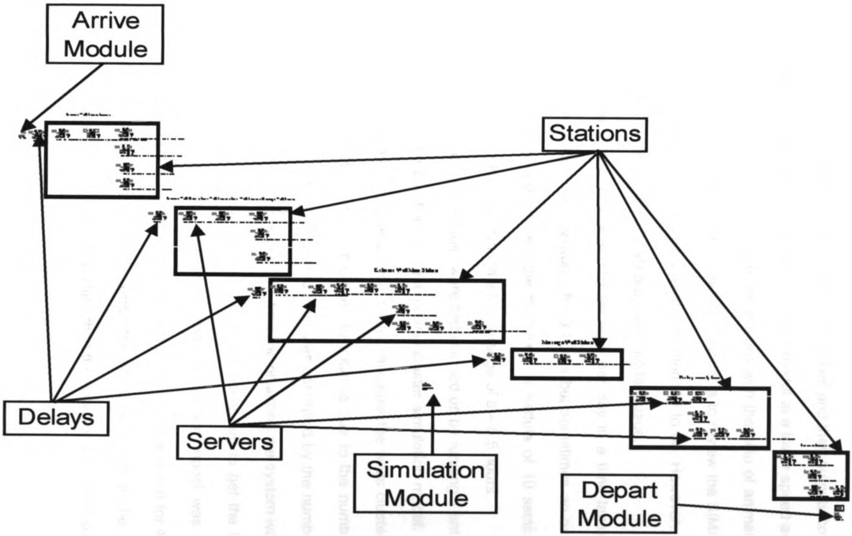


Figure 4.10: Wall Cluster Simulation Model

4.3.4.4 Simulation Model Results

The simulation models were also verified and their outputs compared. The verification was carried out by running the model at a lower speed and observing the passage of entities through the stations with the help of animation. Another method for verification of the simulation model is to review the SIMAN code and to check if the model is doing what it is intended to do. However, this requires being acquainted to the SIMAN programming language.

The factory completes 10 sections per day in a time lapse of 8 – 8.5 hours. The factory usually works for 8 hours but sometimes an overtime of 30 minutes is provided to meet the production schedule of 10 sections per day. Therefore the actual time was taken in a range of 8 – 8.5 hours.

The simulation models, were first warmed up by running 1 entity in case of floor cluster and 2 entities in case of wall cluster simulation model. The number of entities is more in case of wall cluster, because the walls cluster would take longer, as compared to floor cluster, to initialize due to the number of station present in each cluster. The simulation was controlled by the number of entities to be produced by the system. The time for initializing the system was first noted and then it was subtracted from the actual model run to get the true time for processing the entities. The floor cluster simulation model was run for 201 sections and similarly the wall cluster simulation model was run for 402 sections. This was done for nullifying the error that might be in-built in the models. The wall's model was run for more entities than the floor because of its size.

The floor cluster simulation model produced the 10 sections in 8.32 hours and the wall cluster simulation model produced 10 sections in 8.34 hours. The estimated time as computed by the models lies in between the actual range of time the factory works; therefore the models represent the factory.

4.4 Summary

This chapter presented the manufactured housing clusters within a manufactured housing factory based on the literature review and a case study factory. The author visited the factory over a period of 12 weeks and collected the required data for product tree structures, precedence diagrams, facility layout quantitative model recreation and simulation models recreation. In addition, a process for identifying cluster and parts for components assembly redesign has been described. The data formats were developed and were used for developing the existing assembly in terms of product tree structure and the precedence diagram, recreating the facility layout and simulation models. The process of recreation has also been illustrated for model verification and comparing the output. The development of the model was necessary to quantify the effects of the components assembly redesign which will be done in Chapter-V and provide results that would act as a benchmark for the redesign components models.

MANUFACTURED HOUSING COMPONENTS ASSEMBLY REDESIGN PROCESS AND ITS IMPACT ON PRODUCTION PROCESS AND FACILITY LAYOUT

VOLUME - II

By

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CHAPTER - V

MANUFACTURED HOUSING COMPONENTS ASSEMBLIES REDESIGN

5.1 Introduction

In this chapter, the author redesigns the components assemblies that were developed in Chapter 4. The clusters identified for components assembly redesign were the floor cluster and wall cluster. In this chapter, alternative assembly procedures as well as some components integration have been proposed for these clusters. The assembly has been represented with the help of product tree structures and assembly sequence by precedence diagrams. The effect of the components assembly redesign on the material flow cost with help of FactoryFLOW facility layout software and the effect on productivity has been demonstrated by using the Arena simulation software. Information input–output models have also been developed to highlight the information exchange between the two software and an approach to the information exchange has also been presented.

5.2 Components Assembly Redesign

Components assemblies are the building blocks for an assembly. They include both individual parts as well as sub-assemblies. Their redesign would include, change in their assembly sequence and incorporation of some new assemblies. Therefore, the redesign of components assembly systems is proposed by developing new assemblies and component integration.

In the last chapter, inefficient clusters and inefficient parts in the clusters were identified. These clusters were then modeled to depict the existing assembly process, which will be used in this chapter to redesign the components assemblies. The depiction of the existing assembly process was carried out with product tree structures and precedence diagrams, and the modeling was carried out with Arena simulation software (Kelton et. al. 1998) and FactoryFLOW facility layout software (EDS 2001).

5.2.1 Floor Cluster Components Assembly Redesign

The author came up with a new assembly system for the floor cluster. The floor cluster components assembly redesign was carried out by making the assembly operations in the chassis station and the sub-floor station in parallel. Also the tires and the axles were integrated so that they are brought as one unit and the headers were also brought as a prefabricated unit. Below a brief description and graphical step-by-step representation of the new assembly process is provided (Figure 5.1).

The assembly process of the floor starts with the assembly of chassis and sub-floor at the same time. The activities in the chassis station start with the bringing in the chassis frame. The frame is then loaded on the electric hoist and lifted up. The tires and the axles are brought into the station as pre-attached or a single unit (Figure 5.1a). This eliminates the lifting of the frame twice. The axle and tire assembly is aligned below the frame while the frame is being lifted. Once lowered the main axle and tire assembly are attached to the frame. A red electrical wire, which is used for connection to tail lights, is run all along the frame. The chassis is then removed from the chassis station (Figure 5.1b).

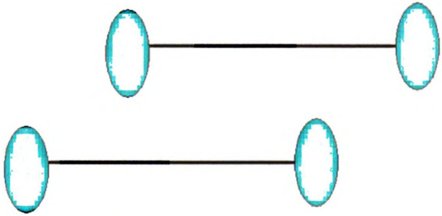

Figure 5.1a: New Floor Assembly Process

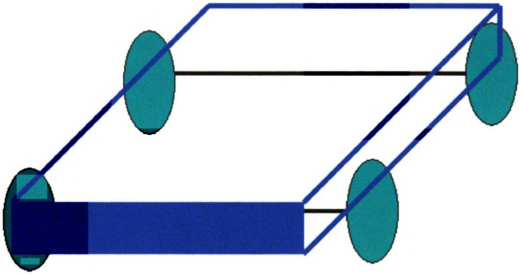

Figure 5.1b: New Floor Assembly Process

While the activities at the chassis station are going on, the sub-floor is being built at the same time. The assembly of the sub-floor starts with attaching the pieces of lumber together with braces to assemble the band joists. The header station was eliminated, as the headers now come as a pre-fabricated unit. The floor joists are then spread on the station floor where the headers are already present. The floor joists, band joists and the headers are then attached together to form the sub-floor. This assembled sub-floor is then lifted up with the help of an electric hoist and the chassis that already has a sheet of membrane and insulation on it, is slid below it (Figure 5.1c). A constraint in this system is that the chassis has to be removed from the station before the sub-floor can be lowered on it. Rough plumbing and rough HVAC is then put on the floor and the HVAC ducts are connected together to form a HVAC system (Figure 5.1d). Insulation is then spread on the sides and plastic membrane is attached to the band joist. Once the activities at the sub-floor station are complete, the floor is moved to the decking station.

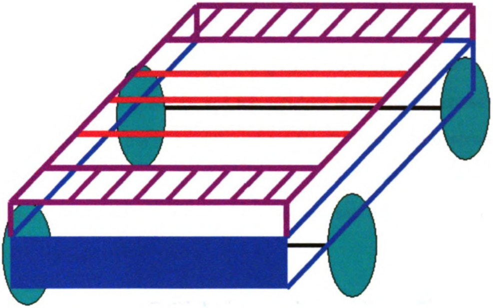

Figure 5.1c: New Floor Assembly Process

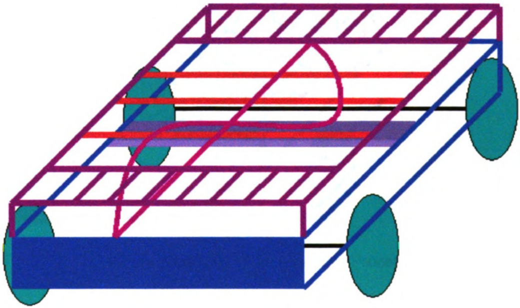

Figure 5.1d: New Floor Assembly Process

The sub-floor and the chassis are now brought into the sub-floor station. The insulation if outside is placed properly, and the glue is spread over band joists and floor joists. Next, the floor decking is spread over the sub-floor to provide covering. Holes are marked and cut for the plumbing and HVAC. The plumbing is then taken out of these holes for connection to the plumbing fixtures and at the same time, the floor decking is being attached to the sub-floor. The HVAC is brought out of the openings and the sub-floor is attached to chassis. The floor is then moved to the next station where the PVC linoleum is spread over the floor decking (Figure 5.1e). This completes the activities at the floor cluster and the floor is now ready for fixing cabinets and bathroom fixtures, depending upon the type of floor section.

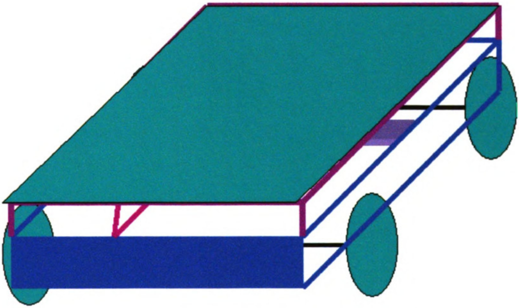

Figure 5.1e: New Floor Assembly Process

5.2.1.1 New Product Tree Structure for Floor Cluster

The product tree structure was modified based on the changes in the existing assembly process. This new assembly system led to the same 3 parts in the existing floor assembly. The first part is the chassis, the second part is the sub-floor, and the third part is the floor decking.

Chassis consists of frame, axle with tires, and red wire. The number of components were reduced in the chassis assembly as the axles and the tires were now brought in as one unit. The plumbing assembly, insulation and the floor decking were the same as the existing floor assembly. The sub-floor assembly was modified and now the headers act as a part instead of a sub-assembly for the sub-floor, as the headers were not being assembled in the feeder station. Figure 5.2 presents the product tree structure for the new floor assembly.

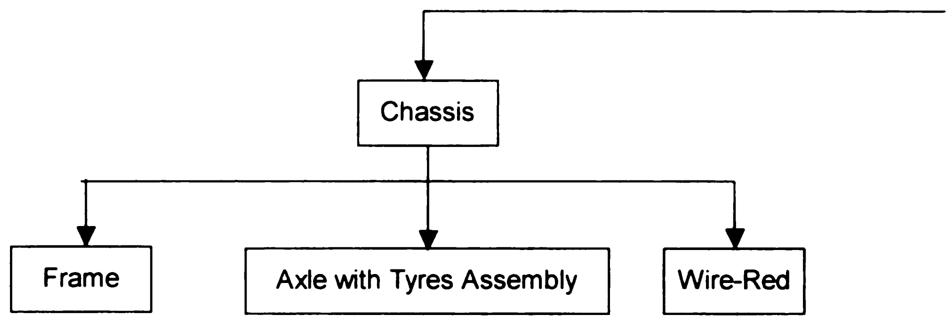

Figure 5.2: New Product Tree Structure For Floor Cluster

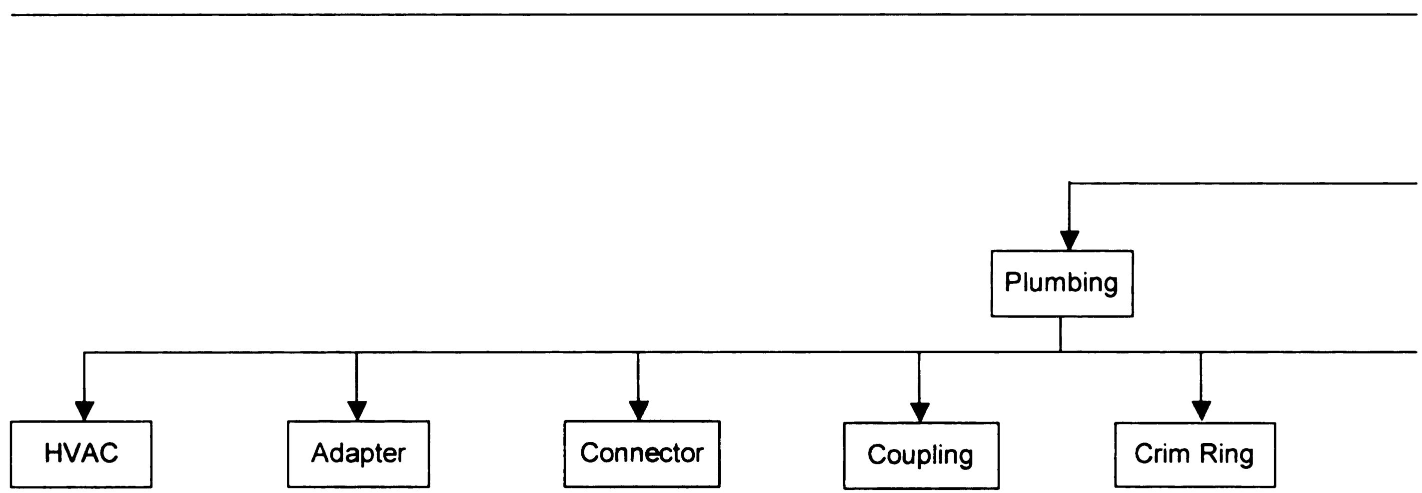

Figure 5.2: New Product Tree Structure For Floor Cluster

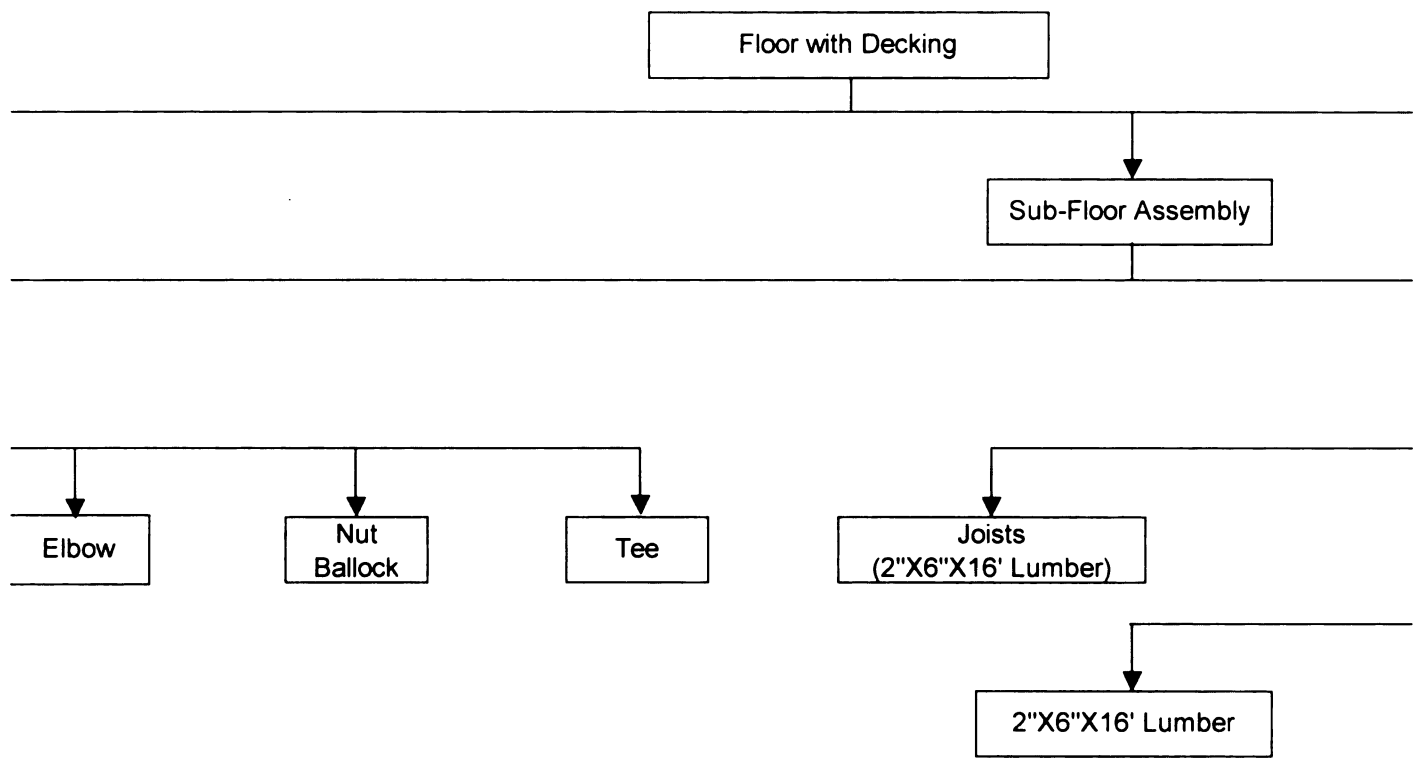

Figure 5.2: New Product Tree Structure For Floor Cluster

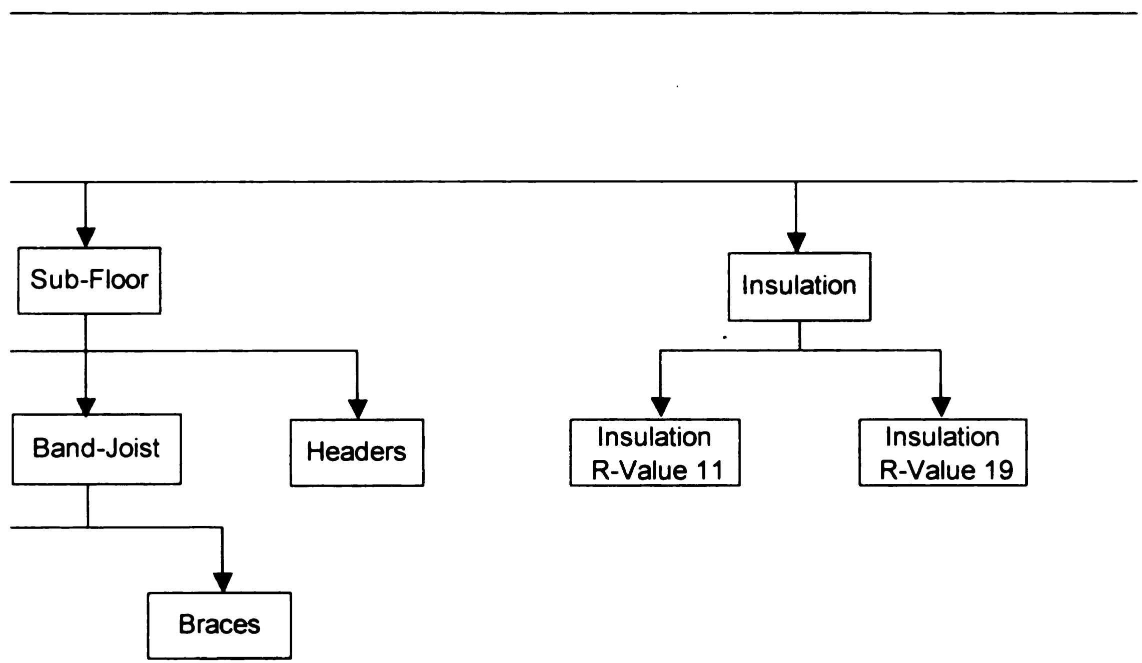

Figure 5.2: New Product Tree Structure For Floor Cluster

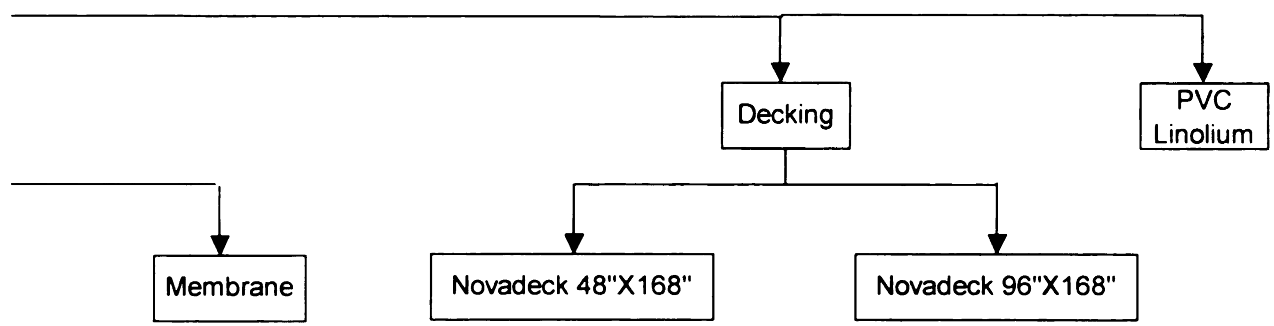

Figure 5.2: New Product Tree Structure For Floor Cluster

5.2.1.2 New Precedence Diagram for Floor Cluster

In the existing floor assembly, the activities at the chassis station were carried out first and the chassis was then passed on to the sub-floor station where the sub-floor was being built on the chassis. In the new floor assembly, the activities at the chassis station and at the sub-floor station are carried out at the same time. This also implies that the sub-floor does not need to wait for the chassis but could be built before the chassis comes in. The floor could either be built at a feeder station or could be built on the floor, in the proposed assembly process, the sub-floor is built on the floor. Table 5.1 lists the new set of activities for the floor cluster and Figure 5.3 illustrates the new precedence diagram for the floor cluster. Below a brief description of some complicated parts of the precedence diagram are also discussed.

Table 5.1: List of New Activities for Floor Cluster

Activity Number	Activity
1	Bring Chassis into the Station
2	Load Chassis Frame on Electric Hoist
3	Move the Electric Hoist Up
4	Allign Main Axle with Tires Below Chassis Frame
5	Lower Chassis Frame over Main Axle and Tires Assembly
6	Attach Main Axle and Tires Assembly with Chassis Frame
7	Run Basic Electrical
8	Remove Chassis from Chassis Station
9	Bring Chassis into the Sub-Floor Station
10	Spread Plastic Membrane over Chassis
11	Spread Insulation
12	Put Rough Plumbing System and Rough HVAC
13	Atach HVAC ducts to form HVAC System
14	Put Insulation on Sides
15	Attach Plastic Membrane with Band Joist
16	Remove Sub-Floor from Station
17	Bring Sub-Floor into the Station
18	Set Insulation
19	Put Glue over Band Joist
20	Spread Glue over Joists
21	Spread Floor Decking on the Sub-Floor
22	Mark and Cut Holes for HVAC and Plumbing
23	Get the Plumbing out
24	Attach Floor Decking to Sub-Floor
25	Bring out HVAC
26	Attach Chassis to Sub-Floor
27	Move the Floor to the next Station
28	Attach PVC Linolium to Floor Decking
2a	Attach Lumber with Braces to Build Band Joist
2b	Allign Band Joists at the Extremes of Station
2c	Put Headers onto the Sub-Floor Station
2d	Spread Joists over Sub-Floor Station
2e	Attach Band Joists and Joists & Headers to Form an Assembly
2f	Lift Sub-Floor Assembly, Slide Chassis Below it, Lower Sub-Floor

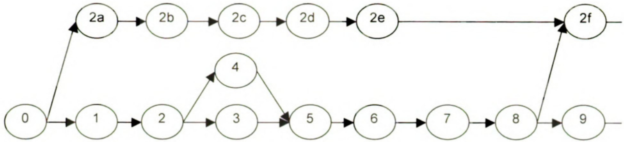

Figure 5.3: New Precedence Diagram for Floor Cluster

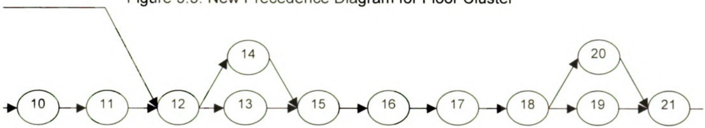

Figure 5.3: New Precedence Diagram for Floor Cluster

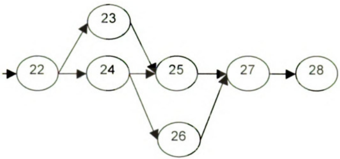

Figure 5.3: New Precedence Diagram for Floor Cluster

The activities at the chassis station and the sub-floor station start out at the same time. The upper branch is for the activities in the sub-floor station and the lower branch represents the chassis station activities. Activity numbers 3 and 4 are carried out at the same time; therefore they can be seen in parallel and also have the same start and finish. Activity 2f can only start when activity 8 and 2e have been completed. Activities 13 & 14 and activities 19 & 20 are also carried out in parallel. Activities 23 & 24 and 25 & 26 have a complex relationship between them. Activities 23 & 24 are in parallel and so are activities 25 & 26, but the start of activity 25 is controlled by activities 23 & 24, whereas the start of activity 26 is only controlled by activity 24. Activity 27 is bounded to both activities 25 & 26 and, therefore, it cannot start if either one of them is not complete.

5.2.1.3 New Facility Layout Model after Changes to the Floor Cluster

The new facility layout model was created to measure the effect of change in components assembly redesign on the material handling cost. The new facility layout model was prepared after making changes to the existing facility layout model.

The facility layout model consists of all the clusters, assemblies, sub-assemblies and parts, which come together to form a complete manufactured house. First the parts that were modified were highlighted. The parts that were modified were:

1. Main Axles
2. Tires

3. Bolt Shakle
4. Lock Nut
5. 2" X 6" X 2' Lumbers in Headers
6. 2" X 6" X 16' Lumbers in Headers

The change in individual parts resulted in the formation of new sub-assemblies and change in the larger assembly. The sub-assemblies were also converted to parts, depending upon whether they were brought in as a pre-fabricated unit or were assembled in a different way. These sub-assemblies are:

1. Axle and Tires Assembly
2. Headers

The assemblies were also modified depending upon the change in their subassemblies and individual parts. These assemblies are:

1. Chassis Assembly
2. Sub-floor Assembly

In the floor assembly, the floor and the sequence of assembly in some of the stations were modified. The stations in which the changes were proposed were:

1. Chassis Station
2. Sub-floor Station

After the stations, assemblies, sub-assemblies and parts that were highlighted were modified, these changes were input into the facility layout model. The changes in the facility layout model took place in stages. The stages in the modification of the facility layout model were:

1. Changes in assembly
2. Changes in material handling quantities
3. Changes in material handling equipment
4. Changes in routing information
5. Changes in activity points
6. Changes in physical layout

The changes in the facility layout model were made one stage after another. Below a brief description of the changes has been described.

1. Changes in assembly

The changes in assembly were the change of an assembly to a part or change of sub-assemblies or parts in the assembly as the changes in the assembly could be the conversion of an assembly into a part, or a part into an assembly. The changes could also be modification of a sub-assembly or formation of a new part. The parts, main axles, tires, bolt shakle and lock nut, were combined into one sub-assembly. But they are represented as a part in the assembly data since the sub-assembly was assembled outside the factory and was brought in as a complete part. This sub-assembly was named "axle and tire assembly" (Figure 5.4). The axle and tire assembly were combined, based on the component integration aspect. Also, it was assumed that headers were produced outside the factory, preferably by the truss sub-contractor and the header sub-assembly was brought in as a prefabricated unit. The parts in the headers were eliminated, thereby leading to the change of header sub-assembly into a part (Figure 5.4).

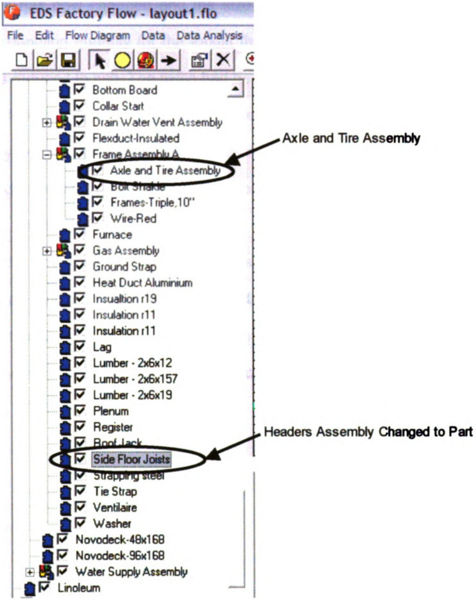

Figure 5.4: Changes in Floor Assembly Data in the Facility Layout Model

2. *Changes in material handling quantities*

A forklift had previously brought in the axles and tires individually. As the assembly has now changed and the size of the assembly has increased, the material handling quantity for the forklift that used to transfer the axles and the tires was reduced to half. The axles had been brought in groups of 28, and in one trip the forklift would also deliver 40 tires, whereas now the axle and tires assembly were brought in only in groups of 14 (Figure 5.5). This led to a fewer number of trips when compared to the trips made by the forklift when delivering the axles and tires individually. In the case of headers, 2 humans used to transfer one header and 1 floor requires 2 headers. The quantity for the headers did not change, as humans were still bringing in the headers. But the trips required for bringing the lumbers to assemble the headers were no longer required, as the headers were a prefabricated unit instead of a sub-assembly.

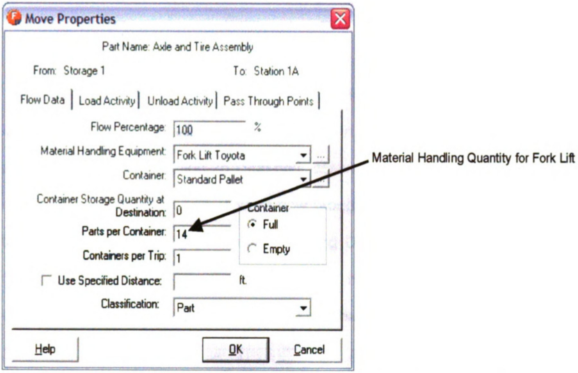

Figure 5.5: Change in Material Handling Quantity of Axle and Tire Assembly

3. *Changes in material handling equipment*

The formation of new axle and tire assembly led to the change in the material handling equipment of tires. The equipment "Forklift Mitsubishi" that was used to transfer the tires from the receiving dock to the main chassis station was no longer required, and it could be used for other material handling activities. The "Forklift Toyota" was now solely used for the purpose of meeting the needs for the material handling activities in the floor cluster. The "Forklift Mitsubishi" was being used in a different cluster and had to travel all the way to the floor cluster to transport the tires from the receiving dock, its extra travel was eliminated by the axle and tire component integration.

4. Changes in routing information

The headers also encountered changes in their routing information. The lumbers for header assembly were brought in from Station-2f (Header sub-assembly station) to Station-2b (Sub-floor assembly station), which is the main chassis station. As the headers were now brought in as a prefabricated unit as trusses, they were brought in from Receiving Dock-2 to Storage-2D and from Storage-2D to Station-2B (Figure 5.6). The material handling quantity and equipment were kept the same as the previous existing facility layout model.

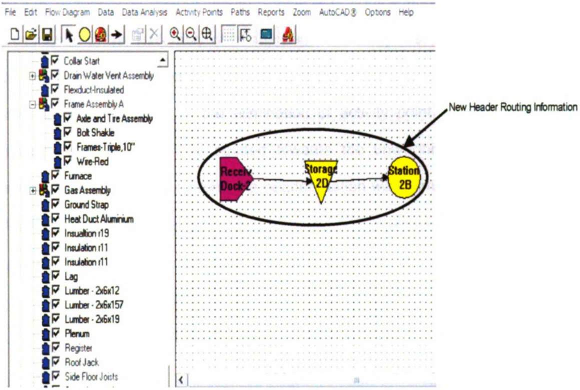

Figure 5.6: New Headers Routing Information

5. *Changes in activity points*

In the existing assembly process, the headers are assembled at a separate sub-assembly station (Station-2f), whereas, in the proposed floor assembly process the headers will be purchased as pre-fabricated units, leading to the elimination of the headers sub-assembly station. Therefore the activity point 2f was eliminated from the activities point list in the FactoryFLOW file.

6. *Changes in physical layout*

The new proposed floor component assembly affected the physical layout of the factory. The header feeder station was completely removed due to the elimination of the assembly of headers in the factory. As the headers were no longer being assembled in the factory, there was no use of the header sub-assembly station 2f. Also the elimination of activity point 2f that represented assembly of floor headers pointed towards the unworthiness of the header station in the layout. Therefore, the header station was eliminated from the CAD layout (Figure 5.7).

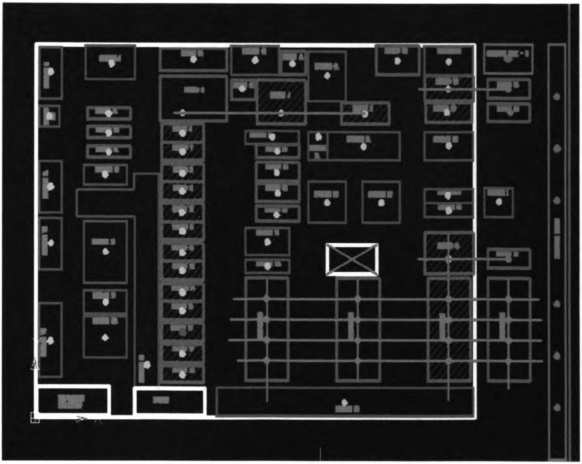

Figure 5.7: New CAD Layout of the Factory After Changes in the Floor Cluster

It should be noted that the changes that were being described in the above section were made for both "Part-A" and "Part-B" of the house. These parts represent the two sections of the house, one is the section that contains the kitchen cabinets and the other part consists of the bathroom fixture assemblies.

5.2.1.4 New Floor Cluster Production Simulation Model

The development of the new floor cluster production simulation model was based upon the changes encountered in the product tree structure and precedence diagram. The new floor cluster production simulation model was developed from the existing floor cluster production simulation model.

Due to the changes in the existing floor assembly system, a new floor assembly system was proposed. The new assembly system was in some ways similar to the existing floor assembly system. The existing assembly system was used as the basis for proposing changes. The changes led to guess estimates for certain new activities, elimination of existing activities (also known as servers in case of simulation model), new time distributions for certain servers, new relationships between stations and servers. There were certain activities that performed the same function but their name was changed in order to have a better understanding of the assembly process. This did not affect their time distributions; for example, aligning the main axle below the chassis is the same as aligning the axle and tire assembly below the chassis. When comparing the activities, “Alignment of axles” and “Alignment of axles with tires”, the latter may take less time, as it is less exhaustive. But still the time distribution was kept the same.

The activity for which a guess estimate was performed is:

1. Lift sub-floor assembly, slide chassis below it, and lower sub-floor

The activities no longer required in the simulation model were:

1. Move the electric hoist up with axle attached
2. Attach tires to main axle
3. Lower the chassis frame with complete assembly
4. Attach lumber to build headers

There were also some activities that required new time distributions. These activities were:

1. Delays placed outside the stations for making sure that only one floor can be processed at any instance of time in the station
2. Lift sub-floor assembly, slide chassis below it, and lower sub-floor

The changes that took place in the production simulation model were also implemented in stages. The stages that led to the development of the new floor cluster simulation models are:

1. Guess estimates for new activities
2. Data analysis for new paths
3. Eliminating unnecessary servers or stations
4. Placing the servers as per new logic and controlling paths
5. Providing new relationships to servers
6. Providing new time distribution to the servers

A brief description of the development of the new production simulation model is provided below for each stage.

1. *Guess estimates for new activities*

The assumption behind guess estimating was that the guess estimates were computed by comparing the time of the activity that needs to be estimated by time consumed by another activity of the same nature. In new floor cluster assembly there was only one activity that was guess estimated. The activity was "Lift sub-floor assembly, slide chassis below it, and lower sub-floor." The time for this activity was estimated by comparing it with the activity, "Load chassis on electric hoist," "Move electric hoist up," and "Lower chassis frame over main axle." The sum of these three activities made up the time for the activity for lifting sub-floor and lowering sub-floor over chassis.

2. *Data analysis for new paths*

Once the guess estimates for the activities were computed, the data analysis for the new set of data was carried out. The data analysis mainly consisted of computing the averages over the nine cycles and finding the paths that would control the simulation. The data analysis was carried out in spreadsheets by first, listing the activities under each station. Then the data were input in 9 columns. The data were averaged and were placed in a column titled "average". The paths were then listed below the spreadsheet and the average time for the paths were found by adding the individual average activity times of the activities present in those paths. Table 5.2 shows a partial data sheet and Table 5.3 shows average time of the paths for the floor cluster.

Table 5.2: Partial Floor Cluster Data Sheet

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
9	Bring Chassis into the Sub-Floor Station	2.46	2.32	1.2	2.42	2.25	2.87	2.58	2.61	1.52	2.2478
10	Spread Plastic Membrane over Chassis	1.68	1.75	2.07	1.35	1.87	1.6	1.72	1.56	3.5	1.9
11	Spread Insulation	1.46	1.67	1.5	1.37	1.5	1.8	2.1	1.32	2.75	1.7189
12	Put Rough Plumbing System and Rough HVAC	2.91	2.72	2.7	3.5	2.28	2.93	2.61	2.78	1.58	2.6678
13	Atach HVAC ducts to form HVAC System	12.82	10.77	14.38	7.67	10.03	16	12.12	12.25	12.15	12.021
14	Put Insulation on Sides	13.65	13.08	7.77	9.9	6.3	7.53	8.61	9.2	9.43	9.4967
15	Attach Plastic Membrane with Band Joist	3.16	4.25	2.75	3.6	2.56	1.56	2.3	2.51	2.42	2.79
16	Remove Sub-Floor from Station	2.65	2.45	3.78	2.88	3	1.5	2.15	2.42	2.35	2.5756
2a	Attach Lumber with Braces to Build Band Joist	8.21	9.65	7.24	7.5	6.9	8.98	9.76	8.45	7.8	8.2767
2b	Allign Band Joists at the Extremes of Station	1.23	1	1.42	1.16	1.08	1.88	1.65	2.1	1.48	1.4444
2c	Put Headers onto the Sub-Floor Station	12.82	13.47	14.1	12.62	11.02	10.42	8.5	11.58	15	12.17
2d	Spread Joists over Sub-Floor Station	2.51	1.45	1.57	2.07	0.72	2.12	2.07	1.52	4.25	2.0311
2e	Attach Band Joists and Joists & Headers to Form an Assembly	6.92	4.52	4.2	5.15	3.24	8.75	6.18	5.14	4	5.3444
2f	Lift Sub-Floor Assembly, Slide Chassis Below it, Lower Sub-Floor	8.87	5.4	12.86	7.34	8.27	3.88	2.26	3	10.2	6.8978

Table 5.3: Average Time of Paths in the Floor Cluster

Path	Average
2a-2b-2c-2d-2e	29.267
1-2-3-5-6-7-8	27.558
2f	6.8978
9-10-11	5.8667

3. *Eliminating unnecessary servers or stations*

The list of activities of existing floor assembly and list of activities for new floor assembly were compared. The comparison was made to find out what activities were no longer taking place in the proposed new floor assembly. The servers pertaining to these activities in the floor simulation model were eliminated. Also, the new precedence diagram was studied closely. After close review of the precedence diagram it was found that certain activities and stations have become in parallel. The stations that are now in parallel are the chassis station and sub-floor assembly station. As per the data analysis, it was found that the sub-floor activities would be the ones controlling the assembly process. This is because the chassis station would always be running faster than the sub-floor station. More time will be required for the sub-floor activities and will overshadow the time taken by the chassis station activities. Therefore, the "chassis station" was eliminated, and only the new sub-floor station activities were modeled.

4. *Placing the servers as per new logic and controlling paths*

The change in the floor assembly process led to the realignment of the servers that represent the activities in the floor cluster. The realignment was carried out for these activities and also for activities within the stations. The decking station did not have any realignment of servers, but the sub-floor had some major changes in the placement of servers. The placement of servers was carried out based on the precedence diagram and based on the elimination of activities and stations. Figure 5.8 shows the new production simulation model for floor cluster.

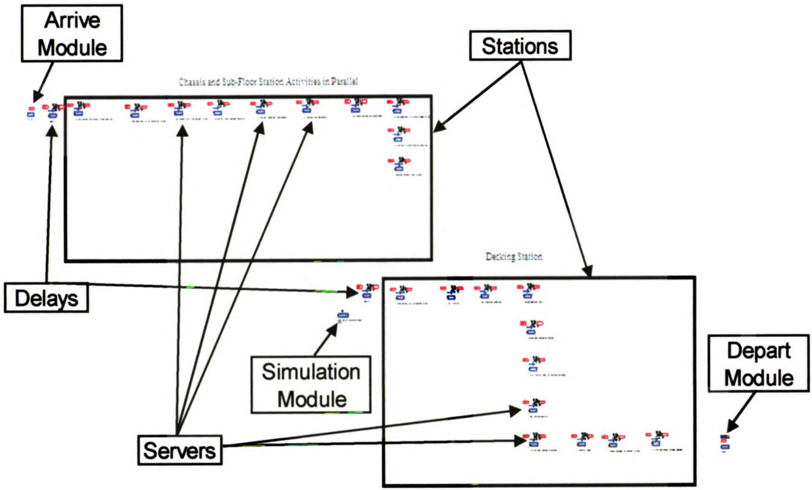

Figure 5.8: New Production Simulation Model for Floor Cluster

5. *Providing new relationships to servers*

Once the servers were placed in the correct logic, they were provided the relationships as depicted in the precedence diagrams. The relationships were provided by opening the server window and then selecting the name of the server that comes next.

6. *Providing new time distribution to the servers*

The distribution for the activity "Lift sub-floor assembly, slide chassis below it, and lower sub-floor" was found by using the Input-Analyzer tool provided in the Arena simulation software (Kelton et. al 1998). The tool was used to find the distribution for any time distribution. It computes the distribution based on the least mean square error, which is one of the measures for finding the least error encountered by the distribution when compared to the original data set.

5.2.1.5 Floor Cluster Components Assembly Redesign Results

The facility layout model and the production simulation model were created solely to measure the effect of components assembly redesign. The facility layout model was used to compute the material handling cost incurred by the factory in one day, whereas the production simulation model was used to measure the time taken to produce 10 floors. There was cost and time savings when the floor cluster was redesigned. It could be interpreted that the floor cluster components assembly redesign would lead to material handling cost and production time savings. A brief description has been provided below of the results for both the new facility layout model after changes to the floor cluster and the new floor cluster production simulation model.

5.2.1.5.1 Facility Layout Model Results After Changes to Floor Cluster

After making changes to the floor cluster, the new facility layout model was verified by reviewing the product structure in the software and checking the assembly logic. The new material handling equipments and quantities were also checked and verified from the factory personnel to provide reasonability.

After making changes to the floor cluster, the new facility layout model was verified by showing the model to the factory personnel the new alternative material handling system. The factory personnel agreed that the model can be implemented in the factory and the material handling cost will reduce. The daily material handling cost as computed by the new facility layout model after making changes to the floor cluster is $1375.68 per day. The total material handling cost saving after making changes to the floor cluster were $9.4 per day. The figures might give an impression that the savings are not very significant. But in fact, the facility layout model consists of more than 2000 parts, and the change in assembly has only been proposed to a cluster containing 30 parts. If compared with the cost incurred and savings only in the floor cluster, this saving will contribute to a large percentage. Figure 5.9 presents the comparison of material handling cost incurred by the existing facility layout model and the new facility layout model after changes to the floor cluster.

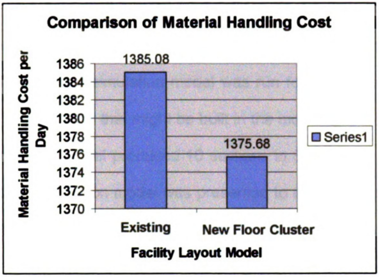

Figure 5.9: Comparison of Material Handling Cost Incurred by the Existing Facility Layout Model and the New Facility Layout Model After Changes to Floor Cluster

5.2.1.5.2 New Floor Cluster Production Simulation Model Results

The new floor cluster simulation model was verified in the same way as the new facility layout model after making changes to the floor cluster. The verification was done by double-checking the relationships, servers' placement, entity movement, and the model logic.

The floor cluster production simulation model was first warmed up by running 1 entity through the simulation model. As with the existing floor cluster production simulation model, the simulation was controlled by a number of entities; similarly the number of sections controlled the simulation time in the new floor cluster production simulation model. This was done so as to compare the time taken to complete the same number of houses and also to compute the time savings. The time for initializing the system was first noted and then it was subtracted from the actual model run to obtain the true time for processing the entities. The floor cluster simulation model was run for 201 sections. This was done for nullifying the error that might be built in the model. The new floor cluster production simulation model produced 10 sections in 6.65 hours. The new floor cluster production simulation model was presented to the factory personnel, and they were in total agreement that implementing such an assembly system would lead to a considerable amount of time savings. The total time savings after implementing the new assembly system was 1.67 hours. Figure 5.10 presents the time comparison of existing floor assembly and new floor assembly.

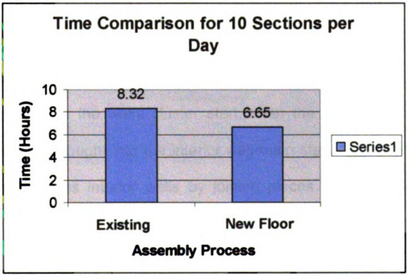

Figure 5.10: Time Comparison of Existing Floor Assembly and New Floor Assembly

5.2.2 Wall Cluster Components Assembly Redesign

The author also came up with a new assembly system for the walls cluster. The walls components assembly redesign was carried out by breaking the activities, primary drywall finishing and secondary drywall finishing, into 4 parts. These 4 parts were then distributed to side walls, end walls, marriage walls and interior walls feeder stations. The windows activity was also broken down into 2 parts and distributed to the side walls and the end walls feeder station. The main purpose of redesigning the components in this way was to relieve the load from the overloaded main stations and pass it on to the feeder stations. Also it was noted that these activities were taking a great deal of time and were causing delays; therefore they were broken down into smaller activities and redistributed. Below, a brief description and graphical step-by-step representation of the new assembly process is provided (Figure 5.11).

The activities in the walls cluster start when the floor with cabinets or bathroom fixtures is brought into the interior wall main station. The interior walls feeder station produces interior walls by joining pieces of lumber together to construct frames, attaching drywall on one side and then cutting them for door and other openings. The interior walls are then transferred to the electric hoist, from where they are transferred to the interior wall main station onto the floor. Before attaching the interior walls to the floors, the bottom of the frame is cut for wiring and other plumbing pipes if necessary. After the interior walls are attached to the floor, they are attached to other adjoining interior walls for lateral stability. The interior walls are then covered by drywall on the other side and the walls are finished by plaster. Both primary (first coat) and secondary (second coat) drywall finishing are carried out at the interior wall main station (Figure 5.11a). Once the interior walls are finished, the floor is moved to the exterior wall main station.

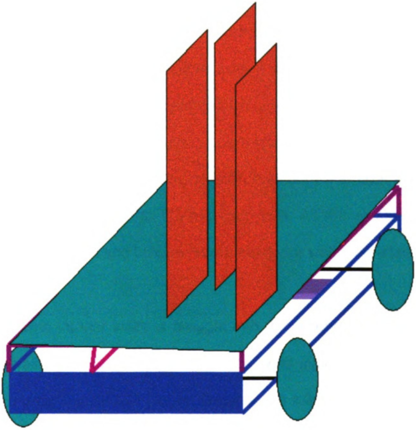

Figure 5.11a: New Walls Assembly Process

While the activities at the interior wall main station are performed, the exterior walls were also being produced for installation in their respective feeder stations. The side walls and the end walls are produced by joining the pieces of lumber together to form frames. Drywall is then attached to only one side of the walls, and the drywall is cut for openings such as doors and windows. Insulation is then spread on the walls. The walls are then finished, using plaster. The drywall finishing, both the first coat and second coat, are applied to the walls, and the windows are attached to the window opening by using eye-shaped bolts. The process and the nature of assembly of the side walls and end walls are similar, but the sizes are different. The end walls are shorter and the side walls are the longer. The end walls, as the name implies, are placed on the smaller ends and the side walls are placed along the longer side of the floor. The marriage walls are assembled by constructing the frames from lumbers, then attaching drywall on one side of the frame and then cutting openings for doors and windows. The marriage wall is also finished by using plaster, and both first coat and second coat drywall finishing is applied to the marriage wall. All the exterior walls are made during the same time and brought into the exterior wall main station one by one and installed.

The floor with interior walls is brought into the exterior wall main station. First, the side walls are brought into the exterior wall main station, followed by end walls and marriage walls. The same sequence is followed when the exterior walls are attached with the floors. Once the walls are attached to the floor, the exterior walls are attached to the interior walls and then to each other. It should be noted that in the new wall assembly process all the walls are brought in with drywall finishing on them. Also the side walls and end walls come to the main station with drywall finished and windows attached (Figure 5.11b, 5.11c, 5.11d). The section is now moved to the marriage wall main station.

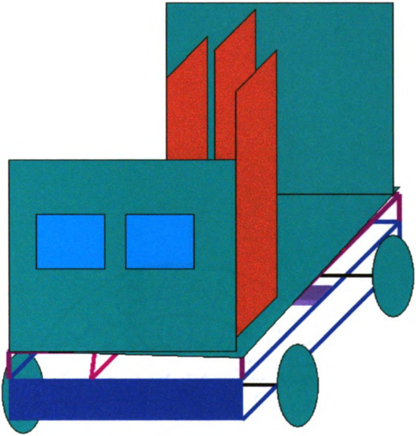

Figure 5.11b: New Walls Assembly Process

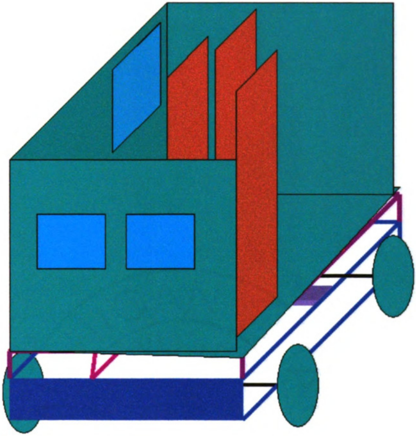

Figure 5.11c: New Walls Assembly Process

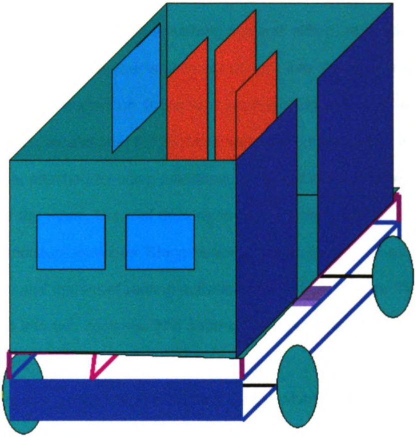

Figure 5.11d: New Walls Assembly Process

The activities at the marriage wall main station cannot be carried out if two sections of the house are not present. Once the two section of a house are brought into the station, the two sections are joined together. Now, the sections will move through the assembly line together and will be separated later. After the sections are joined together, the house is passed on to the roofing station.

There are two sets of activities performed at the roofing station. One set is the wall activities and the other set is the roofing activities. These sets of activities are in parallel, i.e., they take place at the same time. The house from the marriage station is passed on to the roofing station. The wiring in the walls is first carried out followed by wall sheathing and wall siding. At the same time the roof which is built at a feeder station is brought into the main roof assembly station where it is placed on the house by attaching it to the walls. Blow-in insulation is then spread onto the roof and then the roof decking is attached. The roof decking is attached by using pneumatic guns and attaching the decking with the rafters of the truss. The roof decking is then covered by SGL underlayment for avoiding moisture leakages. Shingles are then installed on the roof. The set of wall activities and the set of roofing activities should finish before the house can be separated into two sections. The separated sections are then passed to the finishes station.

The section enters into the finishes station where sanding and painting is carried out. The drywalls are already finished and by the time they would reach the finishes station the drywall is already dry. Once the section is inside the finishes station, the drywalls are sanded and then painted. The section is then cleaned and passed on to the next station.. This completes the activities at the wall cluster, and now the installation of kitchen appliances, carpets etc. can take place.

5.2.2.1 New Product Tree Structure for Wall Cluster

The product tree structure for the wall cluster was modified, based on the changes in the existing wall cluster assembly system. This new assembly system led to regrouping of some of the sub-assemblies and also elimination of some from the main sub-group. The levels of the changed sub-assemblies were now changed and were placed under a different assembly. The new product tree structure for the wall cluster consists of interior walls, exterior walls, rough electrical, cabinets assembly, bathroom fixtures, sheathing, siding, paint, roof assembly and floor assembly.

The new wall cluster product tree structure was a modification from the existing wall cluster product tree structure. The modifications are briefly described. Drywall finishing that was placed as a separate component is now placed under the individual walls. Windows was also kept as a separate component but now they are placed under side walls and end walls. This change was necessary because the walls are now finished and also the windows are also installed on the walls at the feeder station; in the case of interior walls, the drywall finishing is carried out at the main station. Therefore, the drywall finishing became a sub-group of the interior walls, side walls, end walls and marriage walls. As windows were only installed on side walls and end walls, they became a sub-group of side walls and end walls.

The drywall finishing used to consist of tape mesh, plaster and paint. The drywall finishing that is now carried out in the feeder stations, and the main station in the case of interior walls, consists of applying plaster. Painting is still carried out at the end of assembly line before cleaning. Therefore, painting was made as a separate sub-group. The floors sub-group was not expanded and can viewed in Figure 5.2. Detailed new product tree structure for walls has been provided in Appendix-B.

5.2.2.2 New Precedence Diagram for Wall Cluster

The new wall cluster precedence diagram was prepared from modifying the existing wall cluster precedence diagram. In the existing wall assembly, the windows were installed at the roofing main station, and the drywall finishing was carried out when the walls and the roof were installed on the floor. Whereas, in the new walls assembly system, the windows were installed at the side wall feeder station and end wall feeder station using eye-shaped bolts. Also, the drywall finishing was moved to the feeder stations in the case of exterior walls and to main stations in the case of interior walls. The distribution was carried out by breaking down the windows activity into W1, W2; primary drywall finishing into P1, P2, P3, P4; and secondary drywall finishing into S1, S2, S3, S4. The drywall finishing was carried out before the exterior walls could be transferred to the main station for assembly, and in interior walls when the drywall on the other side of interior walls was fixed. Below a brief description of some complicated parts of the precedence diagram has been discussed.

The activities at the floor cluster start when the floor comes into the interior wall main station. The interior walls are produced and then assembled onto the floor. The installation of interior walls is carried out while the exterior walls, namely, side walls, end walls and marriage walls are being produced at their respective feeder stations. Therefore, there are 4 branches that come out of activity 6. The topmost branch is for the interior walls installation on the floor, and the next branches are for exterior walls production in the feeder stations. The exterior walls are only sent to the exterior walls main station when the floor comes into the station and when the drywall finishing, both primary and secondary, are completed. The exterior walls are brought into the exterior wall main station one-by-one and in a sequence; side walls come in first, then the end walls, and finally the end walls. Therefore, the activities 27, 28 and 29 are placed one after another and the arrows from each branch come and join at the start of the nodes. The roofing activities and the walls activities at the roofing main station are carried out in parallel, so the wall activities, namely, 39, 40 and 41 are placed parallel to the roofing activities namely, 42, 43, 44, 45, 46 and 47. Both sets of activities should be complete before the section leaves the roofing station; therefore, both the branches meet at activity 48. The detailed list of activities and the new precedence diagram for the wall cluster is provided in Appendix-C.

5.2.2.3 New Facility Layout Model after Changes to the Wall Cluster

The new facility layout model after changes to the wall cluster was created to measure the effect of change in walls components assembly redesign on the material handling cost. The new facility layout model was prepared after changes to the wall cluster in the existing facility layout model.

First the parts that were modified were highlighted. The parts that were modified were:

1. Gypsum Vinyl Moroccan Sand
2. Windows

The change in individual parts resulted in modification in existing sub-assemblies and change in the larger assembly. These sub-assemblies are:

1. Side Walls
2. End Wall-1
3. End Wall-2
4. Marriage Wall
5. Interior Partition-1
6. Interior Partition-2
7. Interior Partition-3
8. Interior Partition-4
9. Interior Partition-5
10. Interior Partition-6
11. Interior Partition-7

In the wall cluster, the assembly and sequence of assembly in some of the stations was modified. Changes were proposed in the following stations:

1. Interior Wall Main Station
2. Exterior Wall Main Station
3. Roofing Main Station
4. Finishes Station

After the stations, assemblies, sub-assemblies, and parts that were modified were highlighted, these changes were input into the facility layout model. The changes in the facility layout model took place in stages. The stages in the modification of the facility layout model were:

1. Changes in assembly
2. Changes in material handling quantities
3. Changes in material handling equipment
4. Changes in routing information
5. Changes in activity points
6. Changes in physical layout

The changes in the facility layout model were made one stage after another. A brief description of the changes is described below:

1. <u>Changes in assembly</u>

The changes in the walls assembly were the changes of the groups and sub-groups of assembly. The main components that changed groups were drywall finishing and windows. These were now placed under the walls. This change was made because the drywall finishing and windows installation were carried out at the feeder stations, making them as an integral part of the walls. The change of assembly process was the breaking down of the drywall finishing activities and the window installation activity into smaller activities, which were reorganized. The reorganization was such that the drywall finishing for interior walls takes place at the main station. The drywall finishing and the windows installation for exterior walls take place at the feeder stations.

2. *<u>Changes in material handling requirements and material handling quantities</u>*

As mentioned earlier, the drywall finishing activity and the windows activity were broken down into smaller tasks. Therefore, it was necessary to estimate the new material requirements and new material handling quantities for the new system. Certain assumptions were made when associating the new material requirements and material handling quantities. These assumptions are listed below:

- The drywall finishing quantity was distributed such that the each wall had an equal amount of drywall finishing plaster. The total quantity was divided by 5, as there are 2-end walls, 1-side wall, 1 marriage wall and 1-set of interior walls on a section. The quantity now obtained for interior walls was again divided by 7, as there were 7 interior walls on a section. The detailed new quantities are provided in the Table 5.4.

Table 5.4: New Material Quantities for Changes to Wall Cluster

	Drywall Plaster per wall	Window (30"X27") per wall	Window (30"X60") per wall	Window (30"X60")- White Storm per wall	Window (46"X60") per wall
End Wall-1	18.4 sq.ft	2	-	-	-
End Wall-2	18.4 sq.ft	2	-	-	-
Side Wall	18.4 sq.ft	-	2	1	3
Marriage Wall	18.4 sq.ft	-	-	-	-
Interior Wall-1	2.6 sq.ft	-	-	-	-
Interior Wall-2	2.6 sq.ft	-	-	-	-
Interior Wall-3	2.6 sq.ft	-	-	-	-
Interior Wall-4	2.6 sq.ft	-	-	-	-
Interior Wall-5	2.6 sq.ft	-	-	-	-
Interior Wall-6	2.6 sq.ft	-	-	-	-
Interior Wall-7	2.6 sq.ft	-	-	-	-

- The windows were redistributed such that the end walls have 2 - 30"X27" windows each
- The side walls have 2 – 30"X60" windows, 1 – 30"X60" white storm window, and 3 – 46"X60" windows
- It was assumed that in each trip made from the storage to the receiving dock, enough drywall finishing plaster or windows for a section were carried over to the station.
- Also, the drywall finishing at the exterior walls was carried out at only one location, as the stations exterior walls feeder stations are placed very close to each other.

3. *<u>Changes in material handling equipment</u>*

The material handling equipment for the drywall finishing and the windows was not altered. There was one hand trolley and one forklift that was solely dedicated to serving the needs of these activities.

4. *<u>Changes in routing information</u>*

The routing information was now reorganized. The drywall plaster is stored at the storage near the exterior walls feeder station (storage-6) and then is passed on to the marriage wall feeder station (station-6b), which is the middle feeder station. The drywall finishing takes place there and the walls are then transferred to the exterior wall main station. The windows routing information was kept the same, but here the windows traveled to the side walls and end walls feeder station, as these are the only walls that contain the windows. In the case of interior walls, the plastered drywall was routed to reach the interior wall main station (station-5a) and was stored in a storage near the main station (storage-5).

5. *Changes in activity points*

The activity points did not change as their location was preset because of predefined main station, feeder station, and storages. The activity points are only created when the material needs to be transported to a new location that did not previously exist, whereas, in this case the locations were already present and so were the activity points.

6. *Changes in physical layout*

The physical location of the new facility layout model was not altered in the proposed changes to the wall cluster. The station where the drywall finishing, i.e., the finishes station and the windows installation station, i.e., the roofing station still had activities going on in them. Therefore, none of the activity points or the stations were eliminated. The layout of the new facility layout model after changes to the wall cluster is shown in Figure 5.12. As can be seen in the figure, the changes have only been proposed to the wall cluster and not to the floor cluster, since the header feeder station is still present in the layout.

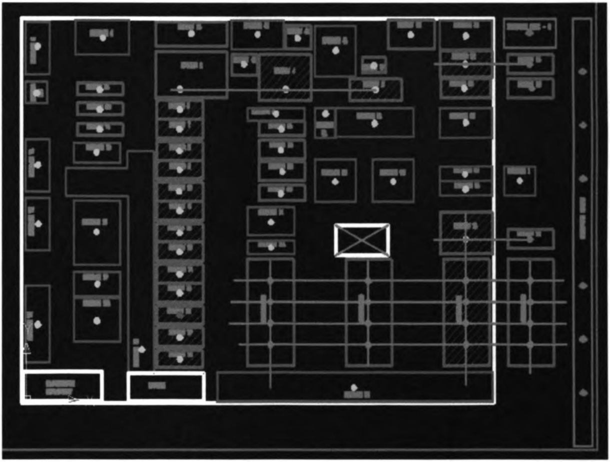

Figure 5.12: New CAD Layout of the Factory After Changes in the Walls Cluster

It should again be noted that the changes that were being described in the above section were made for both "Part-A" and "Part-B" of the house.

5.2.2.4 New Wall Cluster Production Simulation Model

The new wall cluster production simulation model was similar to the recreation of the new floor cluster production simulation model. Also, the changes in the product tree structure and precedence diagram played a major role in the model's development. The new wall cluster assembly system, developed after changes made in the existing assembly system led to guess estimates for certain new activities. Certain existing activities were eliminated and some new activities formed. The guess estimates for these new activities were computed by comparison or mathematical deductions from the existing activities.

The activity for which guess estimate was performed were:

1. Windows installation on side walls - W1
2. Windows installation on end walls - W2
3. Primary drywall finishing at the interior wall main station – P1
4. Primary drywall finishing at the side wall feeder station – P2
5. Primary drywall finishing at the end wall feeder station – P3
6. Secondary drywall finishing at the marriage wall feeder station – P4
7. Secondary drywall finishing at the interior wall main station – S1
8. Secondary drywall finishing at the side wall feeder station – S2
9. Secondary drywall finishing at the end wall feeder station – S3
10. Secondary drywall finishing at the marriage wall feeder station – S4

There were also some activities that required new time distributions. These activities are:

1. Delays placed outside each station to make sure that only one section can be processed at any instance in the station
2. Windows installation activities – W1 and W2

3. Primary drywall finishing activities – P1, P2, P3 and P4
4. Secondary drywall finishing activities – S1, S2, S3 and S4

The changes that took place in the production simulation model were implemented in stages. The stages that led to the development of the new wall cluster simulation models are:

1. Guess estimates for new activities
2. Data analysis for new paths
3. Eliminating unnecessary servers or stations
4. Placing the servers as per new logic and controlling paths
5. Providing new relationships to servers
6. Providing new time distribution to the servers

A brief description of the stages that led to the development of the new wall cluster production simulation model is provided below.

1. *Guess estimates for new activities*

The guess estimates were made by mathematical deductions by comparing the time of the activity that needs to be estimated to the time consumed by another activity of the same nature. The guess estimates were made for activities W1, W2, P1, P2, P3, P4, S1, S2, S3 and S4. The guess estimating for walls was carried out by using spreadsheets. The cycle times for the window installation activities were computed. These times were based on the understanding that the time for side walls was 2/3 times and for end walls it was 1/3 times the original windows installation activity. The primary and secondary drywall finishing times for side walls, end walls, marriage walls, and the set of interior walls were distributed equally, because the drywall plaster quantity was divided equally among the above mentioned set of walls. Table 5.5 presents the cycle times for the guesstimated activities.

Table 5.5: Cycle Time for the Guess Estimated Activities for Walls Cluster

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
P1	Primary Dryall Finishing at Interior Walls Main Station	5.75	5.3125	4.625	5.9375	4.3125	6.0625	5.5	5.0625	4.875	5.27083
P2	Primary Drywall Finishing at Side Walls Feeder Station	5.75	5.3125	4.625	5.9375	4.3125	6.0625	5.5	5.0625	4.875	5.27083
P3	Primary Drywall Finishing at End Walls Feeder Station	5.75	5.3125	4.625	5.9375	4.3125	6.0625	5.5	5.0625	4.875	5.27083
P4	Primary Drywall Finishing at Marriage Walls Feeder Station	5.75	5.3125	4.625	5.9375	4.3125	6.0625	5.5	5.0625	4.875	5.27083
S1	Secondary Dryall Finishing at Interior Walls Main Station	10.5	12	14	12.25	16.25	11.25	13	13.75	11.5	12.7222
S2	Secondary Drywall Finishing at Side Walls Feeder Station	10.5	12	14	12.25	16.25	11.25	13	13.75	11.5	12.7222
S3	Secondary Drywall Finishing at End Walls Feeder Station	10.5	12	14	12.25	16.25	11.25	13	13.75	11.5	12.7222
S4	Secondary Drywall Finishing at Marriage Walls Feeder Station	10.5	12	14	12.25	16.25	11.25	13	13.75	11.5	12.7222
W1	Install Windows on Side Wall	20	21.3333	30	28	24	24.6667	21.3333	16	26	23.4815
W2	Install Window on End Wall	10	10.6667	15	14	12	12.3333	10.6667	8	13	11.7407

2. *Data analysis for new paths*

The data analysis for the new set of data was carried out after the guess estimates for the activities were computed. The data analysis mainly consisted of computing the averages over the nine cycles and finding the paths that would control the simulation. The data analysis was carried out in spreadsheets by first, listing the activities under each station. Then the data was input in the 9 columns. The data were averaged and were placed in a column titled "average". The paths were then listed below the spreadsheet and the average time for that path was found by adding the individual average activity times in that path. The average times for the paths were also computed to provide time durations of delays that were placed outside the stations. Table 5.6 shows a partial data sheet and Table 5.7 shows average time of the paths for wall cluster.

Table 5.6: Partial Walls Cluster Data Sheet

Activity Number	Activity Decription	1	2	3	4	5	6	7	8	9	Average
6	Transfer the Interior Wall to the Floor Assembly/Chassis	0.7	0.5	0.6	0.8	0.9	0.5	0.4	0.5	0.7	0.62222
7	Cut Holes in Interior Walls for Wiring	2.3	5.5	1.8	1.6	2.7	2.4	6	3	8	3.7
8	Attach the Interior Walls to the Floor	6.8	4.2	2.8	3.5	2.4	2.7	6.6	7.8	5.6	4.71111
9	Attach the Interior Walls to other Interior Walls	6.2	4.8	6.6	7.8	8.6	6	12	10	15	8.55556
10	Attach Drywall on the other side of Interior Wall Frame	20	16	15	24	18	16	15	12	21	17.4444
11	Move the Floor with Interior Walls to the Exterior Walls Station	2	3	4	3	2	1	2	3	5	2.77778

Table 5.7: Average Time of Paths in the Walls Cluster

Paths	Average
7-8-9-10-P1-S1-11-12	56.3375
13-14-15-16-W1-P2-S2-17	33.3375
18-19-20-21-W2-P3-S3-22	47.47824
23-24-25-P4-S4-26	35.99306

3. *Eliminating unnecessary servers or stations*

The list of activities of the existing wall cluster assembly and the list of activities for the new wall cluster assembly were compared. The comparison was made so as to find out what activities were no longer taking place in the proposed new wall assembly. The servers pertaining to these activities in the wall cluster production simulation model were eliminated. The activities that were mainly eliminated were the primary drywall finishing, secondary drywall finishing and windows installation. These activities were converted into smaller activities as discussed in the above sections.

4. *Placing the servers as per new logic and controlling paths*

There was no alignment change in the case of the new wall cluster production simulation models. There were new additions in the activities in the interior wall main station that was modeled. Figure 5.13 shows the new wall cluster production simulation model.

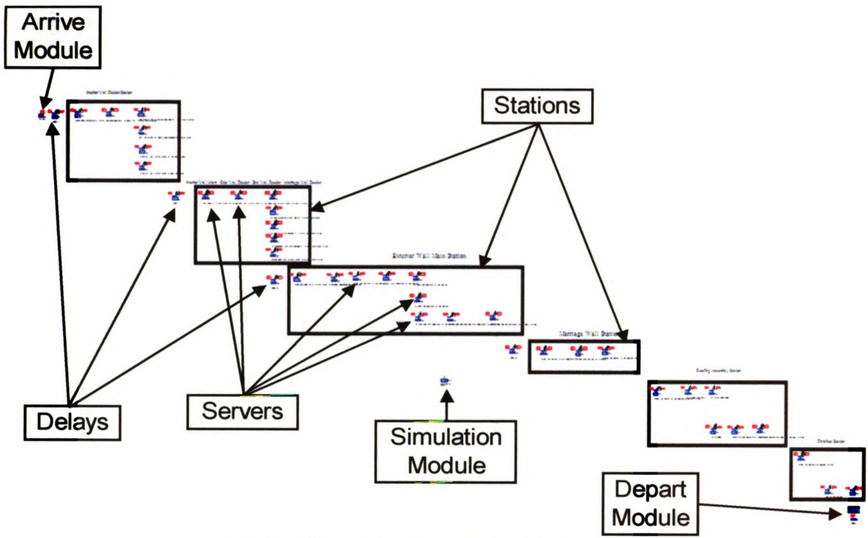

Figure 5.13: New Wall Cluster Production Simulation Model

5. *Providing new relationships to servers*

Once the servers were placed in the correct logic, they were provided the relationships as were depicted in the precedence diagrams. The relationships were provided by opening the server window and then selecting the name of the server that comes next.

6. *Providing new time distribution to the servers*

The distribution for the new activities was found by using the Input-Analyzer tool provided in Arena simulation software (Kelton et. al 1998).

5.2.2.5 Wall Cluster Components Assembly Redesign Results

The facility layout model was used to compute the material handling cost incurred by the factory in one day, whereas the production simulation model was used to measure the time taken to produce 10 floors. Very minimal time savings was achieved, and the material handling cost went up slightly when the wall cluster was redesigned. A brief description of the results for both the new facility layout model after changes to the wall cluster and new wall cluster production simulation model is provided below.

5.2.2.5.1 Facility Layout Model Results After Changes to Wall Cluster

The new facility layout model after making changes to the wall cluster was verified in the same way as the new facility layout model also after making changes to the floor cluster. The daily material handling cost as computed by the new facility layout model after making changes to the floor cluster is $1387.96 per day. The total material handling cost was up by $2.88 per day. The cost increase occurred because the number of trips for delivering the drywall plaster to the storages has now increased, due to the segregation of the drywall finishing activity in the walls cluster. Figure 5.14 presents the comparison of material handling cost incurred by the existing facility layout model and the new facility layout model after changes to wall cluster.

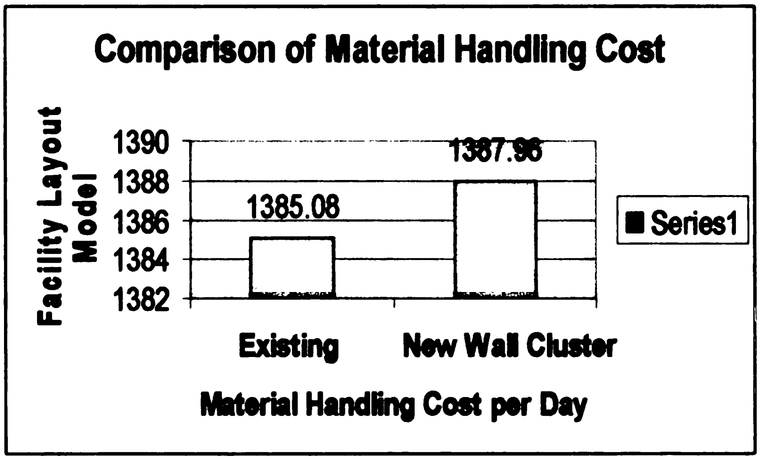

Figure 5.14: Comparison of Material Handling Cost Incurred by the Existing Facility Layout Model and the New Facility Layout Model After Changes to Wall Cluster

5.2.2.5.2 New Wall Cluster Production Simulation Model Results

The new floor cluster production simulation model was verified in the same way as the new wall cluster production simulation model. The floor cluster production simulation model was first warmed up by running 2 entities through the simulation model. In the case of walls, the warm-up of the model was performed by using 2 entities due to sheer increase in the size of the model. Previously, in case of existing wall cluster production simulation model, the simulation had been controlled by number of entities; similarly the number of sections controlled the simulation in the new floor cluster production simulation model. This was done to compare the time taken to complete the same number of houses and also to compute the timesaving. The time for initializing the system was first noted and then it was subtracted from the actual model run to get the true time for processing the entities. The floor cluster simulation model was run for 402 sections. This was done to nullify the error that might be built in the model. The new wall cluster production simulation model produced 10 sections in 8.33 hours. The total timesaving when compared to the existing floor cluster production simulation model was 3 minutes. The reason attributed for the behavior of the simulation model is that the interior wall main station was a bottleneck station. The addition of drywall finishing activities on it leads to overloading the bottleneck station. Therefore, there is not much significant improvement for the walls cluster in terms of production. To overcome this problem, line balancing of the simulation model needs to be performed. The model run after performing line balancing will present a much improved production rate than that presented by either the redesigned assembly process or the line balanced existing assembly process. Figure 5.15 presents the time comparison of existing wall assembly and new wall assembly.

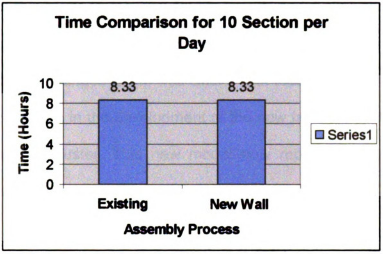

Figure 5.15: Time Comparison of Existing Wall Assembly and New Wall Assembly

5.2.3 New Facility Layout Model after Changes to Floor and Walls Cluster

The facility layout model after changes to the floor and wall cluster was created to show the overall effect of floor and wall cluster components assembly redesign on the material handling cost. The development of the new facility layout model after changes to the floor and wall cluster was made possible, as the facility layout models contained all the clusters of the manufactured housing factory.

5.2.3.1 Development of New Facility Layout Model after Changes to Floor and Walls Cluster

The development of the new facility layout model after changes to floor and walls cluster was carried out by combining the new facility layout model after changes to the floor cluster and new facility layout model after changes to the wall cluster. For this purpose the new facility layout model after changes to the floor cluster was selected and the modification to the wall cluster of this model was carried out. The changes to the wall cluster that took place are the same as changes that took place in the development of the new facility layout model after changes to the wall cluster. This new model now represented the complete factory with modified floor and wall clusters.

5.2.3.2 Results of New Facility Layout Model after Changes to Floor and Walls Cluster

The verification for this model was not performed, as the verification for the clusters that were modified in this model have already been performed individually. The total material handling cost encountered by the new facility layout model after changes to the floor and wall cluster was $1377.48. It was a total savings of $7.6 per day. This result can be interpreted, that when both the floor cluster and wall cluster are redesigned the total cost saving for the factory will be $7.6 per day. Therefore, the extra cost incurred by the wall cluster is consumed by the cost saving made by the floor cluster redesign. Figure 5.16 presents the comparison of material handling cost incurred by the existing facility layout model, the new facility layout model after changes to floor cluster, the new facility layout model after changes to wall cluster and the new combined facility layout model after changes to floor and wall cluster.

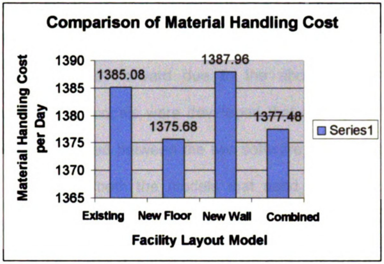

Figure 5.16: Comparison of Material Handling Cost Incurred by The Existing Facility Layout Model, The New Facility Layout Model After Changes to Floor Cluster, The New Facility Layout Model After Changes to Wall Cluster and The New Combined Facility Layout Model After Changes to Floor and Wall Cluster

5.3 Facility Layout and Simulation Software Integration

It is significant that integration of the facility layout and simulation software would be very useful in reducing the manual efforts involved in creating the production simulation model after inputting the data once in the facility layout software or vice-versa. If the software integration is performed, the creation of the simulation model would be automated or vice-versa. Also, the changes once made in facility layout model would not have to be made again in the simulation software. This will result in a substantial amount of timesaving and also a reduction in manual errors, which might be caused during modifications.

The integration of the two software is a very complicated process and requires good understanding of the software code and programming languages. Due to the constraint put forward due to the above-mentioned problems, information input–output models were developed that highlights the information that needs to be exchanged between the two software. These models are used to select the aspects of both the models that need to be integrated and to perform the software integration. The information exchange in-between the two software takes place through spreadsheets or databases. Therefore, certain information to be transferred from one software to another was selected and the transfer of information was carried out by designing "macros" in the spreadsheet.

5.3.1 Information Flow Input–Output Models

The methodology adopted for developing the integrated information input–output model is as follows. First, the information requirements for the two software and the information generated by them are highlighted. Then information input–output models for the two software are developed individually. After developing the individual models, integrated information input–output models are created.

5.3.1.1 Facility Layout and Simulation Software - Information Input–Output Models

The very first step of developing an input–output model is knowing what information is going to travel through the model (BCM-817). It is important in this step is to jot down all the key information required and generated by the facility layout and simulation software. The mapped information will be used in the next section to develop the information input–output model.

5.3.1.1.1 Facility Layout Software - Information Requirements and Generation

The information requirements for the development of the facility layout model and information generated by it are highlighted below.

1. *Information Requirements for the Facility Layout Model*
    - Number of products produced
    - Types of products produced
    - Distances in-between the stations
    - Factory layout
    - Assembly tree
    - Part requirements to build an assembly
    - Part or assembly routing
    - Type of material handling equipment
    - Cost incurred by a material handling equipment for a unit travel distance
    - Distance traveled by the equipment from one point to another
    - Material handling equipment associated with the part or assembly

- Capacity of the material handling equipment
- List of stations
- Function of stations i.e. dock, process, assembly

2. *Information Generated by the Facility Layout Model*

- Total material handling cost
- Total distance traveled by a material handling equipment
- Total cost of trip made by a material handling equipment
- Total number of trips made by a material handling equipment
- Total distance traveled by the part or assembly
- Number of trips made by the part or assembly
- Percentage utilization of the material handling equipment

5.3.1.1.2 Simulation Software - Information Requirements and Generation

The information requirements for the development production simulation model and information generation by it are highlighted below.

1. *Information Requirements for the Production Simulation Model*

- Simulation Time
- Cycle times
- Cycle times distribution
- Sequences or Routing information
- Distances in-between the stations
- Type of material handling equipment

- Number of trips made by the part or assembly
- Percentage utilization of the material handling equipment
- Capacity of the material handling equipment
- Routing time
- Capacity of station
- Failure probability of station
- Scrap rate

2. *Information Generated by the Production Simulation Model*

    - Number of products produced
    - Types of products produced
    - Average queue time
    - Number of products present in the queues
    - Average cycle times
    - Number of observations made
    - Percentage time the station is available
    - Percentage time the station is busy
    - Resource failures
    - Number of scrap products

5.3.1.2 Information Input–Output Model for the Software

The information input\–output models were prepared by using the representation technique input–output models. The input–output model for the software were prepared by linking the information requirement with the generated information on the other end. The link was provided by the software and the software analysis, which is represented by a box.

5.3.1.2.1 Information Input–Output Model for Facility Layout Software

The facility layout software primarily takes the number of products produced, types of products produced, factory layout, assembly tree, Part requirements to build an assembly and converts it into the total material handling cost and the material flow related results. The software also gives output in terms of flow lines, distance-intensity charts and distance cost reports. These outputs contain the information like total distance traveled by the material handling equipment, the total number of trips made by the material handling equipment, total distance traveled by the part or assembly, total number of trips made by the part or assembly, etc. This information is used to reduce the material handling cost incurred by the factory by conducting "what-if" analysis. The input–output model is used to show the information input and the information output provided by the software. The conversion process for this data has not been discussed. Figure 5.17 represents the information input–output model for the facility layout software.

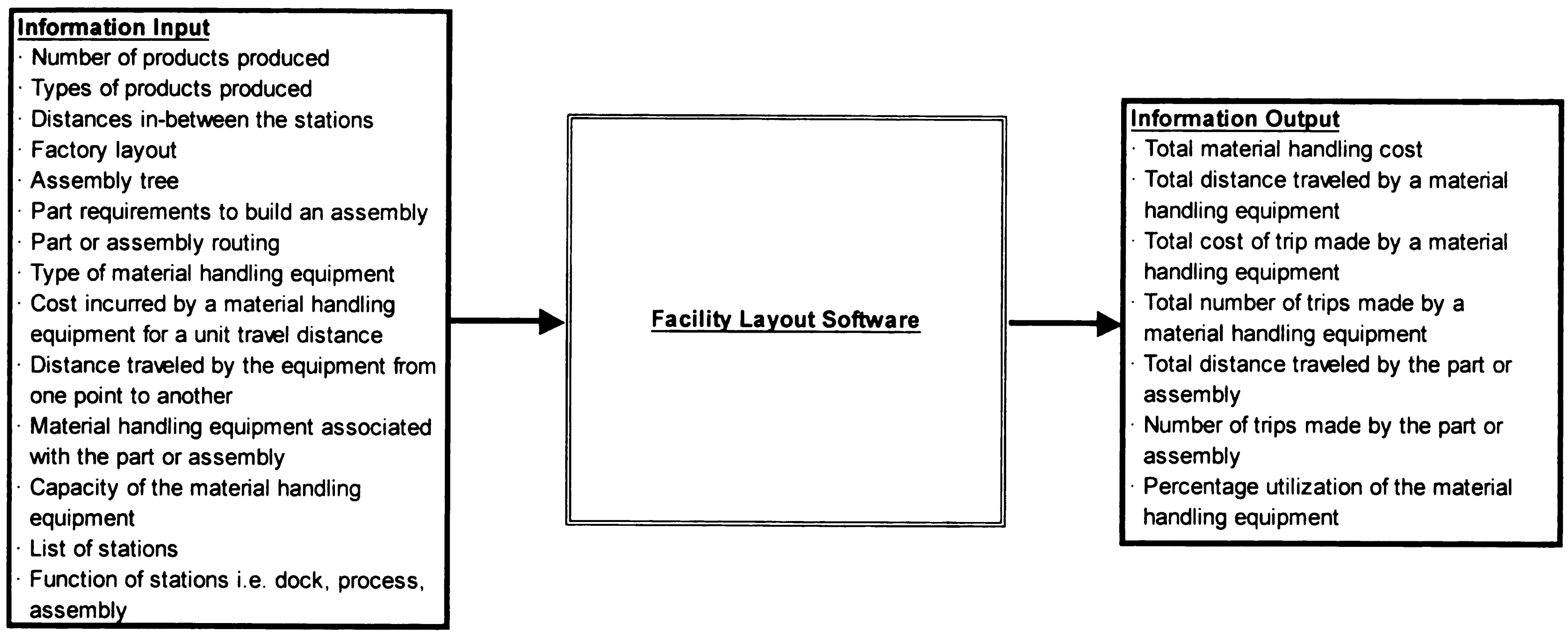

Figure 5.17: Information Input–Output Model for Facility Layout Software

5.3.1.2.2 Information Input–Output Model for Simulation Software

The simulation software is used to compute the production rate of the factory. This is done by simulating the factory into the software. The simulation software employs the information like simulation time, cycle times, cycle time distributions to compute the number of entities produced, types of entities produced, average queue time, average cycle times etc. This output is analyzed to pinpoint the bottleneck stations, to design "what-if" scenarios and to improve the production of the factory. The calculation can be based both on deterministic time durations or stochastic time durations. The input–output model is used to show the information input and the information output provided by the software. The conversion process for these data has not been discussed. Figure 5.18 represents the information input–output model for the simulation software.

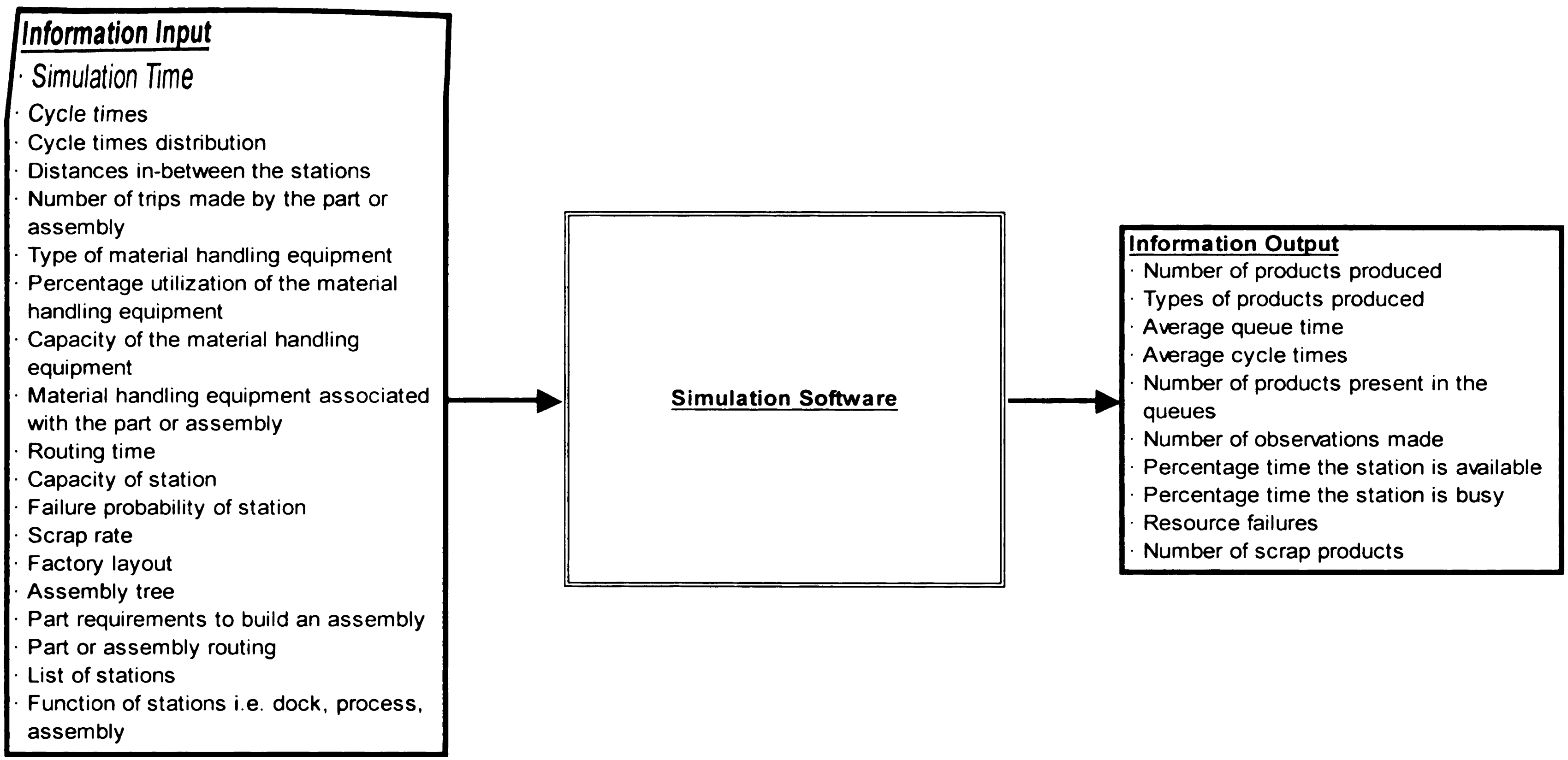

Figure 5.18: Information Input–Output Model for Simulation Software

5.3.1.2.3 Integrated Information Models for the Two Software

The integration of the facility layout and simulation software is important as the integration would be very useful in reducing the manual efforts involved in creating or modifying a production simulation model after the data have been provided to the facility layout software. The integration of software implies that they would work in conjunction rather than separate. This will result in a significant amount of timesaving and also reduction in manual errors.

The integrated information facility layout and simulation software model were developed by combining the input–output models for facility layout and simulation software. The information requirement for the facility layout was first listed. This information was then transformed into the facility layout information output. Part of this output became the input for the simulation model, but there was still some information missing. It was found by comparing the output of the facility layout model with the input of the simulation model. The missing information was listed and was shown as the additional information needed for the development or modification of the simulation model. At last the comprehensive output that would be generated as a result of this integration was listed. This comprehensive output consisted of outputs of both facility layout and simulation software. Figure 5.19 presents the information input–output model for the facility layout and simulation software.

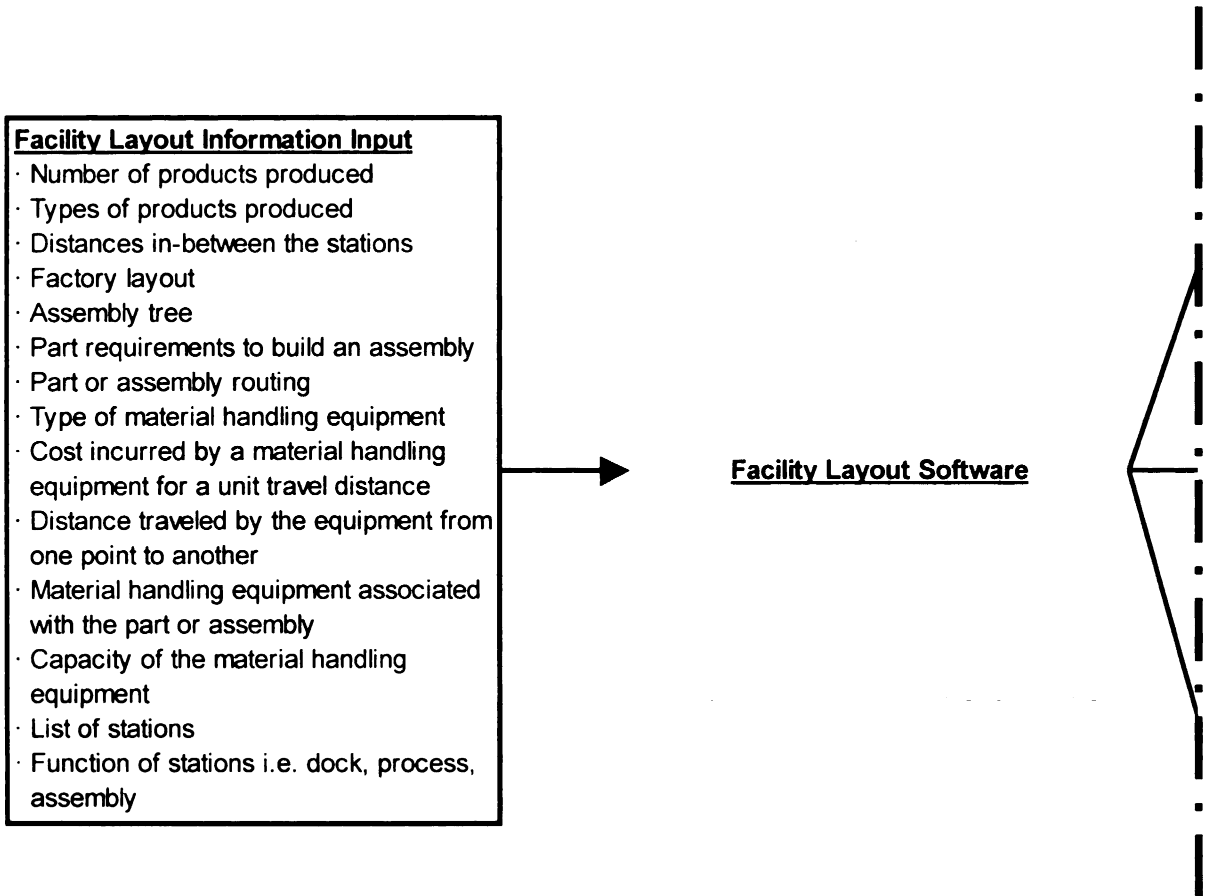

Figure 5.19a: Integrated Information Model for Facility Layout and Simulation Software

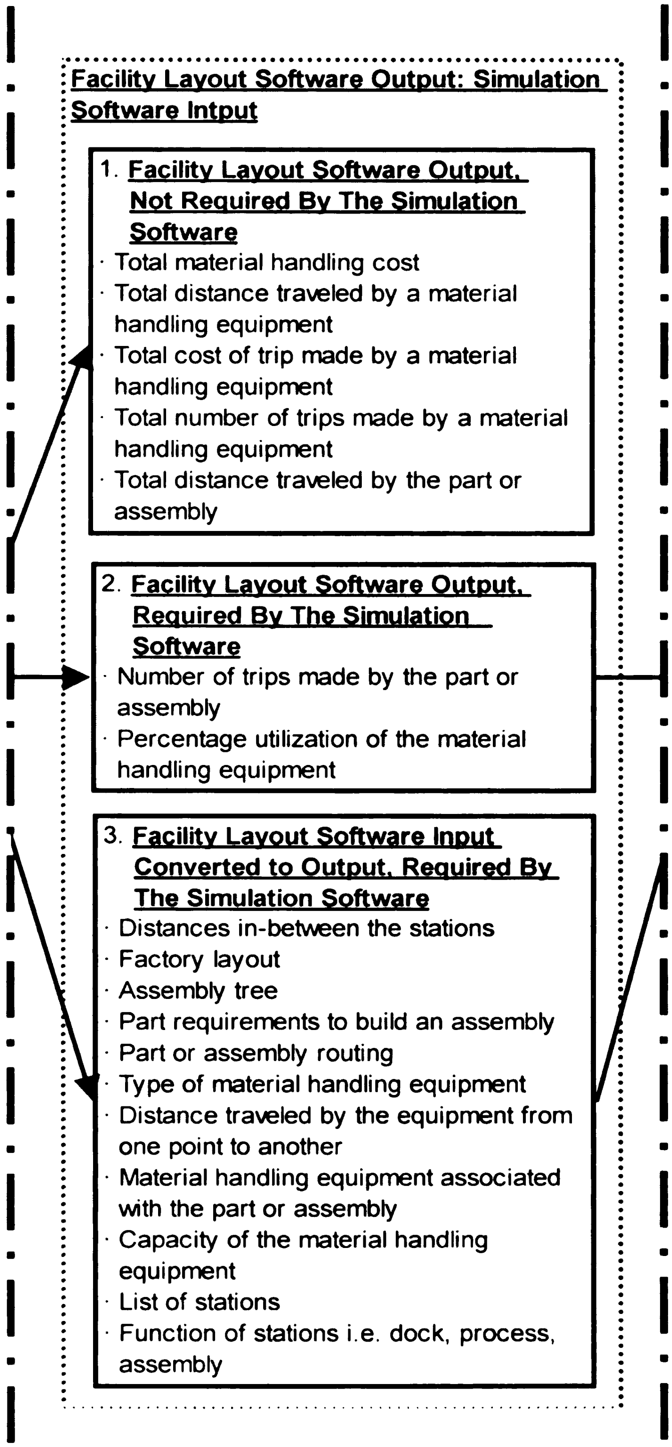

Figure 5.19b: Integrated Information Model for Facility Layout and Simulation Software

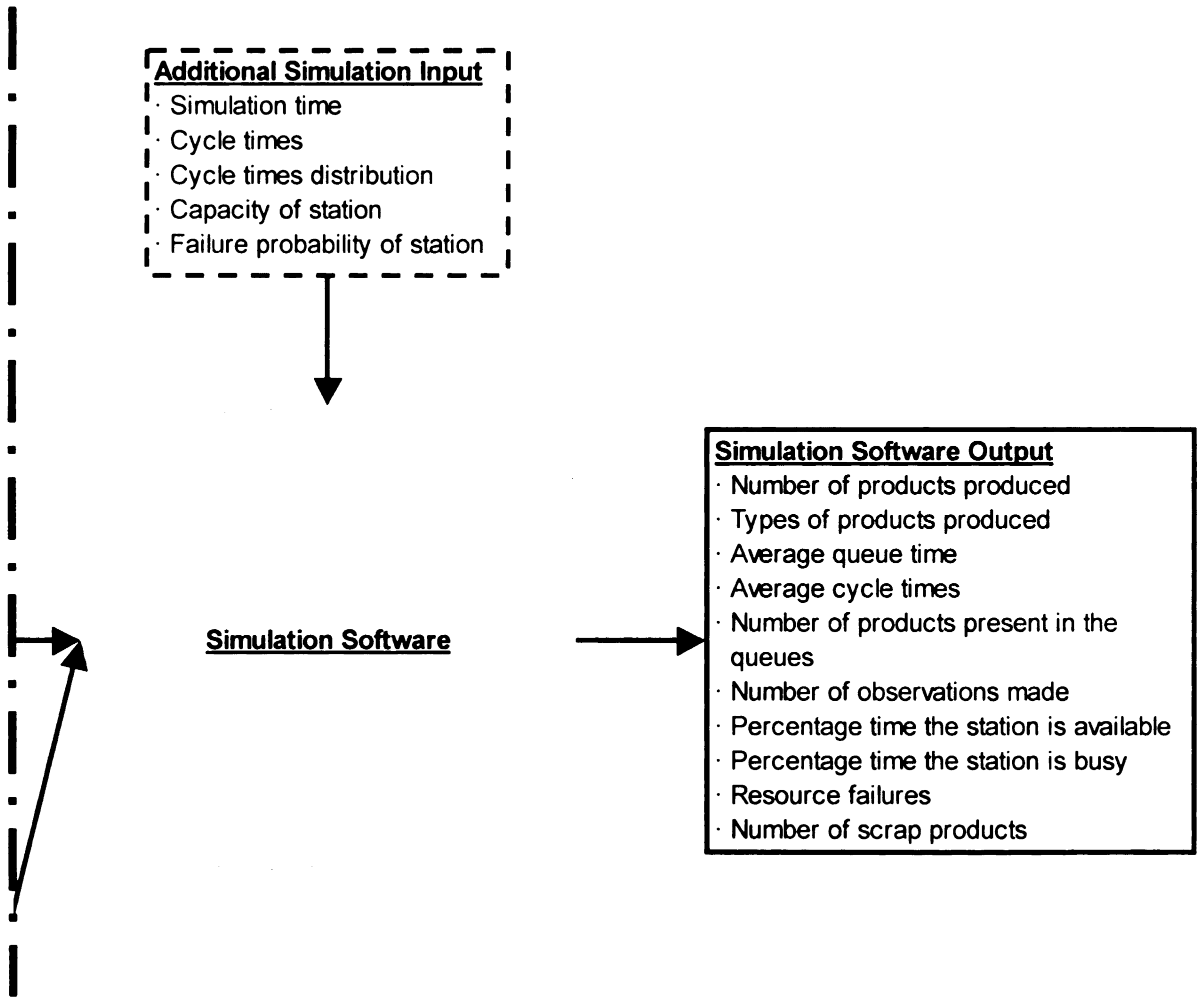

Figure 5.19c: Integrated Information Model for Facility Layout and Simulation Software

Similarly, an integrated information simulation and facility layout software model was developed by combining the input–output models for simulation and facility layout software. In this case, the information flow was taking place from the simulation software to the facility layout software. In such an integration the information flow takes place from the simulation software to the facility layout software. The input of information will take place in the simulation software and the data will then be passed on to the facility layout software. Figure 5.20 presents the information input–output model for the simulation and facility layout software.

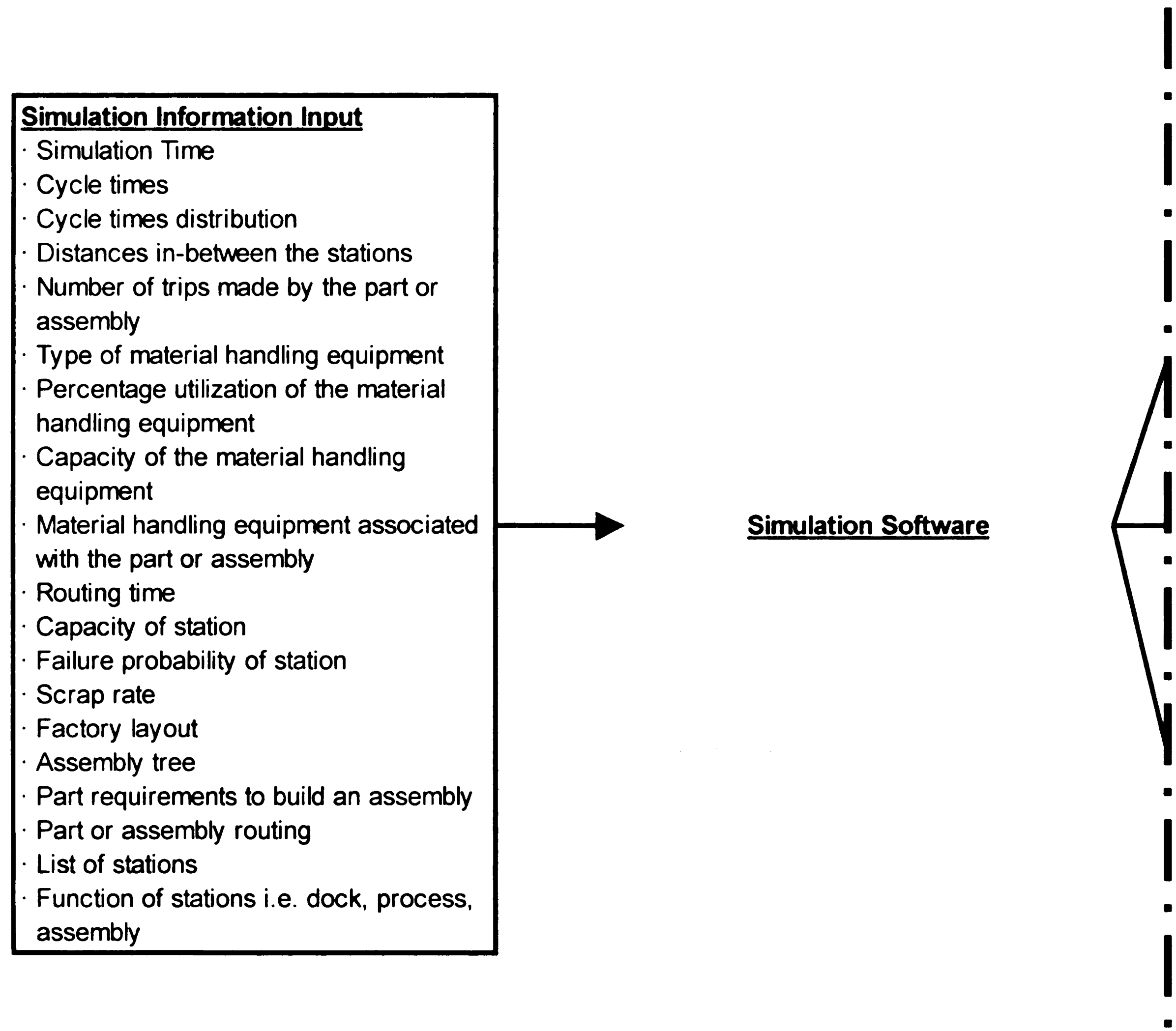

Figure 5.20a: Integrated Information Model for Simulation and Facility Layout Software

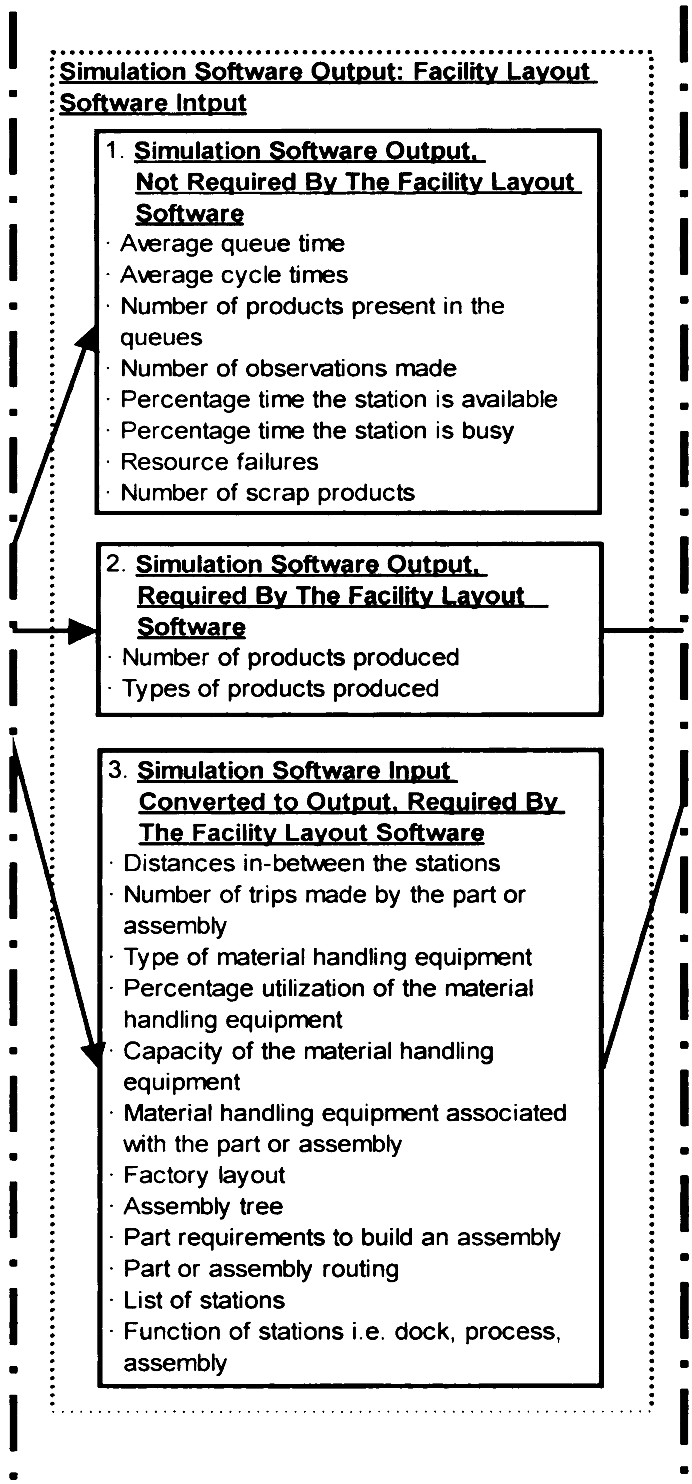

Figure 5.20b: Integrated Information Model for Simulation and Facility Layout Software

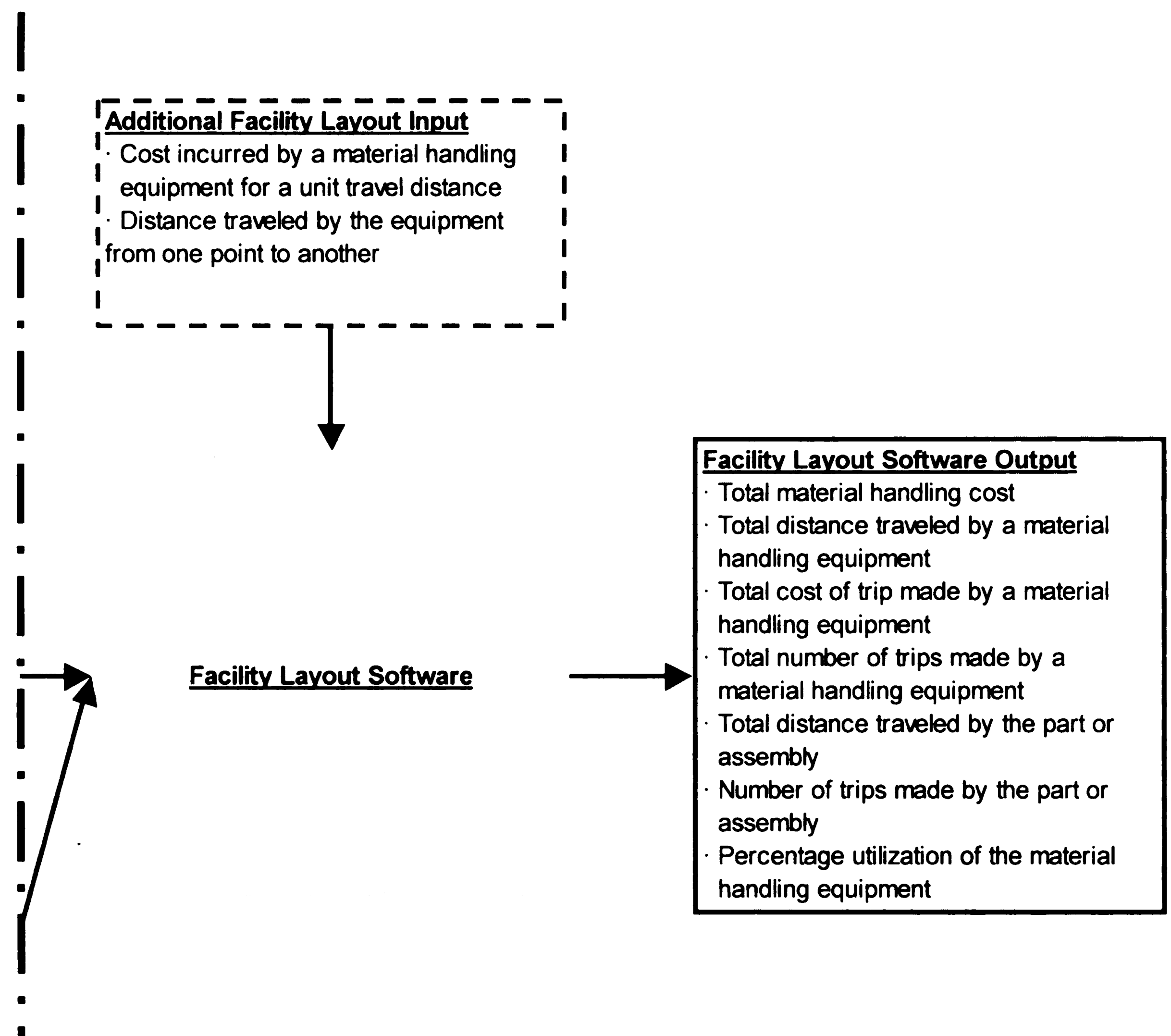

Figure 5.20c: Integrated Information Model for Simulation and Facility Layout Software

A dynamic model for the information flow taking place in between the facility layout and simulation model was also developed. This model shows that the two software will work in conjunction and the links are dynamic. The change made in one model will be implemented in the other. The data can be stored in a database or spreadsheet and the data modification will also be automated. Also the models could be generated with the information in the database. The dynamic information presented in the model is a list of all the information required and generated by the two software. Figure 5.21 presents the dynamic information exchange model.

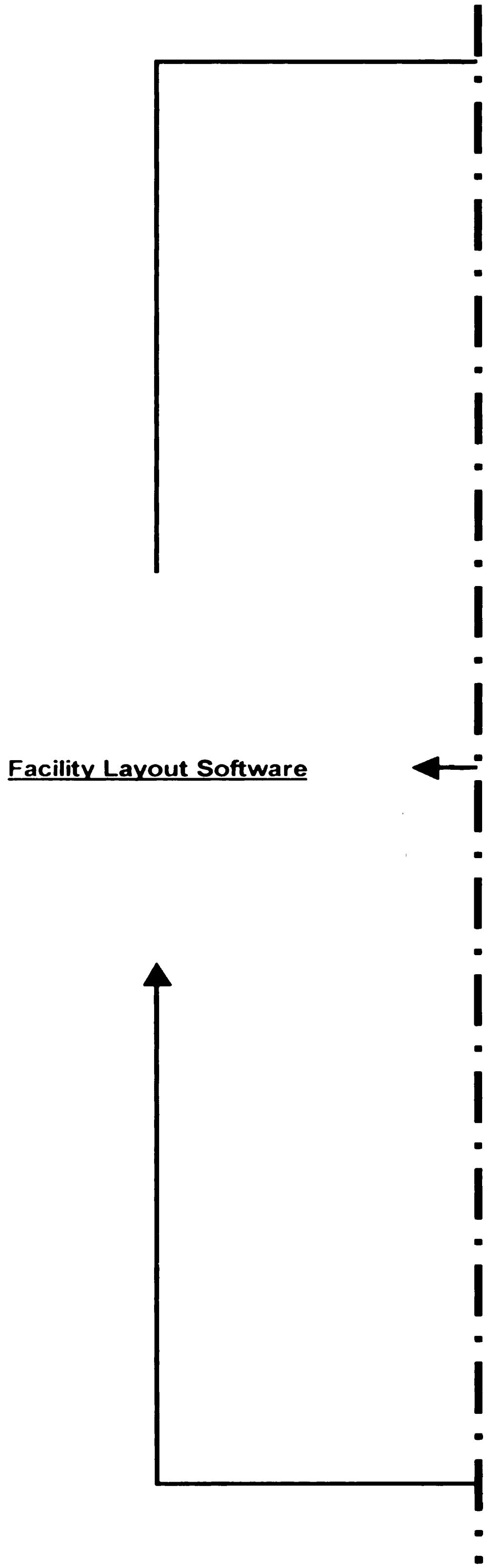

Figure 5.21a: Dynamic Information Exchange Model

Dynamic Information Exchange

- Number of products produced
- Types of products produced
- Distances in-between the stations
- Factory layout
- Assembly tree
- Part requirements to build an assembly
- Part or assembly routing
- Type of material handling equipment
- Cost incurred by a material handling equipment for a unit travel distance
- Distance traveled by the equipment from one point to another
- Material handling equipment associated with the part or assembly
- Capacity of the material handling equipment
- List of stations
- Function of stations i.e. dock, process, assembly
- Total material handling cost
- Total distance traveled by a material handling equipment
- Total cost of trip made by a material handling equipment
- Total number of trips made by a material handling equipment
- Total distance traveled by the part or assembly
- Number of trips made by the part or assembly
- Percentage utilization of the material handling equipment
- Simulation Time
- Cycle times
- Cycle times distribution
- Capacity of station
- Failure probability of station
- Scrap rate
- Average queue time
- Average cycle times
- Number of products present in the queues
- Number of observations made
- Percentage time the station is available
- Percentage time the station is busy
- Resource failures
- Number of scrap products

Figure 5.21b: Dynamic Information Exchange Model

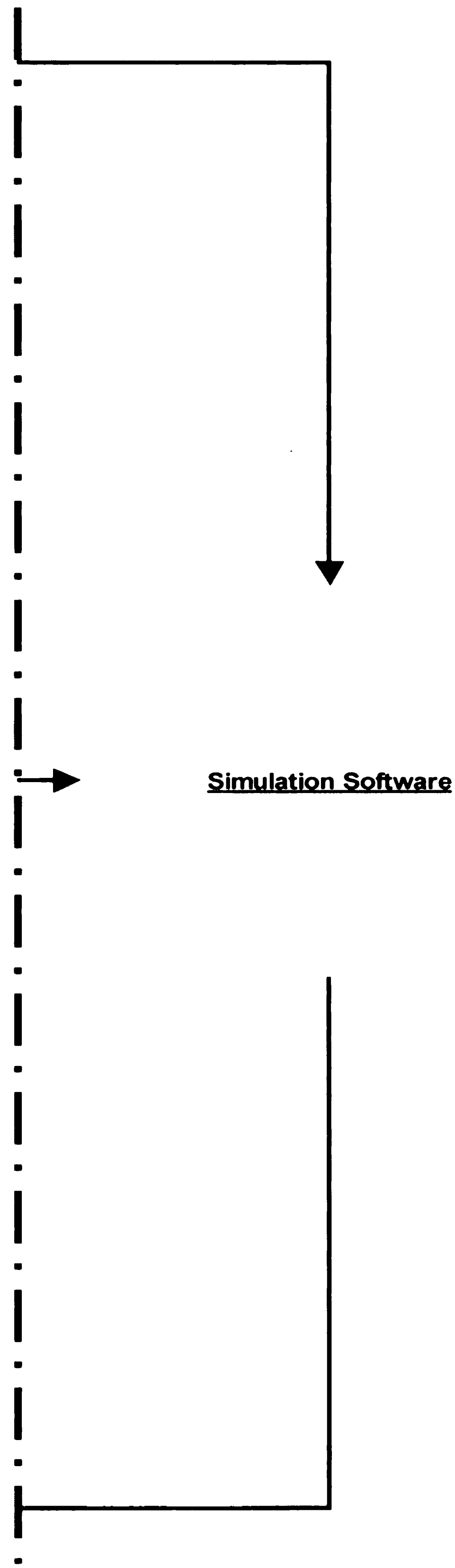

Figure 5.21c: Dynamic Information Exchange Model

The approach in which data is input into one software and then transferred into another would cause data input in two stages. The first stage of data input occurs when one model is created. The second stage of data input is when the output of the first software has been collected and extra information is input into the second software. In such a case, the information input will take place in two stages and the system may not be totally automated. The duplication of data can be greatly reduced by using such an integration strategy, but the data exchange process will still be static. The changes made in one model will have to be made in the other model. This makes the data exchange process static. To overcome this problem a dynamic simulation data exchange model was created.

The dynamic information exchange model of facility layout and simulation software can be developed by creating a common database or by using an interactive spreadsheet. Both facility layout and simulation models can be created from a spreadsheet or a database. Therefore, if a common spreadsheet can be designed such that the two models can be created from it, the spreadsheet or database can also be used for transferring the data dynamically. Such a spreadsheet would work in the background of the two software. The data change in the spreadsheet would also change the two models. Therefore, this process is dynamic. The advantages of such a process is that the process will be more robust and automated. The data exchange would become dynamic and the changes made in one model or in the data spreadsheet could be incorporated in the other model automatically. No manual changes will be required. One disadvantage of such a system could be that if the number of entities that can be handled in one software exceeded the limit, a flag / warning cannot come up. Then the other software cannot detect if the limit of the entities has been exceeded and has caused a bottleneck, or is causing extra material handling cost. The system does not have the power to create "what-if" scenarios by itself. It still requires human input. Hence, the system is not intelligent. But out of the two approaches, the dynamic approach is the best solution to the software integration problem.

5.3.2 Approaches to Integrating the Facility Layout and Simulation Software

Many approaches could be employed for integrating the facility layout and simulation software. As per author's understanding, the two approaches that could be used to integrate the two software are:

1. Data transfer from one software to another by employing two spreadsheets or databases.

   This approach is also highlighted by the information input–output models used to transfer information from one software to another, by making the output of the first software the input of the other software. In this approach there are two spreadsheets, which are used to create the two models. The information is input in the first spreadsheet and then fed into the first software. The model in that software is then run to produce an output. This output is categorized into 3 categories. These 3 categories are: the data output by one software not required by the other software, the data output by one software required by the other software, and data which were input into the first software and output through the same software which were also required by the other software.

2. Data transfer through a common spreadsheet or database.

   This approach is highlighted by the dynamic information exchange model. In such a case, a common file serves as the input and output for the two software. All the information required and generated by the two software is stored in a single spreadsheet or database. Each software inputs the respective information that is required by the software. It then produces information, which is used by the other software. The spreadsheet or the database is a dynamic file that can change the content by itself. Such a file would be helpful when changes are made to either of the models and the change can be seen in the other model. Such an approach would result in transferring the data from either software to another.

As per author's understanding, the most effective approach can be to create a database or a spreadsheet file that contains all the information required by both facility layout and simulation software (explained above), which is represented by the dynamic information exchange model.

5.3.3 Software Integration Demonstration Example

In this research author made an attempt to input the information both in FactoryFLOW facility layout software and Arena simulation software with a spreadsheet. Both the software were also used to provide their output in a spreadsheet. The author was successful in importing and exporting the information requirements and information generated into a spreadsheet. Both these software have different formats in which the information can be imported or exported. This was the main problem encountered by the author while providing the information inputs.

The author started by creating an input spreadsheet for the Arena simulation software for developing a simulation model of limited scope. The information that needed to be transferred was highlighted and an input spreadsheet file was created. The spreadsheet once created was fed into the Arena simulation software to develop the model. The model was then run to determine the output and the input, which was earlier, fed into the spreadsheet file is also created as an output. This information was then transferred to a spreadsheet that contained the additional information required by the FactroyFLOW software to create a model, but which was not present in the first spreadsheet used to create the simulation model. The information was transferred by designing a "macro" in the spreadsheet. A macro is a set of keystrokes and instructions that are recorded, saved, and assigned to a short key code. When the key code is typed or the recorded keystrokes are played, the instructions get executed.

This input file for the FactoryFLOW software was then fed into the software to create the facility layout model. The model was constructed and run to create the desired output. One of the limitations of this example is that the scenario assumed was limited to a certain extent. Not all the information as highlighted in the information input–output models was incorporated. This example is visualized in figure 5.22.

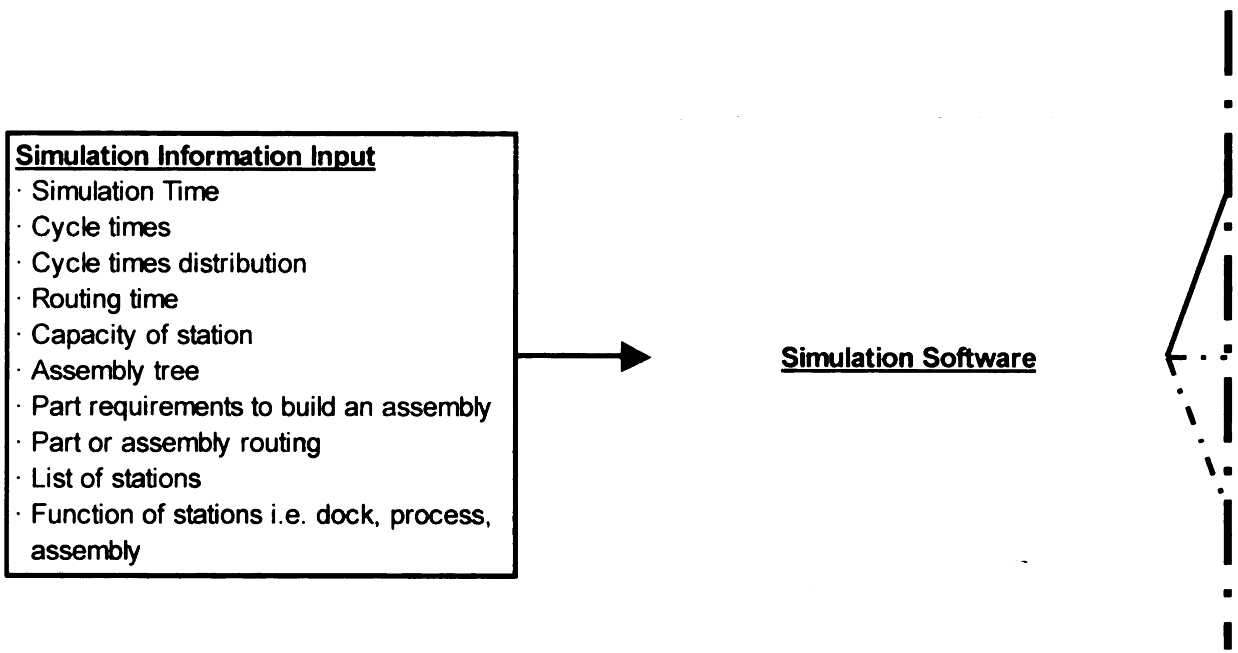

Figure 5.22a: Integrated Information Input-Output Model for the Demonstration Example

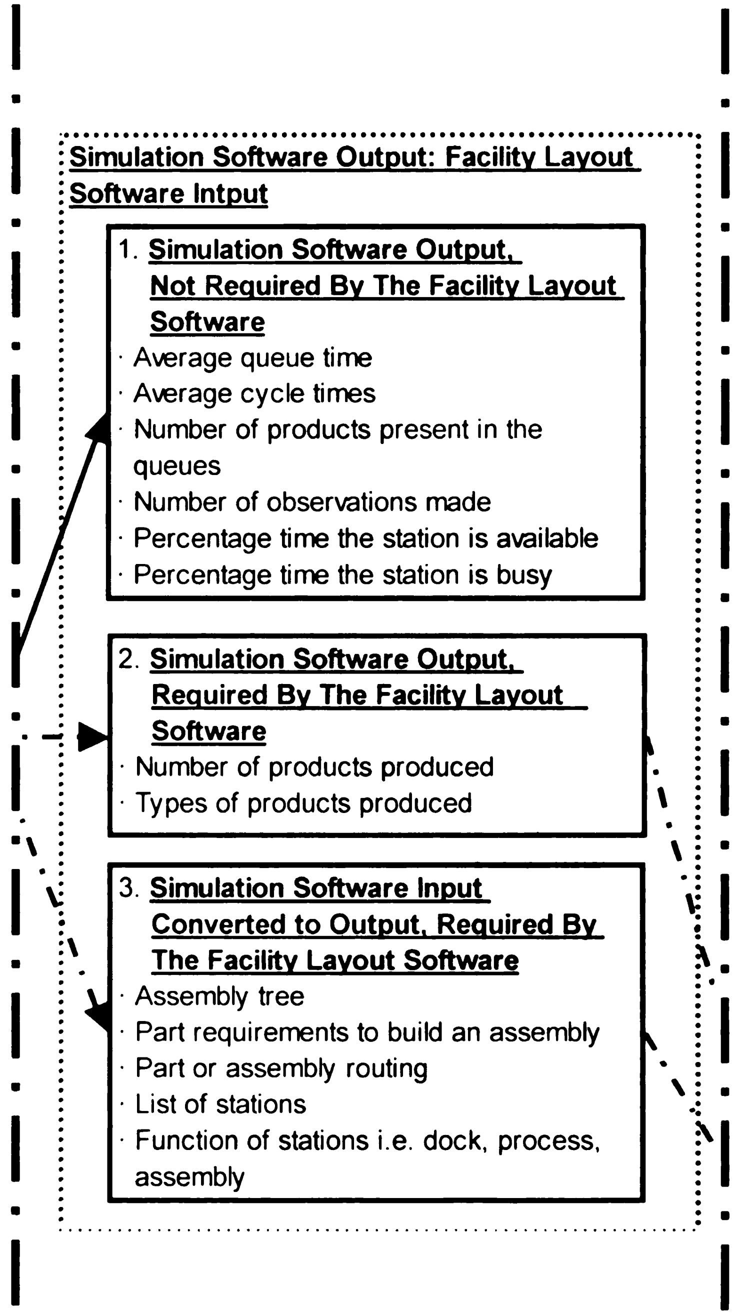

Figure 5.22b: Integrated Information Input-Output Model for the Demonstration Example

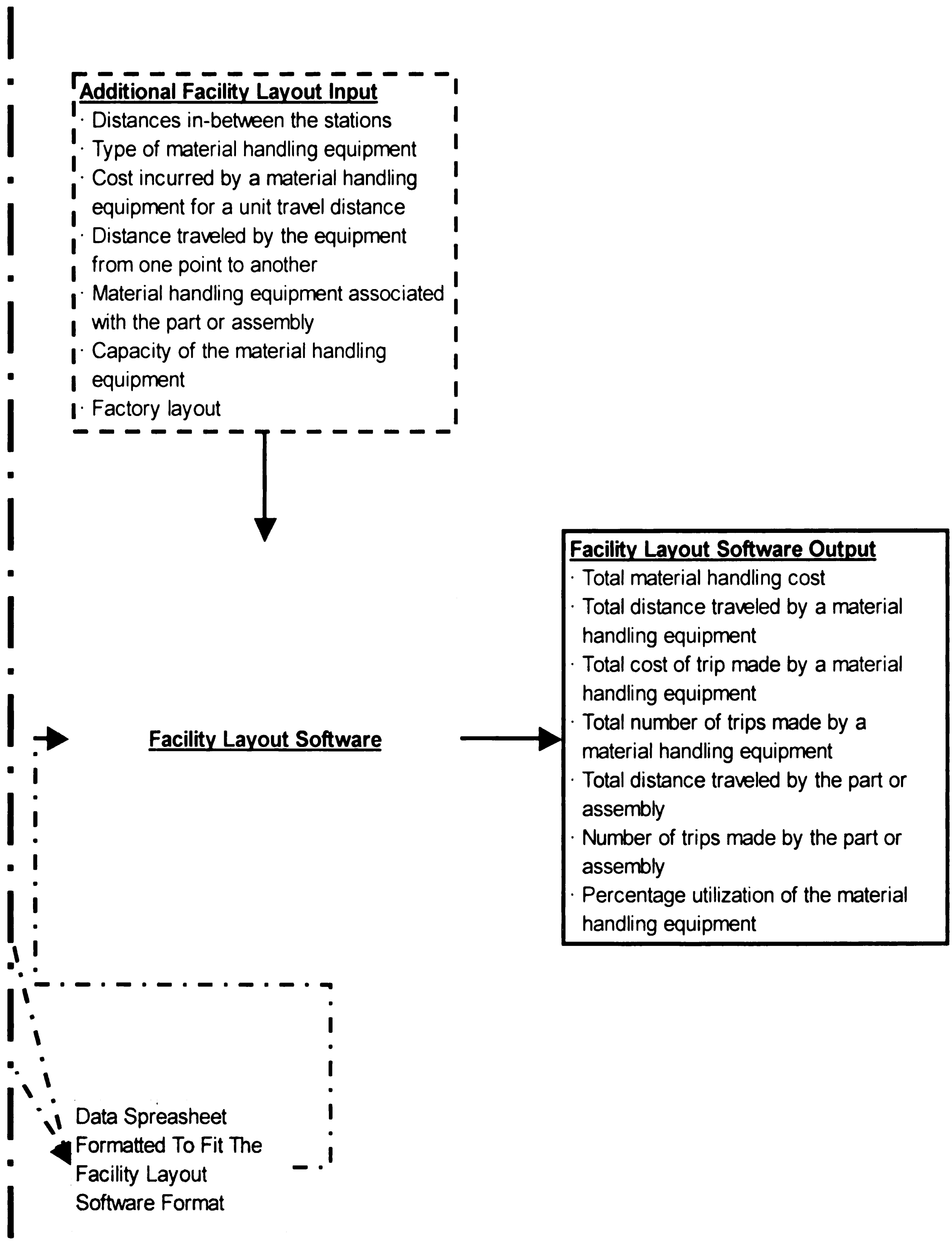

Figure 5.22c: Integrated Information Input-Output Model for the Demonstration Example

The author also interviewed with a representative from the company that develops facility layout software. The representative was in total agreement with designing "macros" for the data exchange. In the discussion, the author and the company representative, concluded that this approach is very effective when the modeler is not exposed to the codes of the software that could be used to change the format of the output of one of the software making it acceptable to the other. This brought the discussion to the conclusion that there should be a standard format of data exchange between the facility layout and simulation software developed by different companies. If the data exchange format is standardized, the next step would be to develop an interactive or dynamic interface between the two software and the file containing all the inputs and outputs of the two software.

The representative of the company also pointed out that they have also come up with a solution for data exchange. As per their approach, the modeler can input all the information directly into the software and develop a file, which contains all the information. The file is called the "Simulation Data Exchange" file with a file extension of .sdx. This file can then be input into the simulation software and create a simulation model. But again the file format that is created should be acceptable to the other software. Here the information flow is taking place from the facility layout software to the simulation software.

5.4 Summary

Manufactured housing components assembly redesign is carried out for only the floor and walls cluster. This analysis can be carried out for other clusters as well. Also, many scenarios in each cluster can also be developed. To achieve the best results, manufactured housing components assembly redesign should be carried out before the assembly process can be line balanced in the simulation software or can be optimized for the material handling cost in the facility layout software. This analysis basically focused on creating a process that consumes least material handling cost and takes the least possible amount of time.

This chapter outlines the process for redesigning the components assembly of a manufactured housing plant. The author presents the methodology of developing the redesigned components assemblies. The evaluation of the components assembly redesign using the FactoryFLOW facility layout and Arena simulation software was also explained. The industry personnel evaluated the results of the redesigned components assembly process for both the floor and wall cluster.

The author also developed integrated information input–output models for facility layout and simulation software. These models are used for understanding the data exchange that is taking place in-between the two software. Two approaches for data transfer are also presented and an approach to data transfer is implemented by using a small-scale demonstration example.

CHAPTER - VI

SUMMARY AND CONCLUSIONS

6.1 Introduction

The primary intent of this research is to show the effect of manufactured housing components assemblies redesign on the productivity of the production process and the material handling cost of the facility layout. To accomplish this, extensive literature review from a new area of the manufacturing and industrial engineering called "Design for Manufacture and Assembly" was carried out.

The research included mapping the assembly procedure for the existing components and the components assemblies redesign procedure. The research also sought to demonstrate how the redesign of the components assembly systems affects the productivity of the production process and the material handling cost of the facility layout. To attain this objective, the author utilized two software for evaluating the components assembly redesign alternatives. In addition, the integrated information input–output model were prepared to help identify the information flow taking place between the two software. This integrated information input–output model of the facility layout and simulation software can further be used to integrate the two software. The following paragraphs provide the outline of each chapter to summarize the methodology followed during the research.

Chapter II presented the review of existing and ongoing research and literature in the area of the manufactured housing industry, and design for manufacture and assembly. Existing research and literature were classified into three categories, namely, Manufactured Housing Production Process, Material Management and Supply Chain; Facility Layout Research in Manufacturing

Industries; and Design for Manufacture, Design for Assembly and Design for Manufacture and Assembly.

In Chapter III, the author outlined the major tools and techniques of design for manufacture and assembly. The chapter explained the objectives of DFMA, DFM and DFA. In addition, the chapter also gave a comprehensive overview of the various approaches and techniques of DFM and DFA. Chapter III also provided a brief overview of the product tree structure, precedence diagrams, FactoryFLOW facility layout software, and Arena simulation software, which are used in developing existing and new components assemblies.

Chapter IV mainly dealt with identification of the inefficient clusters, parts; developing the existing assemblies; developing existing facility layout and simulation models for these clusters. The clusters that were identified were the floor and wall clusters. The floor and wall assembly representation was done by product tree structure and the assembly sequence representation was done by precedence diagrams. Once the existing assemblies were developed, they were modeled in the facility layout and simulation software. The models were verified and the outputs were compared in terms of daily material handling cost and time taken to produce 10 floors.

Chapter V presented the redesign floor and walls components assemblies. The new assemblies developed by the author were for the floor and walls cluster. The new assemblies were depicted in the product tree structure and precedence diagrams. These assemblies were then depicted in the FactoryFLOW facility layout software and Arena simulation software. The outputs produced by the software were compared to the outputs of the existing assembly systems. Also, the factory personnel provided the practical feasibility for these new assemblies. Once the material handling cost and the production was compared for the existing and new assembly systems, integrated information input - output models were developed. Also an attempt was made for transferring data in between the two software.

6.2 Summary of Research Objectives

The overall goal of the proposed research is to demonstrate the effect of components assembly redesign on the productivity of the production process and the material flow cost of the facility layout of a manufactured housing production plant.

6.2.1 To explore possible changes to the components assembly systems

The following steps were taken to achieve objective I.

Step-1: Study and understand the manufactured housing assembling process.

To achieve the above mentioned step, the manufactured house was broken down into components and the assembly process studied in detail. Moreover, the assembly process at the feeder station was also studied.

Step-2: Identify clusters and parts of clusters of manufactured housing assembly that are inefficient and can be done differently by incorporating new assemblies.

The inefficient clusters and inefficient parts in a cluster were identified by conducting interviews with the factory personnel and by author's observations over several factory visits. Inefficient clusters identified were the floor and walls clusters.

Step-3: Develop product tree structure for existing components assembly.

The author studied the technique product tree structure and the parts of each component very closely. The product tree structure for the existing floor and walls clusters were developed.

Step-4: Develop precedence diagrams for existing components assembly process.

The author studied the assembly procedure of the complete manufactured house and also explored details of the assembly of floors and walls. Each activity in the station and in the floor and walls clusters was studied. Relationships were developed and in-turn precedence diagrams for existing floor and walls clusters were developed.

Step-5: Develop new assemblies for these inefficient parts.

The new assemblies that were developed were represented by the new product tree structures, and the assembly sequence intent was represented by the new precedence diagrams. The new product tree structures and new precedence diagrams were developed for both floor and walls cluster. Also animation for the new assembly procedure was developed to collect feedback from the factory personnel on these new assemblies.

6.2.2 To recreate the material handling analysis of facility layout and the production process simulation models

The following steps were taken to achieve objective II.

Step-1: Study the manufactured housing production process and facility layout.

In order to recreate the material handling analysis of facility layout and the production simulation models, the manufactured housing production process and facility layout were studied. This involved extensive literature review and several visits to the factory.

Step-2: Explore different techniques and software of simulation and facility layout modeling.

Different techniques and software for facility layout and simulation modeling were considered but the author chose Arena simulation software for developing production simulation models. Since the facility layout model had already been developed in FactoryFLOW facility layout software, the author studied FactoryFLOW facility layout software.

Step-3: Recreate the existing facility layout model.

This step included study of a previously developed facility layout model, verifications, data collection, and modification for the recreation of the existing facility layout model.

Step-4: Recreate production simulation models.

In this step, data pertaining to the floor and walls cluster in terms of cycle times were collected for the recreation of the production simulation models. Once the data were collected, the production simulation models for the existing floor and walls assembly were developed. These models were then verified and outputs compared.

6.2.3 To demonstrate the impact of the revised component assembly on the production process and the material handling aspect of the facility layout

The steps taken to achieve objective III are as follows.

Step-1: Develop new facility layout model to depict the changes made in the components assembly of the cluster.

New facility layout models were developed after modifying the existing facility layout model in the specific clusters that would represent the new assemblies. The new product tree structures played a vital role in these modifications. The material handling analysis was carried out for both the floor and wall cluster individually and combined.

Step-2: Develop new production simulation model for the cluster.

New production simulation models were created individually for the floor and walls cluster to compute new productivities. These models were developed by using the precedence diagrams that depict the assembly sequence and were then verified.

Step-3: Compare the physical layout, material handling cost of the facility layout and the productivity obtained from the production simulation model.

The material handling cost computed by the existing facility layout model and the ones produced by the new facility layout models were compared. The productivity for the production simulation models for the floor and walls cluster was also compared.

6.2.4 To explore the link between two aspects in objective III by integrating facility layout and simulation models

The steps taken to fulfill objective IV are as follows.

Step-1: Highlight the information requirements for the two software and the information generated by them.

In this step, the information required and generated by the facility layout and the simulation software was listed. The list produced was a comprehensive list for both the software.

Step-2: Develop information input–output models for the two software individually.

Input–output modeling technique was used to represent the information requirement and generation for the two software. Information input–output models were developed for both facility layout and simulation software. The information that was listed in the previous step was used to determine the inputs and outputs for both the software.

Step-3: Develop integrated information input- output models for the two software.

This step consisted of developing an integrated model that highlights and consists of the information requirements and generation of the two software. The integrated information input–output models were developed such that the information is input into one model, and then the information generated by the that model and some external information input provide enough information for the other model development. Also a dynamic information exchange model was also developed. This model represents the information as dynamic, such that the modifications made in one model dynamically affects the changes made in the other.

Step-4: Explore the data exchange in between the facility layout and simulation models.

In this step, an attempt has been made to create the two models from spreadsheets. The models were created successfully by inputting different spreadsheet files to the software but a common format for creation of the facility layout and simulation models could not be achieved. Therefore, it is important to establish a common format for exchange in between the software. A demonstration example was developed and the data transfer between the two spreadsheets was achieved by designing a “macro”.

6.3 Limitations of Research

One of the major limitations of this research was that the complete manufactured housing components assemblies were not redesigned. Due to the scope and the timeframe, only two manufactured housing clusters were redesigned. In order to generate an efficient assembly process, a complete manufactured housing assembly process needs to be redesigned. If partial redesign is carried out, it would lead to more heavily loaded bottlenecks than the regular production process, as the equilibrium is now disturbed.

Another major drawback of this research was that different scenarios for the components assembly redesign were not developed to evaluate the effectiveness for each redesign. Many different type of scenarios for each cluster can be developed and can be evaluated for both the productivity and material handling cost. Different scenarios must be developed and the most effective option in terms of productivity and material handling cost should be chosen for that particular component.

This analysis considered the quantitative aspect of the facility layout for the manufactured housing components assembly redesign. The analysis can also be carried out for the qualitative aspect of facility layout. In addition, the quantitative aspect of the facility layout was considered in 2-dimensions, due to the scope of research. To make the output more accurate, the quantitative aspect can also be carried out for a 3-dimnesions.

This research required the use of two software, and the input of data and modifications was a very tedious process. This analysis will be much more accurate, fast and reliable if the two software are integrated.

Finally, the thesis scope of research is limited to show the effect of components assembly redesign on the facility layout and production process of a manufactured housing factory. However, a recommendation of integrating the facility layout and production process, and finding the optimal solution for the same is outside the scope of this research. Further research will be carried out for integrating and finding the optimal facility layout and production process. This research makes an attempt to show the practitioners a stepwise approach that needs to be followed to redesign existing manufactured housing components assembly redesign to evaluate its effectiveness in terms of material handling cost and productivity.

6.4 Conclusion

Although manufactured homes have come a long way from trailers, there has been little effort to improve their assembly process. There is no standard way or procedure adopted for designing the components assembly process. Manufactured housing industry lacks any information associated with the process of components assembly design. There is a need to learn and adopt techniques from other disciplines that are more experienced and have learnt lessons. This industry should learn the components assemblies of other advanced industries like automobile industry and based on the feasibility should adopt techniques used in that field. The following section presents the major conclusions from this research work:

- The author strongly believes that the manufactured housing components assembly redesign is a critical factor. Components assemblies of a manufactured housing factory should be evaluated and redesigned for improving the overall efficiency of the manufactured housing production plant.
- As per this research, it can be concluded that manufactured housing components assembly redesign can lead to material handling cost and/or time savings. Various new ways of assembling components can be explored with the objective of either reducing the material handling cost for some specific production or increasing the production for some material handling cost. Also component assembly redesign based on incorporation of new assemblies and assembly sequencing can also be explored that can reduce material handling cost and at the same time increase production.
- The manufactured housing components assemblies should be evaluated from time to time, and the best option that might be most

feasible for the prevalent demand should be implemented. For example, if the demand is not quite high and the market is seeing a downward trend, the components should be designed so as to give the required output for the least amount of cost. Same scenarios can also be applied when there is a high demand.

- Many components that are used to produce manufactured houses are assembled in the factory. Some of these components assemblies are time consuming, and they delay the assembly of other components. Manufacturers should consider sub-contracting the assembly of these components, for example, floor headers, to sub-contractors.
- The software integration will play a major role in reducing the manual effort required for data input and model development. The software integration will also reduce the errors introduced during data input.
- The dynamic information exchange in between the software is the future of software integration. Dynamic integration holds a lot of advantages when compared to static data transfer.

The author based on the factory visits, interviews and research came to the following observations:

- Most manufactured housing factories follow same process of assembly. The manufactured housing industry is a labor intensive industry, therefore it has an opportunity to try different options and is not constrained by fixed machine / equipment based assembly.

- As the manufactured housing industry is labor intensive industry, it allows for flexibility in assembly but manufacturers should consider automation. Certain areas should be automated to speed up the process.
- All the parties involved in the manufactured housing industry must be educated in the area of components assemblies. Training should be provided to all members of the industry, especially the ones directly involved with the assembly. As these people are the best guides to better assembly process.

6.5 Future Research Areas

Some of the future areas recommended by the author are described in the following sections:

6.5.1 Optimal Components Assembly Redesign

The research area that can be defined as the continuation of this research is the optimal components assembly redesign. In this research, various alternatives to the components assemblies can be developed, and the best solution can be picked for each component. Optimal in this context is either lowest possible material handling cost and/or highest possible production rate. The best solution for each component can be picked and combined together to yield an overall optimal solution to the component assembly design problem. Various factors that would lead to an overall optimal solution would need to be taken into account such as the qualitative aspect of facility layout, supply chain etc..

6.5.2 Dynamic Integrated System

Another research area that could also be defined as the continuation of this research is the development of dynamic integrated system of facility layout and simulation software. For developing such an integrated system the very first step is to arrive at a common format for data exchange in-between the software. In such a system, a common file will serve as the input and output for the two software. All the information required and generated by the two software will stored in a single spreadsheet or database. The software input the respective information that is required by the software, will produce information, which is used by the other software. The spreadsheet or the database is a dynamic file that can change the content by itself. Such a file would be helpful when changes are made to either of the models and the change can be seen in the other model. Also it is necessary that only spreadsheet or database can be used for information transfer. Different formats such as "Simulation Data Exchange" file can also be used but the file modified so it can be dynamic. But before it can happen, the software developers would need to accept a common format for data exchange.

6.5.3 Modeling of Resources in Simulation

The simulation models that were developed in this research focused on the entity i.e. the manufactured house section. A simulation study should be conducted in which in addition to the entity the resources are also modeled. This would lead to more accurate modeling of the manufactured housing production plant. In such a case, the shortages, breakdown of sub-assembly stations and machines can also be taken into account. Such a model would also present over utilized and under utilized resources.

6.5.4 Whole House Based Redesign of a House

Another future research area is the whole house based redesign of a house to achieve performance competitive and environmentally responsive homes. In such research, the design of the house will be the variable parameter, which will be optimized to have better performance competitive and be environmentally responsive. Whole House based redesign of the production process and design based on optimizing individual subsystems will play a major role in improving the production efficiency. The issues of environmentally responsible usage of the house over the course of its lifetime and during its manufacture, as well as the assembly, transportation and installation would play a major role in the industry's adoption of whole-house based redesign. In addition, various approaches such as open buildings, lean building design etc. could be employed for whole house redesign.

6.6 Summary

The manufactured housing industry produces one of the most popular factory-built housing, and it has a great potential to meet the increasing demand for affordable housing. However, the industry's assembly procedure for assembling the manufactured house in this industry is still primitive. There is a need to introduce advanced and futuristic techniques and equipments currently used in other progressing manufacturing industries.

As a part of the research project funded by the NSF-PATH initiative, this research explores the tools and technologies used in other manufacturing industries. This research presents a way of representing the assemblies and their assembly sequence by developing product tree structures and precedence diagrams. This research also describes the redesign of manufactured housing components assemblies, which can be implemented in the manufactured housing industry. The research develops an alternative assembly process for parts of the manufactured housing assembly. The effect of the change in the assembly process was shown on the material flow cost and the productivity with help of FactoryFLOW facility layout software and Arena simulation software. In addition, this research also presents integrated information input–output model, which can be used to integrate the two software. Two approaches for data transfer between the two software are also illustrated and a demonstration example was developed to show the data exchange between the two software by one of the approach.

APPENDICES

APPENDIX-A

SAMPLE INTERVIEWS

1. What position do you work in the manufactured housing factory?

2. Which cluster (e.g. floor, roofs etc.) do you mainly work in?

3. Is there a particular manufactured housing cluster (e.g. floor, roofs etc.) where you see a problem?

4. What do you think are inefficient assembly parts (e.g. roofing assembly) in that cluster?

5. Why do you think the above-mentioned assemblies are inefficient?

6. Do you think the above-mentioned assemblies can be done differently or modified?

7. If you think that these assemblies can be done differently, what way would you prefer assembling them? Please mention which assembly and how?

8. Do you think any of the above-mentioned assemblies can be brought in as a prefabricated unit? If yes, please specify which one?

1. What position do you work in the manufactured housing factory?

2. Do you think that the ____________________ assembly can be done differently? Please comment.

3. Do you think the ____________________ assembly can be done as shown in the precedence diagram? Please comment.

4. What do you think about the practical feasibility of the new proposed __________ assembly?

APPENDIX-B

WALL ASSEMBLY PRODUCT TREE STRUCTURE

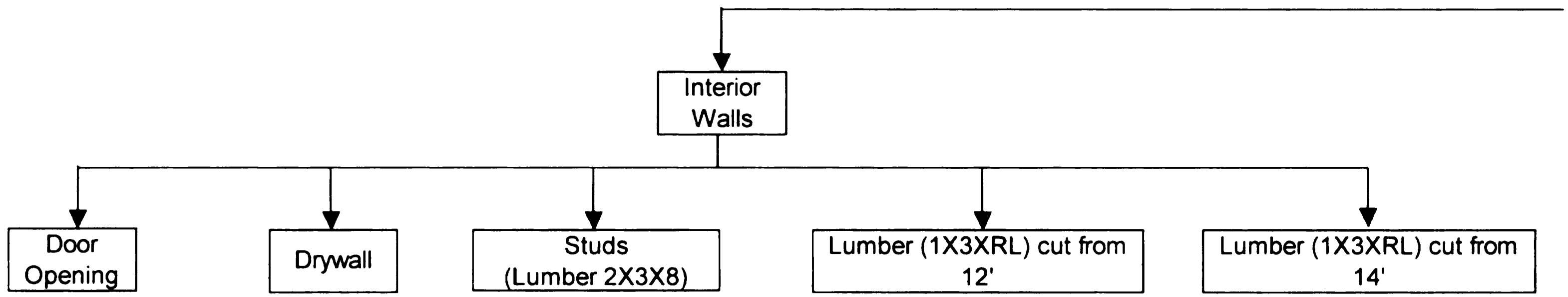

Figure B1a: Product Tree Structure for Wall Cluster

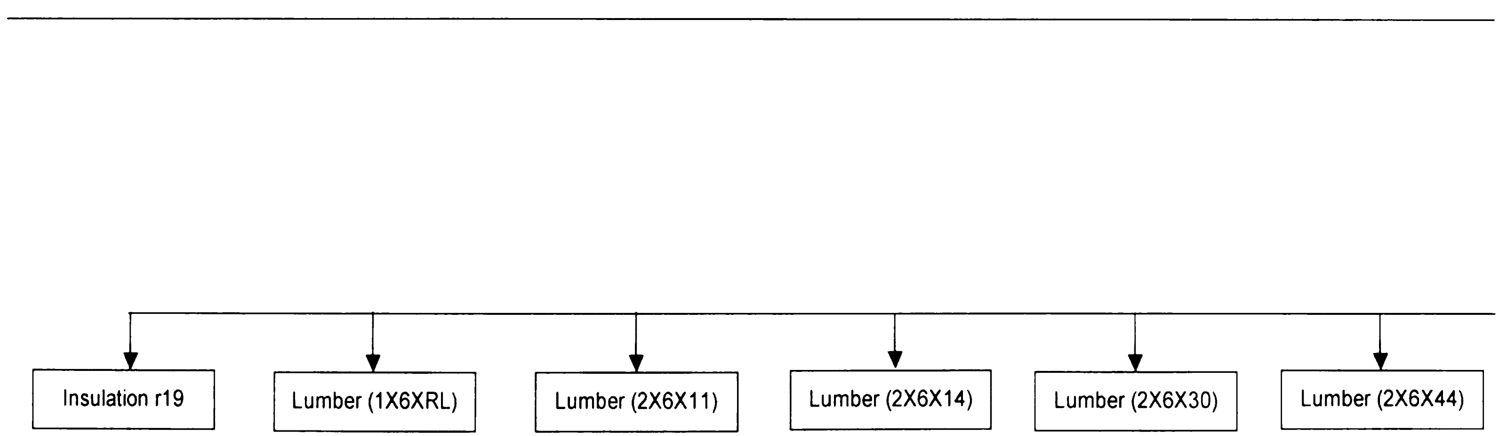

Figure B1b: Product Tree Structure for Wall Cluster

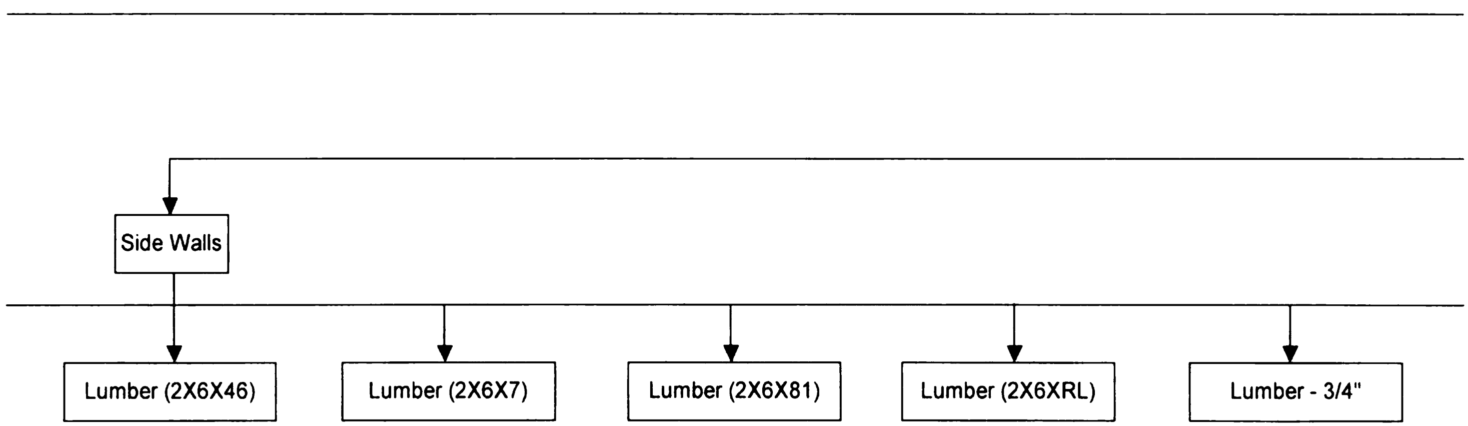

Figure B1c: Product Tree Structure for Wall Cluster

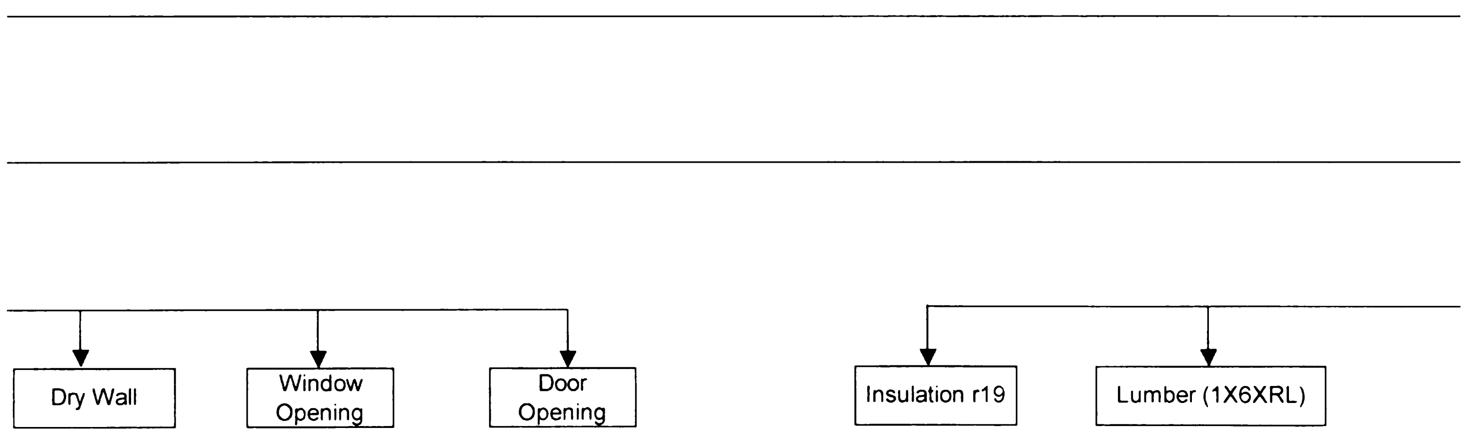

Figure B1d: Product Tree Structure for Wall Cluster

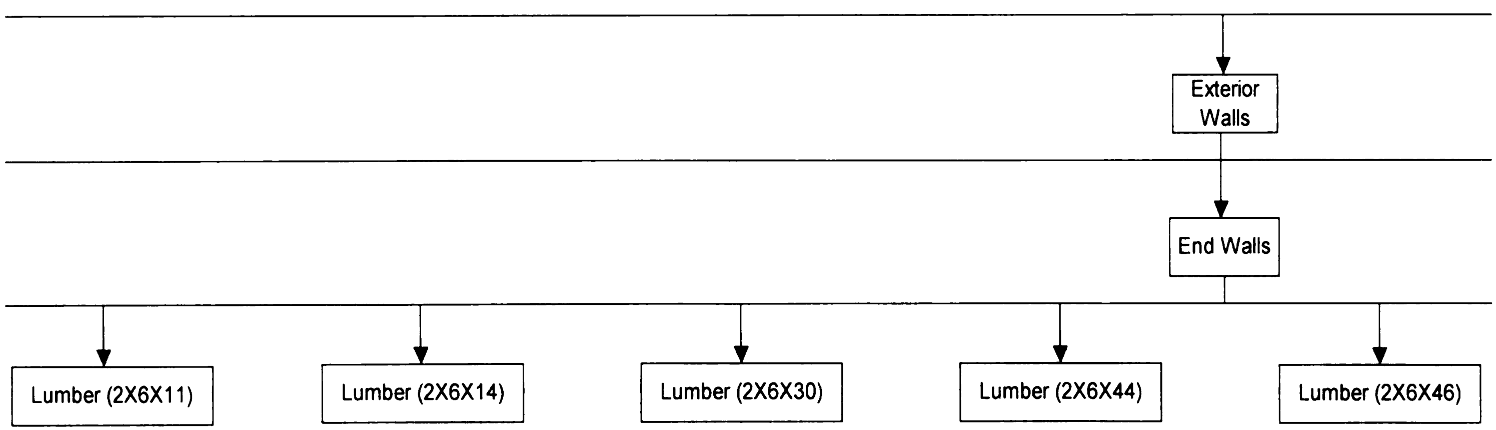

Figure B1e: Product Tree Structure for Wall Cluster

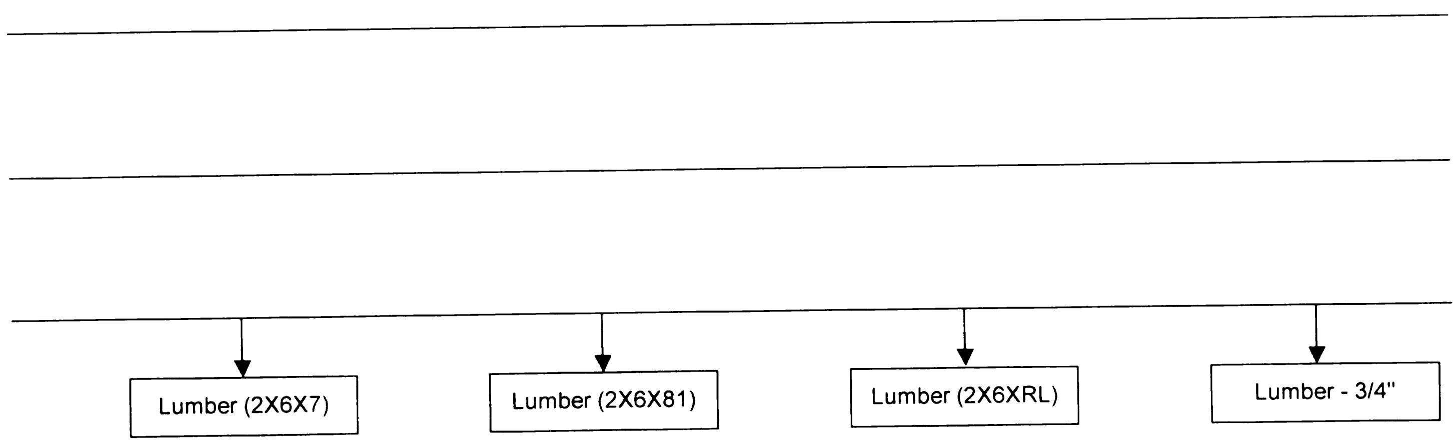

Figure B1f: Product Tree Structure for Wall Cluster

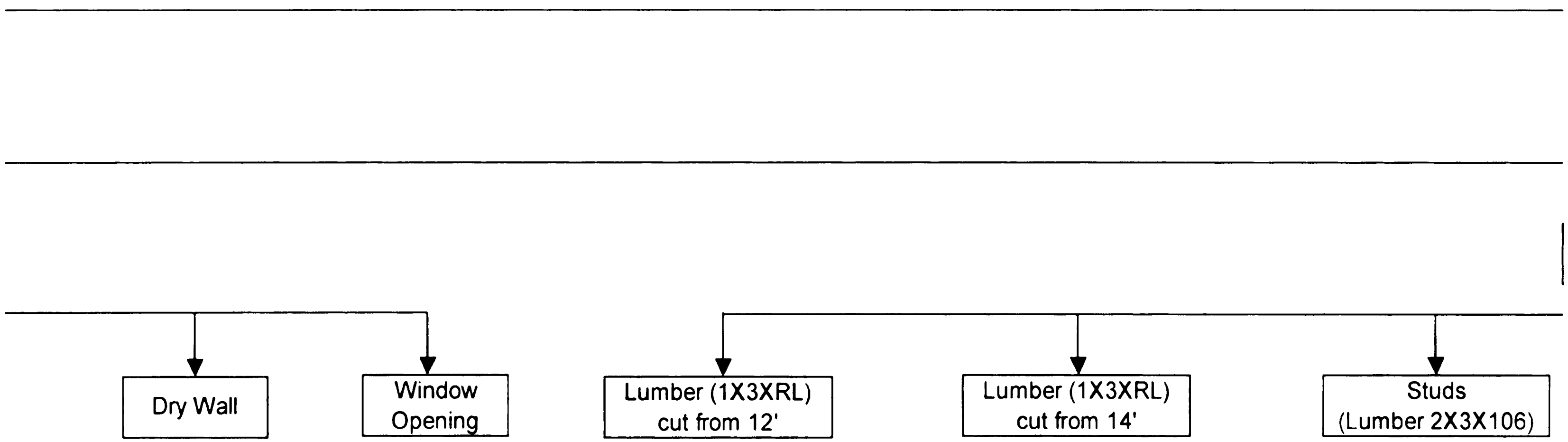

Figure B1g: Product Tree Structure for Wall Cluster

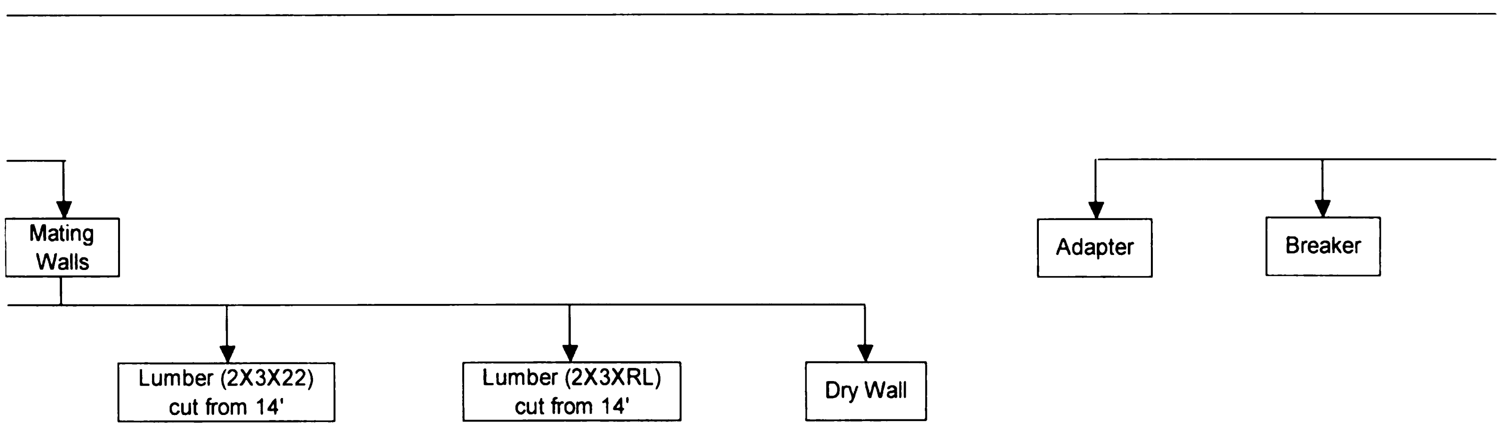

Figure B1h: Product Tree Structure for Wall Cluster

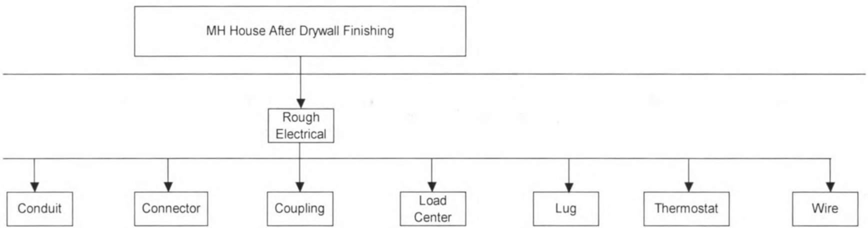

Figure B1i: Product Tree Structure for Wall Cluster

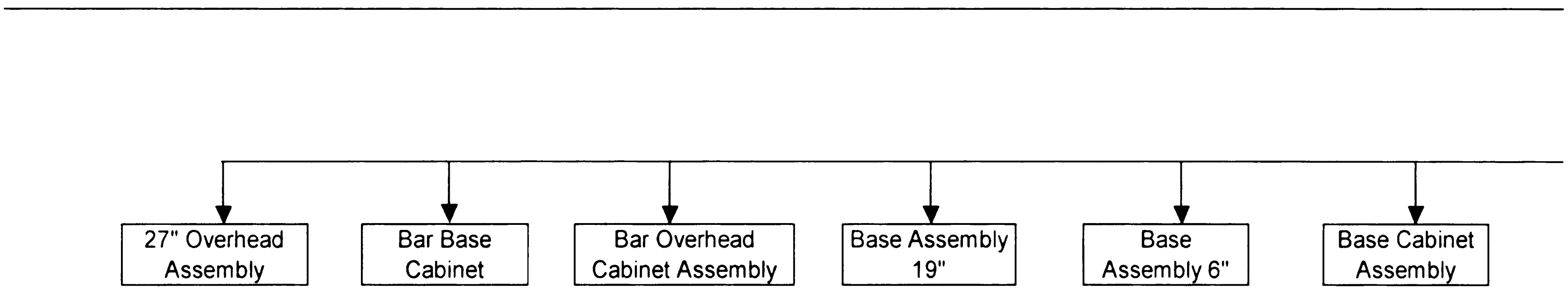

Figure B1j: Product Tree Structure for Wall Cluster

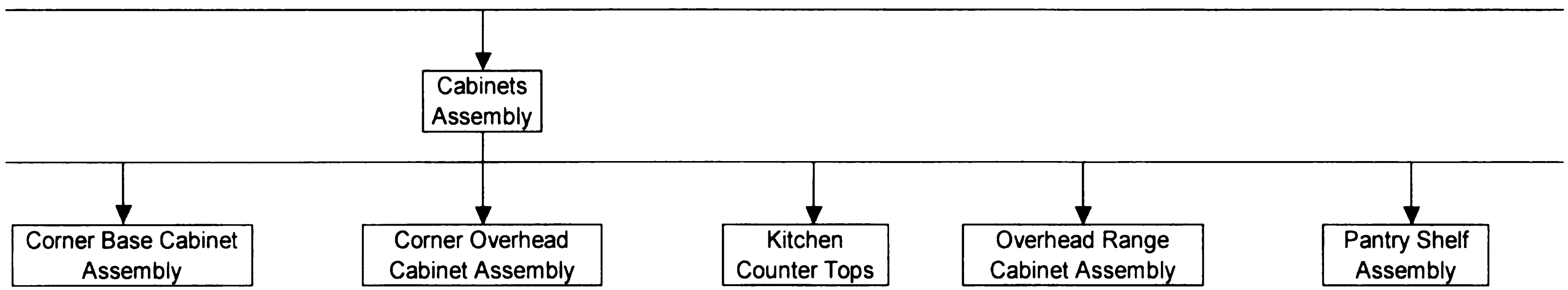

Figure B1k: Product Tree Structure for Wall Cluster

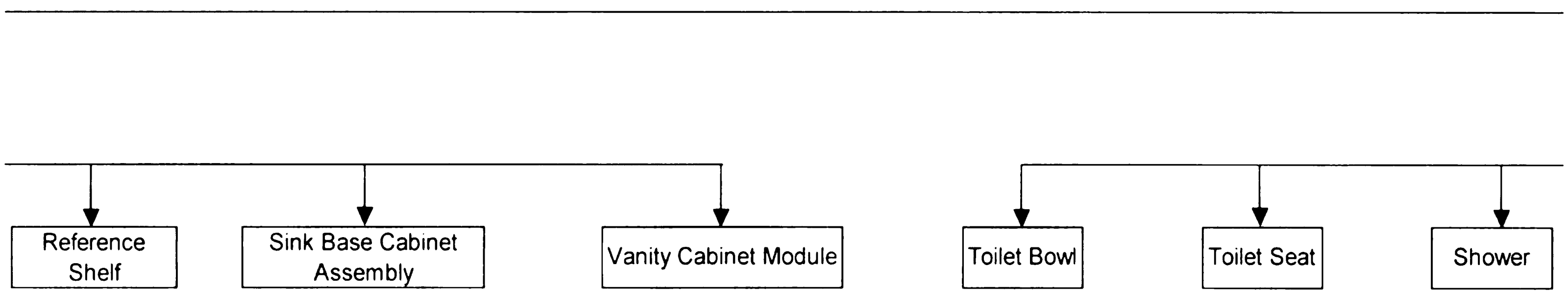

Figure B1I: Product Tree Structure for Wall Cluster

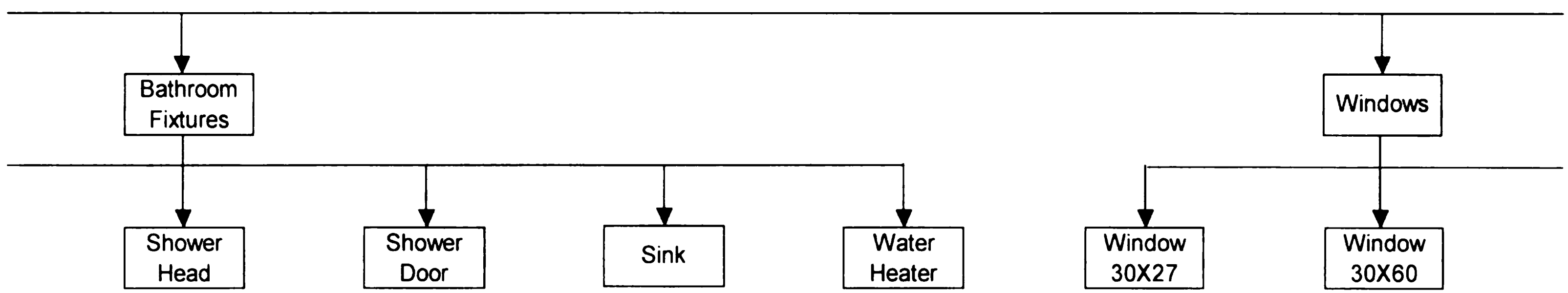

Figure B1m: Product Tree Structure for Wall Cluster

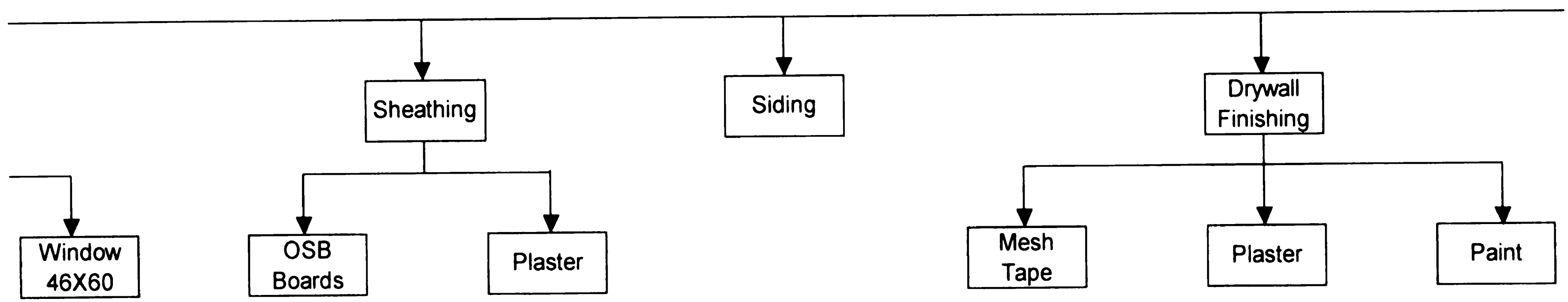

Figure B1n: Product Tree Structure for Wall Cluster

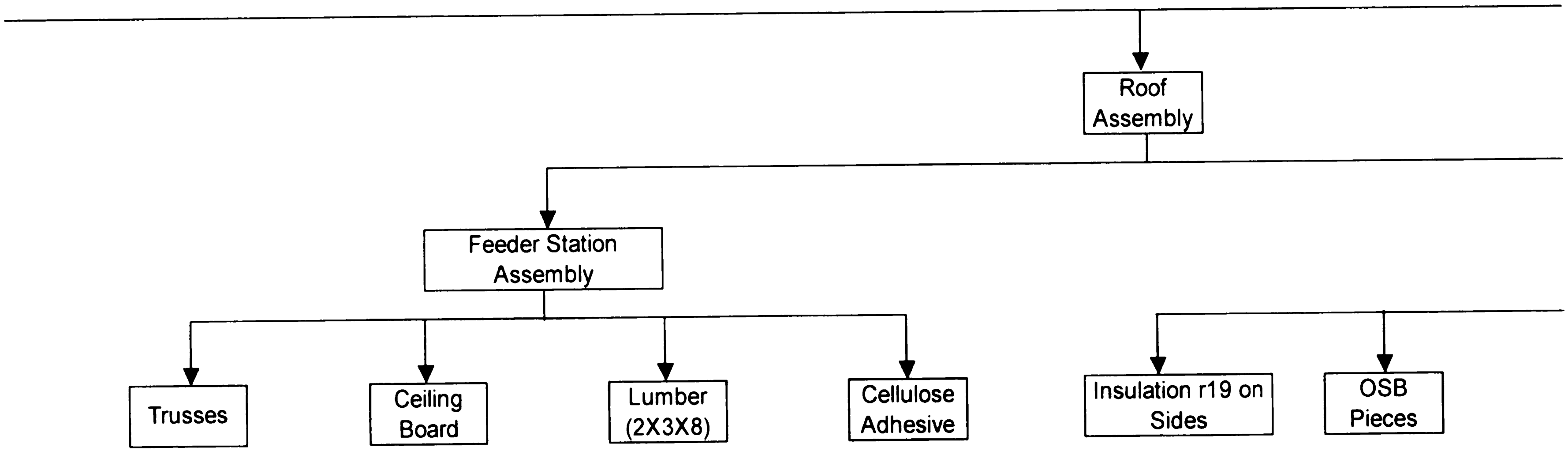

Figure B1o: Product Tree Structure for Wall Cluster

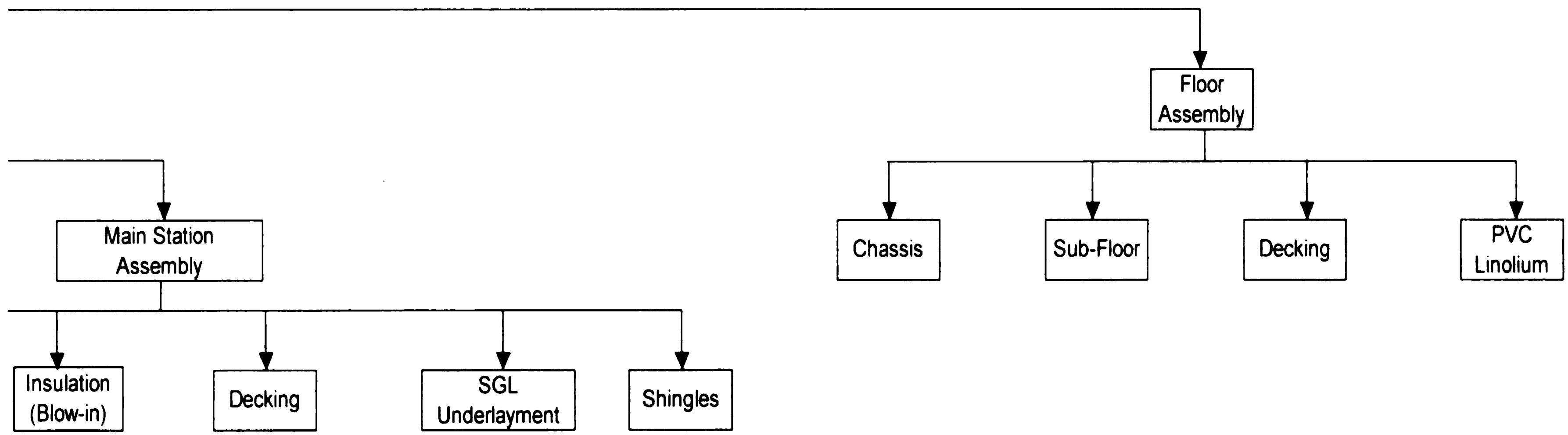

Figure B1p: Product Tree Structure for Wall Cluster

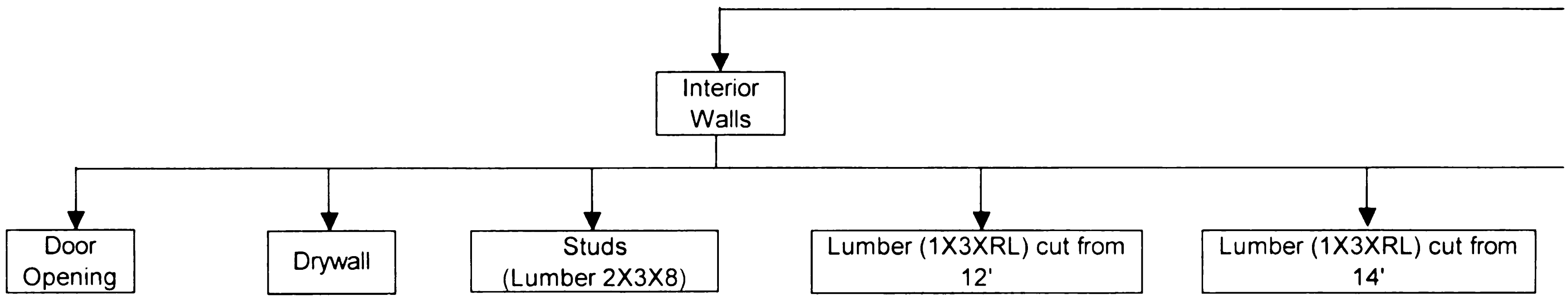

Figure B2a: New Product Tree Structure for Wall Cluster

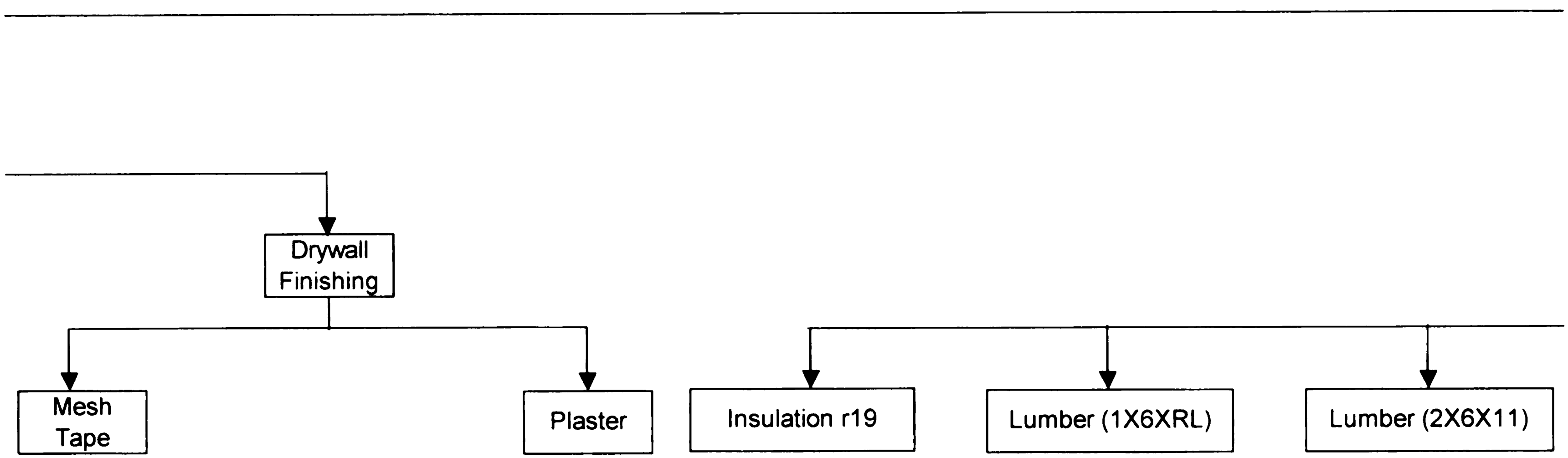

Figure B2b: New Product Tree Structure for Wall Cluster

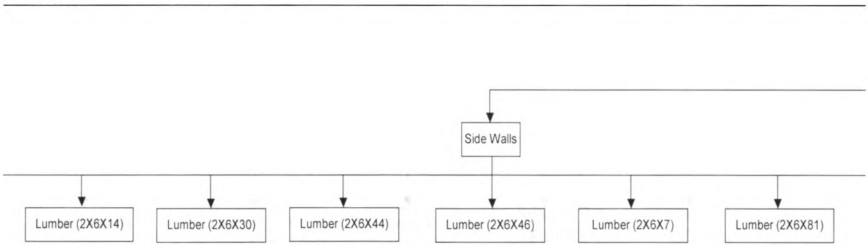

Figure B2c: New Product Tree Structure for Wall Cluster

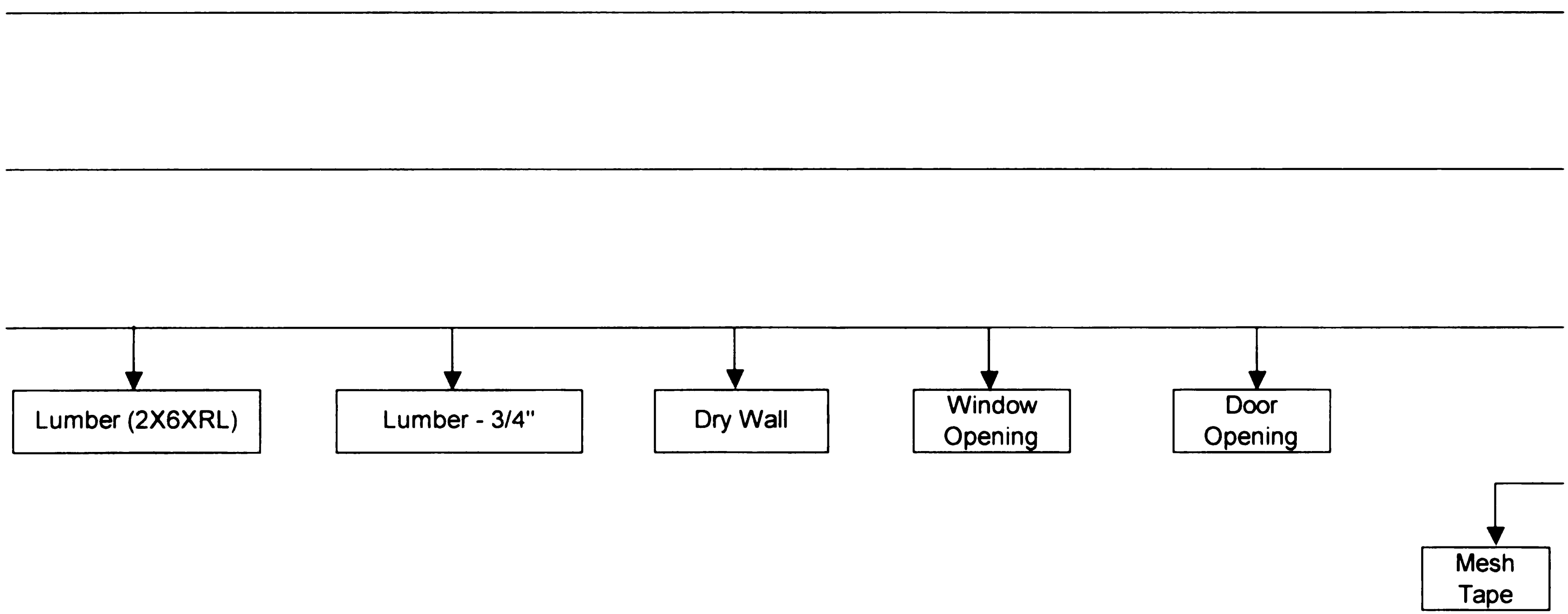

Figure B2d: New Product Tree Structure for Wall Cluster

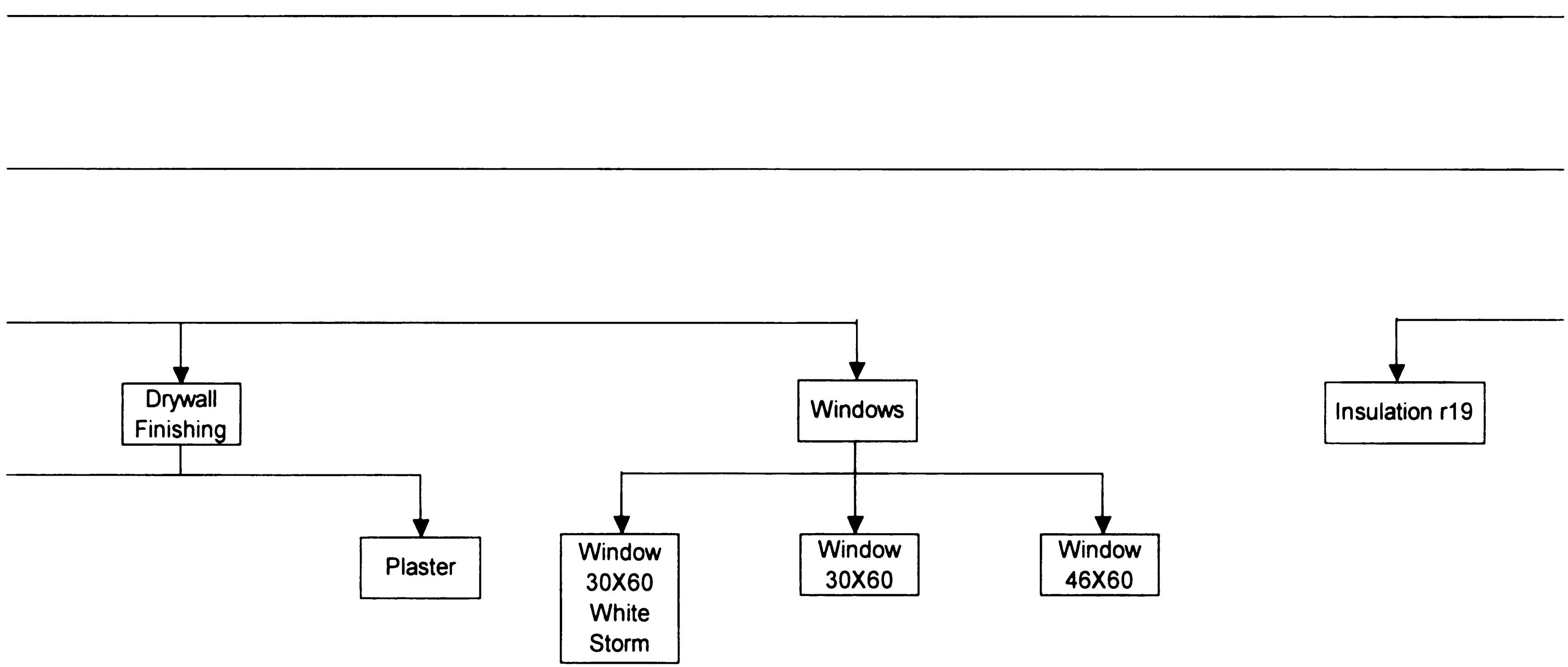

Figure B2e: New Product Tree Structure for Wall Cluster

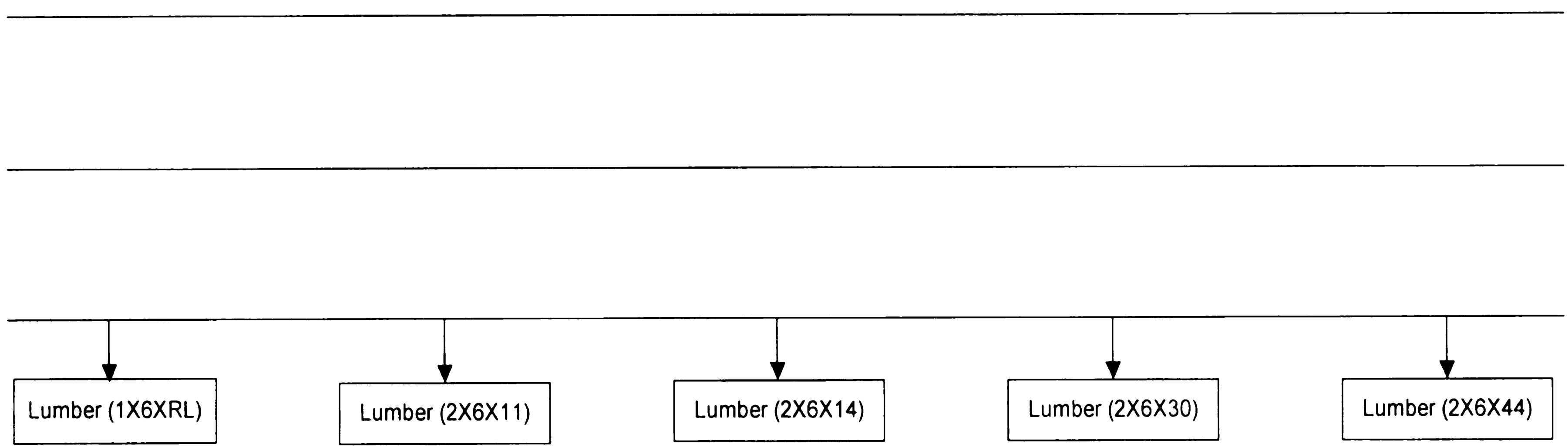

Figure B2f: New Product Tree Structure for Wall Cluster

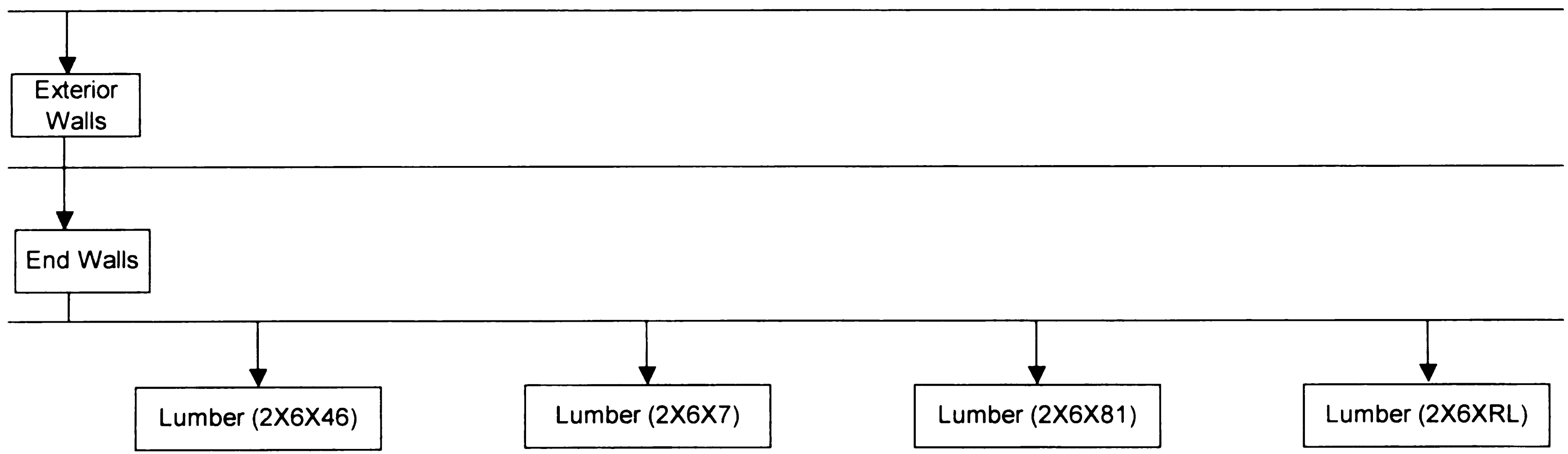

Figure B2g: New Product Tree Structure for Wall Cluster

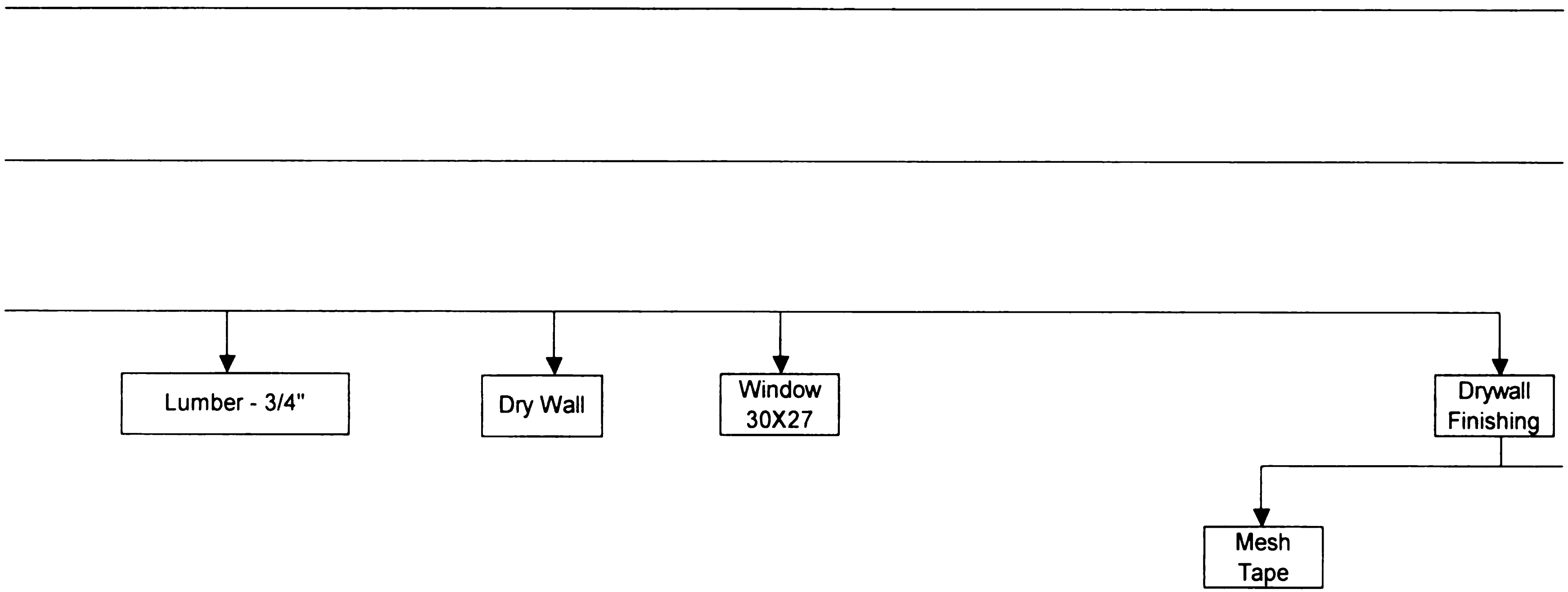

Figure B2h: New Product Tree Structure for Wall Cluster

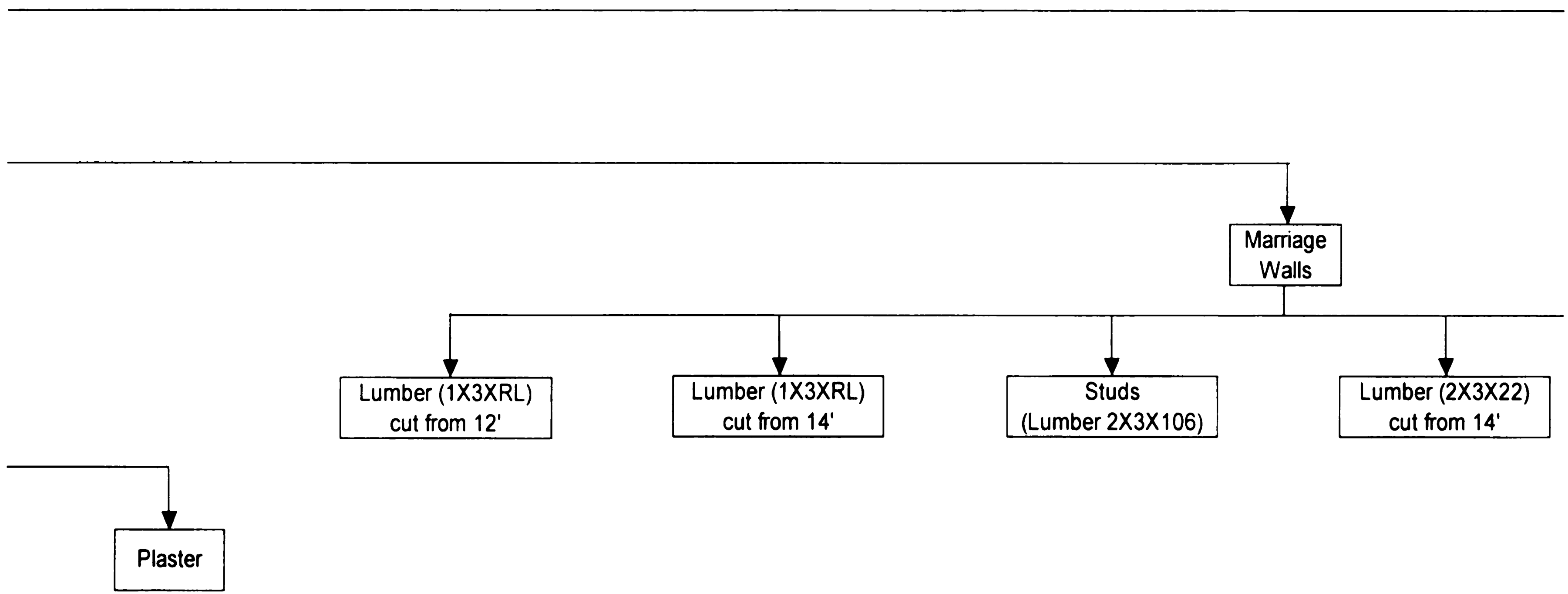

Figure B2i: New Product Tree Structure for Wall Cluster

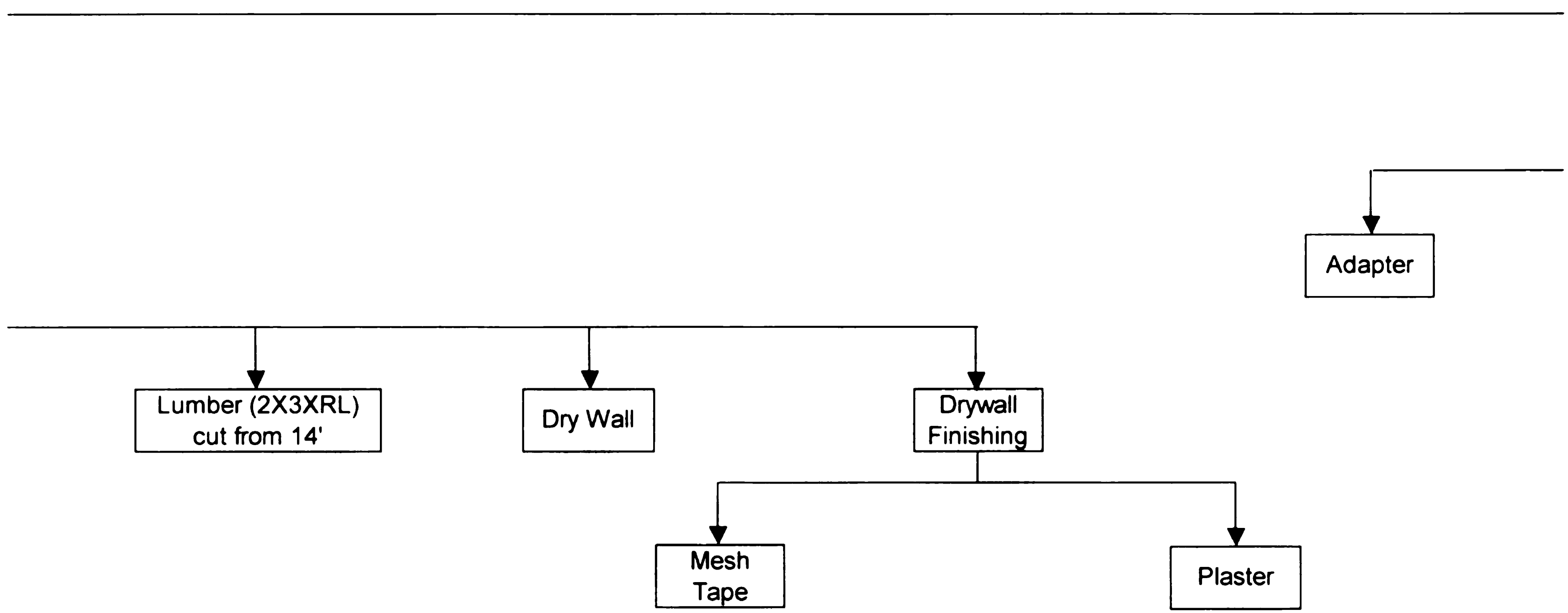

Figure B2j: New Product Tree Structure for Wall Cluster

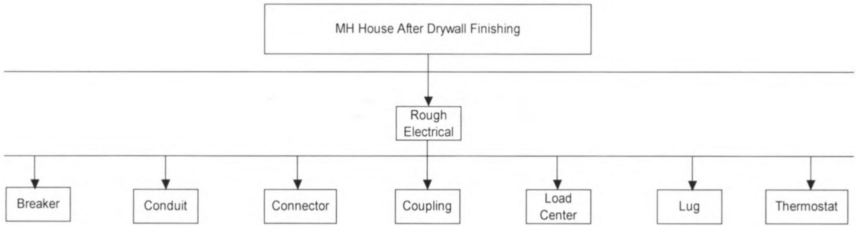

Figure B2k: New Product Tree Structure for Wall Cluster

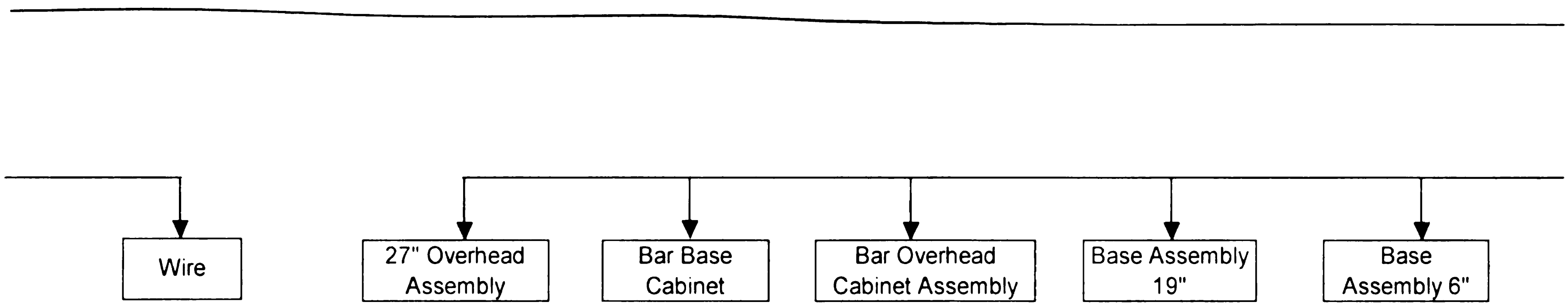

Figure B2I: New Product Tree Structure for Wall Cluster

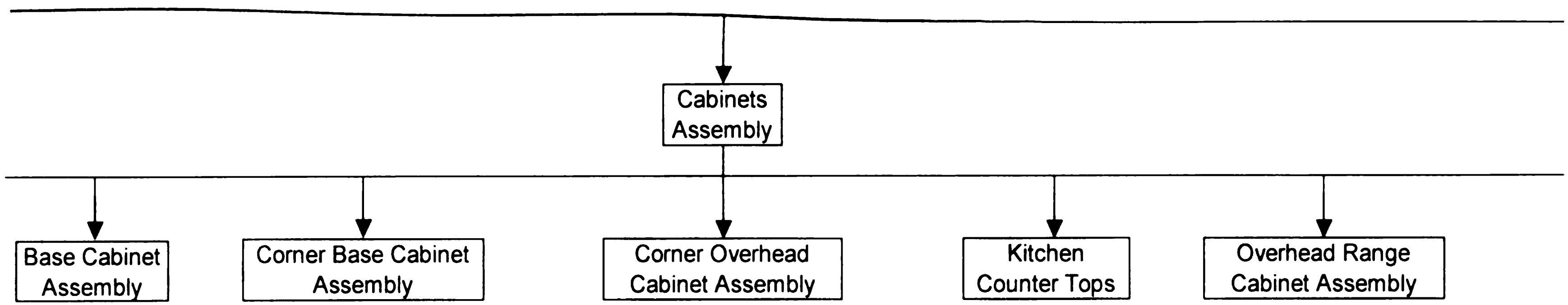

Figure B2m: New Product Tree Structure for Wall Cluster

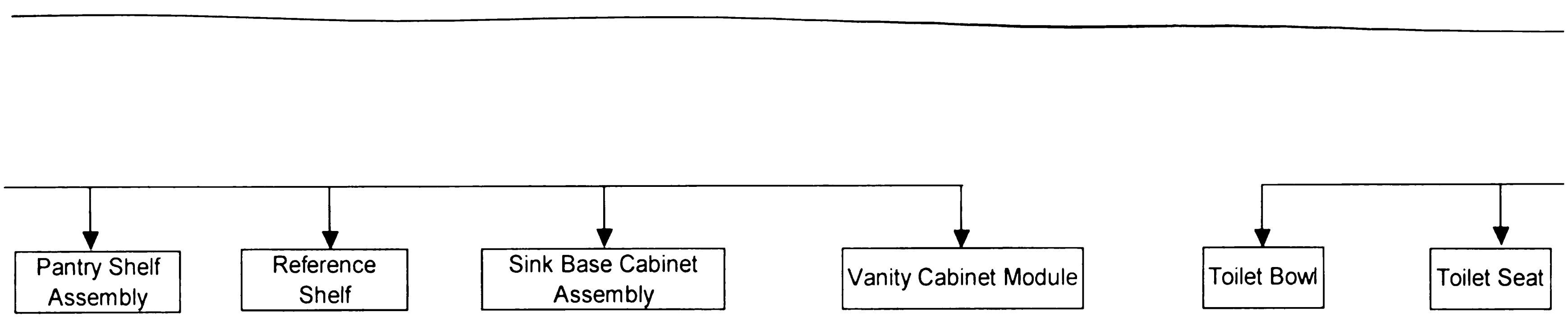

Figure B2n: New Product Tree Structure for Wall Cluster

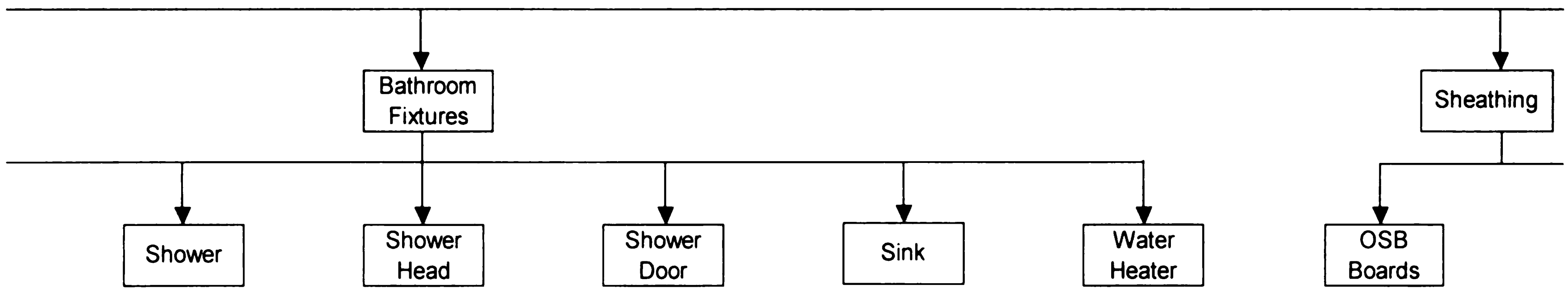

Figure B2o: New Product Tree Structure for Wall Cluster

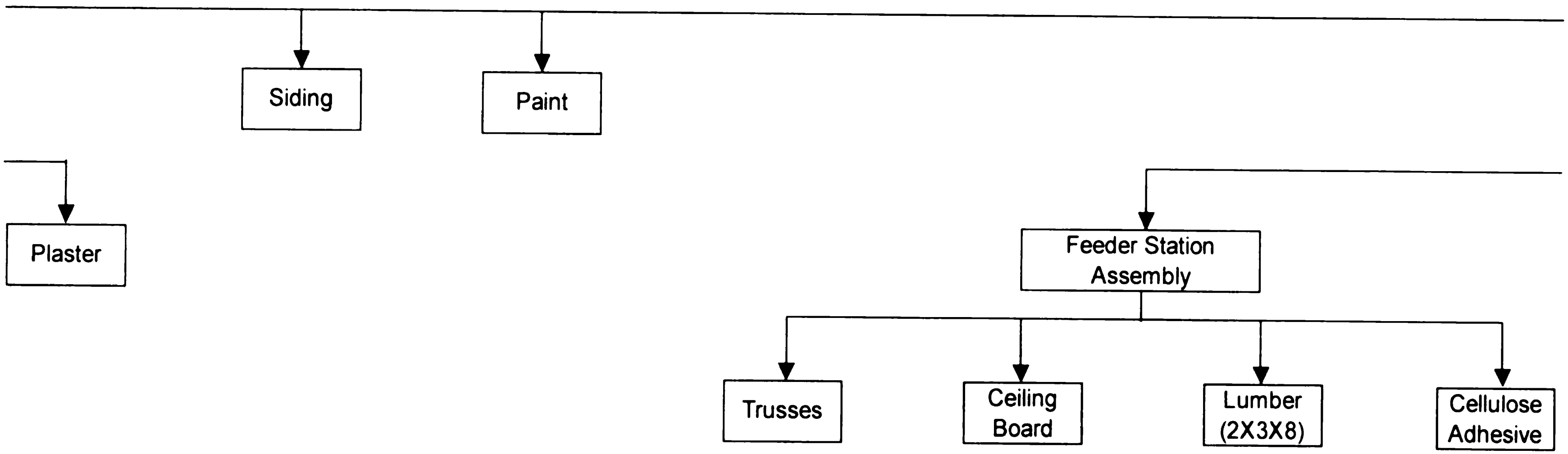

Figure B2p: New Product Tree Structure for Wall Cluster

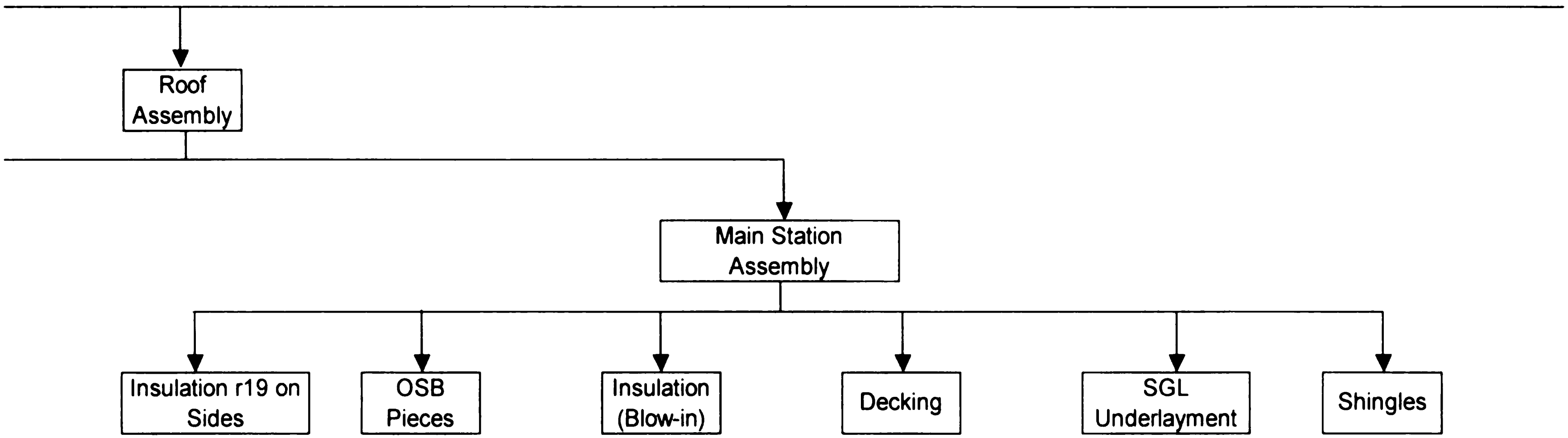

Figure B2q: New Product Tree Structure for Wall Cluster

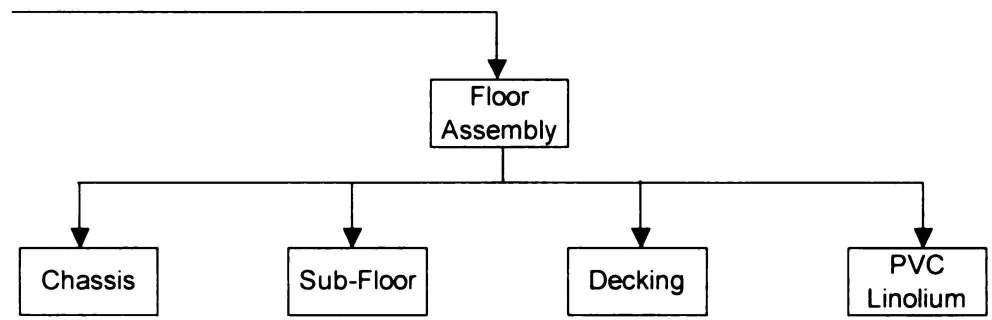

Figure B2r: New Product Tree Structure for Wall Cluster

APPENDIX-C

LIST OF ACTIVITIES AND PRECEDENCE DIAGRAMS FOR WALL CLUSTER

Table C1: List of Activities in Wall Cluster

Activity Number	Description
1	Bring Floor Assembly with Bathroom Fixtures in Interior Walls Station
2	Attach Lumbers to construct Interior Wall Frames
3	Allign and Attach Drywall on one side of Interior Wall Frame
4	Cut the Drywall for Interior Doors and Windows Openings
5	Transfer the Interior Wall to the Electric Hoist
6	Transfer the Interior Wall to the Floor Assembly/Chassis
7	Cut Holes in Interior Walls for Wiring
8	Attach the Interior Walls to the Floor
9	Attach the Interior Walls to other Interior Walls
10	Attach Drywall on the other side of Interior Wall Frame
11	Move the Floor with Interior Walls to the Exterior Walls Station
12	Bring the Floor with Interior Walls into the Exterior Walls Station
13	Attach Lumbers to construct Side Wall Frames
14	Spread Insulation on Side Wall
15	Allign and Attach Drywall on one side of Side Wall Frame
16	Cut the Side Drywall for Doors and Windows Openings
17	Transfer the Side Wall to the Floor Assembly with Interior Walls
18	Attach Lumbers to construct End Wall Frames
19	Spread Insulation on End Wall
20	Allign and Attach Drywall on one side of End Wall Frame
21	Cut the End Drywall for Doors and Windows Openings
22	Transfer the End Wall to the Floor Assembly with Interior Walls
23	Attach Lumbers to construct Marriage Walls Frames
24	Allign and Attach Drywall on one side of Marriage Wall Frame
25	Cut the Marriage Drywall for Doors and Windows Openings
26	Transfer the Marriage Wall to the Floor Assembly with Interior Walls
27	Bring the Side Wall to the Floor Assembly with Interior Walls
28	Bring the End Wall to the Floor Assembly with Interior Walls
29	Bring the Marriage Wall to the Floor Assembly with Interior Walls
30	Attach the Side Walls to the Floor Assembly with Interior Walls
31	Attach the End Walls to the Floor Assembly with Interior Walls
32	Attach the Marriage Walls to the Floor Assembly with Interior Walls
33	Attach Side Walls, End Walls and Marriage Walls
34	Move the Section With Wall Assembly to the Marriage Wall Station
35	Bring the Section with Wall Assembly to the Marriage Station
36	Attach the Two Floor Sections of a House
37	Move the House to the Roofing Station
38	Bring the House to the Roofing Assembly Station
39	Install Electrical Work in Walls
40	Install Wall Sheathing
41	Transfer the Roof Assembly from Feeder Station to Main Station
42	Attach the Roof Assembly to End and Side Walls
43	Spread Insulation on Roof Assembly
44	Attach Roof Decking
45	Install Windows
46	Install Siding
47	Cover the Roof Decking with SGL Underlayment Paper
48	Install Shingles
49	Separate the House into Two Sections
50	Move the Completed Section from the Roofing Station to Finishes Station
51	Bring the Section into Finshes Station
52	Primary Drywall Finishing (First Coat)
53	Secondary Drywall Finishing (Second Coat)
54	Final Drywall Finishing (Sanding and Painting)
55	Cleaning

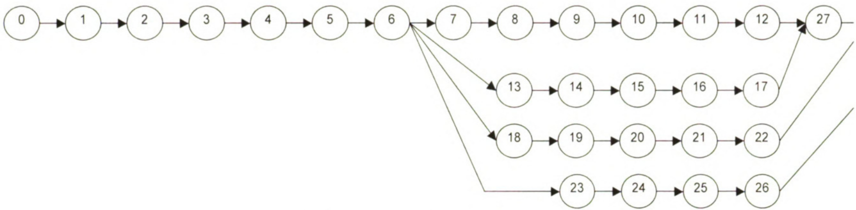

Figure: C1a: Precedence Diagram for Wall Cluster

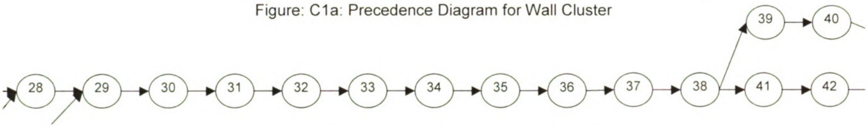

Figure: C1b: Precedence Diagram for Wall Cluster

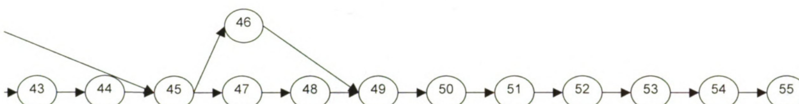

Figure: C1c: Precedence Diagram for Wall Cluster

Table C2: List of New Activities for Wall Cluster

Activity Number	Description
1	Bring Floor Assembly with Bathroom Fixtures in Interior Walls Station
2	Attach Lumbers to construct Interior Wall Frames
3	Allign and Attach Drywall on one side of Interior Wall Frame
4	Cut the Drywall for Interior Doors and Windows Openings
5	Transfer the Interior Wall to the Electric Hoist
6	Transfer the Interior Wall to the Floor Assembly/Chassis
7	Cut Holes in Interior Walls for Wiring
8	Attach the Interior Walls to the Floor
9	Attach the Interior Walls to other Interior Walls
10	Attach Drywall on the other side of Interior Wall Frame
11	Move the Floor with Interior Walls to the Exterior Walls Station
12	Bring the Floor with Interior Walls into the Exterior Walls Station
13	Attach Lumbers to construct Side Wall Frames
14	Spread Insulation on Side Wall
15	Allign and Attach Drywall on one side of Side Wall Frame
16	Cut the Side Drywall for Doors and Windows Openings
17	Transfer the Side Wall to the Floor Assembly with Interior Walls
18	Spread Insulation on End Wall
19	Attach Lumbers to construct End Wall Frames
20	Allign and Attach Drywall on one side of End Wall Frame
21	Cut the End Drywall for Doors and Windows Openings
22	Transfer the End Wall to the Floor Assembly with Interior Walls
23	Attach Lumbers to construct Marriage Walls Frames
24	Allign and Attach Drywall on one side of Marriage Wall Frame
25	Cut the Marriage Drywall for Doors and Windows Openings
26	Transfer the Marriage Wall to the Floor Assembly with Interior Walls
27	Bring the Side Wall to the Floor Assembly with Interior Walls
28	Bring the End Wall to the Floor Assembly with Interior Walls
29	Bring the Marriage Wall to the Floor Assembly with Interior Walls
30	Attach the Side Walls to the Floor Assembly with Interior Walls
31	Attach the End Walls to the Floor Assembly with Interior Walls
32	Attach the Marriage Walls to the Floor Assembly with Interior Walls
33	Attach Side Walls, End Walls and Marriage Walls
34	Move the Section With Wall Assembly to the Marriage Wall Station
35	Bring the Section with Wall Assembly to the Marriage Station
36	Attach the Two Floor Sections of a House
37	Move the House to the Roofing Station
38	Bring the House to the Roofing Assembly Station
39	Install Electrical Work in Walls
40	Install Wall Sheathing
41	Install Siding
42	Transfer the Roof Assembly from Feeder Station to Main Station
43	Attach the Roof Assembly to End and Side Walls
44	Spread Insulation on Roof Assembly
45	Attach Roof Decking
46	Cover the Roof Decking with SGL Underlayment Paper
47	Install Shingles
48	Separate the House into Two Sections
49	Move the Completed Section from the Roofing Station to Finishes Station
50	Bring the Section into Finshes Station
51	Final Drywall Finishing (Sanding and Painting)
52	Cleaning
P1, P2, P3, P4	Primary Drywall Finishing (First Coat)
S1, S2, S3, S4	Secondary Drywall Finishing (Second Coat)
W1, W2	Install Windows

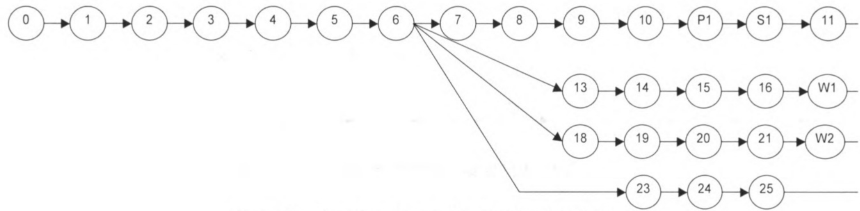

Figure C2a: New Precedence Diagram for Wall Cluster

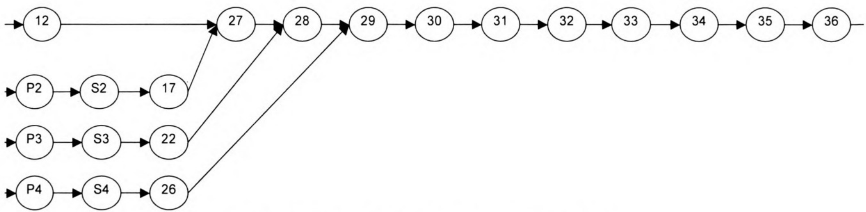

Figure C2b: New Precedence Diagram for Wall Cluster

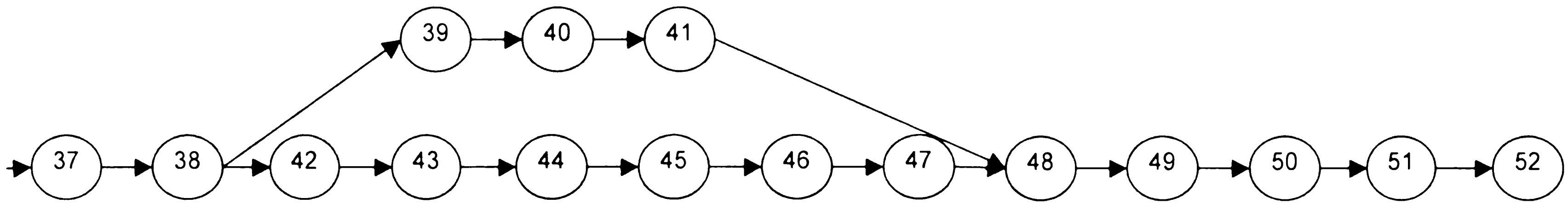

Figure C2c: New Precedence Diagram for Wall Cluster

APPENDIX-D

DATA SETS FOR SIMULATION MODELS

Table D1a: Floor Cluster Data Set

Chassis Station Cycle Times in Minutes

Activity Number	Activity	1	2	3	4	5	6	7	8	9	Average
1	Bring Chassis into the Station	3.77	2.2	3.23	3.08	2.93	2.78	2.17	2.82	6.93	3.323333
2	Load Chassis Frame on Electric Hoist	3.69	3.88	5.2	2.05	2.3	1.12	1.25	0.78	5.57	2.871111
3	Move the Electric Hoist Up	2.35	0.52	4.13	4.12	3.8	1.01	0.63	0.87	2.1	2.17
4	Allign Main Axle Below Chassis Frame	2.58	0.78	1.7	0.43	1.4	1.13	0.52	0.7	3.02	1.362222
5	Lower Chassis Frame over Main Axle	2.83	1	3.53	1.17	2.17	1.75	0.38	1.35	2.53	1.856667
6	Attach Main Axle with Chassis Frame	9.38	3.9	15.67	3.17	20.15	4.38	3.77	5.18	18.65	9.361111
7	Move the Electric Hoist Up with Axle Attached	0.52	4.25	11.53	6.8	0.57	1.03	0.42	1.05	1.77	3.104444
8	Attach Tires to Main Axle	9.98	9.83	8.72	11.4	9.08	6.01	5.22	11.68	11.45	9.263333
9	Lower the Chassis Frame with Complete Assembly	0.65	4.33	1.68	5.97	0.43	1.6	0.32	0.47	5.33	2.308889
10	Run Basic Electrical	10.62	2.2	1.43	1.03	2.12	3.67	5.45	1.75	2.27	3.393333
11	Remove Chassis from Station	15.42	3.03	3.62	4.4	3.78	0.48	1.45	6.48	2.58	4.582222

Table D1b: Floor Cluster Data Set

Sub-Floor Station Cycle Times in Minutes

Activity Number	Activity	1	2	3	4	5	6	7	8	9	Average
12	Attach Lumber with Braces to Build Band Joist	8.21	9.65	7.24	7.5	6.9	8.98	9.76	8.45	7.8	8.276667
13	Allign Band Joists at the Extremes of Station	1.23	1	1.42	1.16	1.08	1.88	1.65	2.1	1.48	1.444444
14	Bring Chassis into the Station	2.46	2.32	1.2	2.42	2.25	2.87	2.58	2.61	1.52	2.247778
15	Spread Plastic Membrane over Chassis	1.68	1.75	2.07	1.35	1.87	1.6	1.72	1.56	3.5	1.9
16	Spread Insulation	1.46	1.67	1.5	1.37	1.5	1.8	2.1	1.32	2.75	1.718889
17	Put Rough Plumbing System and Rough HVAC	2.91	2.72	2.7	3.5	2.28	2.93	2.61	2.78	1.58	2.667778
18	Attach Lumber to Build Headers	5.61	6.2	5.25	5.35	3.62	5.9	4.28	5.8	3.5	5.056667
19	Put Headers onto the Chassis	12.82	13.47	14.1	12.62	11.02	10.42	8.5	11.58	15	12.17
20	Spread Joists over Chassis	2.51	1.45	1.57	2.07	0.72	2.12	2.07	1.52	4.25	2.031111
21	Attach Band Joists and Joists & Headers	6.92	4.52	4.2	5.15	3.24	8.75	6.18	5.14	4	5.344444
23	Atach HVAC ducts to form HVAC System	12.82	10.77	14.38	7.67	10.03	16	12.12	12.25	12.15	12.02111
22	Put Insulation on Sides	13.65	13.08	7.77	9.9	6.3	7.53	8.61	9.2	9.43	9.496667
24	Attach Plastic Membrane with Band Joist	3.16	4.25	2.75	3.6	2.56	1.56	2.3	2.51	2.42	2.79
25	Remove Sub-Floor from Station	2.65	2.45	3.78	2.88	3	1.5	2.15	2.42	2.35	2.575556

Table D1c: Floor Cluster Data Set

Decking Station Cycle Times in Minutes

Activity Number	Activity	1	2	3	4	5	6	7	8	9	Average
26	Bring Sub-Floor into the Station	2.65	1.58	2.9	2.56	2.92	3.64	2.48	2.42	3.7	2.761111
27	Set Insulation	2.2	3.7	2.3	2.88	2.63	2.81	1.3	4.18	3.52	2.835556
28	Put Glue over Band Joist	1.8	1.7	1.73	2	1.82	2.6	1.51	2.58	2.22	1.995556
29	Spread Glue over Joists	3.08	2.5	3.73	4.53	3.84	3.81	2.72	3.12	2.59	3.324444
30	Spread Floor Decking on the Sub-Floor	1.6	2.13	5.9	5.18	4.6	5.38	3.6	5.69	5.4	4.386667
31	Mark and Cut Holes for HVAC and Plumbing	4.8	3.78	9.25	6.58	8.91	5.2	3.98	4.6	8.43	6.17
32	Get the Plumbing out	2.2	2.1	2.5	1.8	1.83	2.2	2.62	2.45	1.78	2.164444
33	Attach Floor Decking to Sub-Floor	7	7.85	14.06	21.1	15.12	14.89	10.53	13.56	11.12	12.80333
34	Bring out HVAC	8	4.63	7.38	18.38	12.36	10.16	9.18	16.1	16.13	11.36889
35	Attach Chassis to Sub-Floor	4.85	6.33	7.52	9.6	7.63	5.8	6.59	7.18	7.57	7.007778
36	Move the Floor to the next Station	5.36	6.31	7.6	5.34	6.36	8.58	7.42	8.65	8.96	7.175556
37	Attach PVC Linolium	7.25	6.1	6.2	7.21	6.35	7.1	6.5	6.87	6.58	6.684444

Table D2a: New Floor Cluster Data Set

Chassis Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
1	Bring Chassis into the Station	3.77	2.2	3.23	3.08	2.93	2.78	2.17	2.82	6.93	3.323333
2	Load Chassis Frame on Electric Hoist	3.69	3.88	5.2	2.05	2.3	1.12	1.25	0.78	5.57	2.871111
3	Move the Electric Hoist Up	2.35	0.52	4.13	4.12	3.8	1.01	0.63	0.87	2.1	2.17
4	Allign Main Axle with Tires Below Chassis Frame	2.58	0.78	1.7	0.43	1.4	1.13	0.52	0.7	3.02	1.362222
5	Lower Chassis Frame over Main Axle and Tires Assembly	2.83	1	3.53	1.17	2.17	1.75	0.38	1.35	2.53	1.856667
6	Attach Main Axle and Tires Assembly with Chassis Frame	9.38	3.9	15.67	3.17	20.15	4.38	3.77	5.18	18.65	9.361111
7	Run Basic Electrical	10.62	2.2	1.43	1.03	2.12	3.67	5.45	1.75	2.27	3.393333
8	Remove Chassis from Chassis Station	15.42	3.03	3.62	4.4	3.78	0.48	1.45	6.48	2.58	4.582222

Table D2b: New Floor Cluster Data Set

Sub-Floor Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
9	Bring Chassis into the Sub-Floor Station	2.46	2.32	1.2	2.42	2.25	2.87	2.58	2.61	1.52	2.247778
10	Spread Plastic Membrane over Chassis	1.68	1.75	2.07	1.35	1.87	1.6	1.72	1.56	3.5	1.9
11	Spread Insulation	1.46	1.67	1.5	1.37	1.5	1.8	2.1	1.32	2.75	1.718889
12	Put Rough Plumbing System and Rough HVAC	2.91	2.72	2.7	3.5	2.28	2.93	2.61	2.78	1.58	2.667778
13	Atach HVAC ducts to form HVAC System	12.82	10.77	14.38	7.67	10.03	16	12.12	12.25	12.15	12.02111
14	Put Insulation on Sides	13.65	13.08	7.77	9.9	6.3	7.53	8.61	9.2	9.43	9.496667
15	Attach Plastic Membrane with Band Joist	3.16	4.25	2.75	3.6	2.56	1.56	2.3	2.51	2.42	2.79
16	Remove Sub-Floor from Station	2.65	2.45	3.78	2.88	3	1.5	2.15	2.42	2.35	2.575556
2a	Attach Lumber with Braces to Build Band Joist	8.21	9.65	7.24	7.5	6.9	8.98	9.76	8.45	7.8	8.276667
2b	Allign Band Joists at the Extremes of Station	1.23	1	1.42	1.16	1.08	1.88	1.65	2.1	1.48	1.444444
2c	Put Headers onto the Sub-Floor Station	12.82	13.47	14.1	12.62	11.02	10.42	8.5	11.58	15	12.17
2d	Spread Joists over Sub-Floor Station	2.51	1.45	1.57	2.07	0.72	2.12	2.07	1.52	4.25	2.031111
2e	Attach Band Joists and Joists & Headers to Form an Assembly	6.92	4.52	4.2	5.15	3.24	8.75	6.18	5.14	4	5.344444
2f	Lift Sub-Floor Assembly, Slide Chassis Below it, Lower Sub-Floor	8.87	5.4	12.86	7.34	8.27	3.88	2.26	3	10.2	6.897778

Table D2c: New Floor Cluster Data Set

Decking Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
17	Bring Sub-Floor into the Station	2.65	1.58	2.9	2.56	2.92	3.64	2.48	2.42	3.7	2.761111
18	Set Insulation	2.2	3.7	2.3	2.88	2.63	2.81	1.3	4.18	3.52	2.835556
19	Put Glue over Band Joist	1.8	1.7	1.73	2	1.82	2.6	1.51	2.58	2.22	1.995556
20	Spread Glue over Joists	3.08	2.5	3.73	4.53	3.84	3.81	2.72	3.12	2.59	3.324444
21	Spread Floor Decking on the Sub-Floor	1.6	2.13	5.9	5.18	4.6	5.38	3.6	5.69	5.4	4.386667
22	Mark and Cut Holes for HVAC and Plumbing	4.8	3.78	9.25	6.58	8.91	5.2	3.98	4.6	8.43	6.17
23	Get the Plumbing out	2.2	2.1	2.5	1.8	1.83	2.2	2.62	2.45	1.78	2.164444
24	Attach Floor Decking to Sub-Floor	7	7.85	14.06	21.1	15.12	14.89	10.53	13.56	11.12	12.80333
25	Bring out HVAC	8	4.63	7.38	18.38	12.36	10.16	9.18	16.1	16.13	11.36889
26	Attach Chassis to Sub-Floor	4.85	6.33	7.52	9.6	7.63	5.8	6.59	7.18	7.57	7.007778
27	Move the Floor to the next Station	5.36	6.31	7.6	5.34	6.36	8.58	7.42	8.65	8.96	7.175556
28	Attach PVC Linolium to Floor Decking	7.25	6.1	6.2	7.21	6.35	7.1	6.5	6.87	6.58	6.684444

Table D2d: New Floor Cluster Data Set

Controlling Path Calclation

Path	Average
2a-2b-2c-2d-2e	29.26667
1-2-3-5-6-7-8	27.55778
2f	6.897778
9-10-11	5.866667

Table D3a: Wall Cluster Data Set

Interior Walls Feeder Station (For 1 Wall)

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
1	Bring Floor Assembly with Bathroom Fixtures in Interior Walls Station	0.7	0.8	0.8	0.6	0.6	0.5	0.2	0.8	0.5	0.611111
2	Attach Lumbers to construct Interior Wall Frames	1.8	1.8	2.4	1.5	1.6	1.4	2.5	2.6	1.9	1.944444
3	Allign and Attach Drywall on one side of Interior Wall Frame	1.2	1.5	1.5	1.4	1.1	1.6	1.9	2	1	1.466667
4	Cut the Drywall for Interior Doors and Windows Openings	1.9	1.8	2.05	1.3	1.5	1	1.3	2.8	1.2	1.65
5	Transfer the Interior Wall to the Electric Hoist	0.5	0.3	0.3	0.8	0.4	0.3	0.4	0.4	0.5	0.433333

Table D3b: Wall Cluster Data Set

Interior Walls Main Station (Times are for 1 section)

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
6	Transfer the Interior Wall to the Floor Assembly/Chassis	0.7	0.5	0.6	0.8	0.9	0.5	0.4	0.5	0.7	0.622222
7	Cut Holes in Interior Walls for Wiring	2.3	5.5	1.8	1.6	2.7	2.4	6	3	8	3.7
8	Attach the Interior Walls to the Floor	6.8	4.2	2.8	3.5	2.4	2.7	6.6	7.8	5.6	4.711111
9	Attach the Interior Walls to other Interior Walls	6.2	4.8	6.6	7.8	8.6	6	12	10	15	8.555556
10	Attach Drywall on the other side of Interior Wall Frame	20	16	15	24	18	16	15	12	21	17.44444
11	Move the Floor with Interior Walls to the Exterior Walls Station	2	3	4	3	2	1	2	3	5	2.777778

Table D3c: Wall Cluster Data Set

Side Walls Feeder Station (For 1 Wall)

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
13	Attach Lumbers to construct Side Wall Frames	0.8	0.7	0.4	0.7	0.4	0.4	0.6	0.5	0.4	0.544444
14	Spread Insulation on Side Wall	1.1	1.5	2.5	1.1	1.6	0.9	1.7	1	1.2	1.4
15	Allign and Attach Drywall on one side of Side Wall Frame	0.9	0.5	1	0.7	0.8	0.4	0.6	0.6	0.7	0.688889
16	Cut the Side Drywall for Doors and Windows Openings	9	14	17	9	8	17	12	5	10	11.22222
17	Transfer the Side Wall to the Floor Assembly with Interior Walls	1.7	2	1.6	1.4	1.5	1.7	1.8	1.5	1.5	1.633333

Table D3d: Wall Cluster Data Set

End Walls Feeder Station (For 1 Wall)

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
18	Attach Lumbers to construct End Wall Frames	2.4	0.9	1.5	1.2	1.8	1.7	1.2	0.8	1.7	1.466667
19	Spread Insulation on End Wall	0.6	0.7	1.5	0.9	1.2	1.2	1	1.8	2	1.211111
20	Allign and Attach Drywall on one side of End Wall Frame	1.7	1.2	1	1.6	3	3	1.5	1.8	1.8	1.844444
21	Cut the End Drywall for Doors and Windows Openings	5	8	8	7	14	14	8	18	8	10
22	Transfer the End Wall to the Floor Assembly with Interior Walls	2	2	6	2	2	3	3	4	5	3.222222

Table D3e: Wall Cluster Data Set

Marriage Walls Feeder Station (For 1 Wall)

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
23	Attach Lumbers to construct Marriage Walls Frames	0.9	1.5	0.8	1.4	1	8	1.5	1	1.8	1.988889
24	Allign and Attach Drywall on one side of Marriage Wall Frame	1.1	4.1	1.4	1.4	1.8	1.5	2.1	1.8	1.4	1.844444
25	Cut the Marriage Drywall for Doors and Windows Openings	14	6	18	6	9	10	16	9	18	11.77778
26	Transfer the Marriage Wall to the Floor Assembly with Interior Walls	1.7	1.8	4	2.5	3.6	1.9	1.8	1.8	2.4	2.388889

Table D3f: Wall Cluster Data Set

Exterior Walls Main Assembly Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
12	Bring the Floor with Interior Walls into the Exterior Walls Station	1.2	1.1	1.2	1.6	1.2	1.5	1	0.9	0.7	1.155556
27	Bring the Side Wall to the Floor Assembly with Interior Walls	2	4	5	3	2	1.5	2	2	3	2.722222
30	Attach the Side Walls to the Floor Assembly with Interior Walls	14	10	12	16	22	14	16	10	13	14.11111
28	Bring the End Wall to the Floor Assembly with Interior Walls	3	4	6	8	5	5	6	5	4	5.111111
31	Attach the End Walls to the Floor Assembly with Interior Walls	18	10	8	9	25	28	13	12	17	15.55556
29	Bring the Marriage Wall to the Floor Assembly with Interior Walls	2	2	2	1.5	3	4	2	2	1	2.166667
32	Attach the Marriage Walls to the Floor Assembly with Interior Walls	10	8	7	14	18	22	12	18	16	13.88889
33	Attach Side Walls, End Walls and Marriage Walls	10	11.5	8	8	10.5	14	16	12	14	11.55556
34	Move the Section With Wall Assembly to the Marriage Wall Station	1.2	1.5	1.2	0.9	0.5	0.6	0.6	0.4	1	0.877778

Table D3g: Wall Cluster Data Set

Marriage Walls Main Assembly Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
35	Bring the Section with Wall Assembly to the Marriage Station	2	3	3	3	5	6	2	4	5	3.666667
36	Attach the Two Floor Sections of a House	20.5	26	20	19	22.5	18	23	27	16	21.33333
37	Move the House to the Roofing Station	3	4	5	4	5	6	5	4	3	4.333333

Table D3h: Wall Cluster Data Set

Roofing Assembly Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
38	Bring the House to the Roofing Assembly Station	2.5	3.6	1.8	2.5	1.7	2	3.5	2.7	1.5	2.422222
39	Install Electrical Work in Walls	15	12	15	15	18	19	16	18	26	17.11111
40	Install Wall Sheathing	28	32	35	30	22	31	33	30	37	30.88889
41	Transfer the Roof Assembly from Feeder Station to Main Station										
42	Attach the Roof Assembly to End and Side Walls										
43	Spread Insulation on Roof Assembly										
44	Attach Roof Decking										
45	Install Windows	30	32	45	42	36	37	32	24	39	35.22222
46	Install Siding	26	28	23	21	23	25	26	33	31	26.22222
47	Cover the Roof Decking with SGL Underlayment Paper										
48	Install Shingles										
49	Separate the House into Two Sections	10	15	12	9	6	15	14	13	15	12.11111
50	Move the Completed Section from the Roofing Station to Finishes Station	2	3	4	2	3	3	4	5	5	3.444444

Table D3i: Wall Cluster Data Set

Finishes Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
51	Bring the Section into Finshes Station	2	3	7	5	2	2	3	4	7	3.888889
52	Primary Drywall Finishing (First Coat)	23	21.25	18.5	23.75	17.25	24.25	22	20.25	19.5	21.08333
53	Secondary Drywall Finishing (Second Coat)	21	24	28	24.5	32.5	22.5	26	27.5	23	25.44444
54	Final Drywall Finishing (Sanding and Painting)	25.5	20	21	23	29	29.5	22.5	22.5	26	24.33333
55	Cleaning	7.5	12.5	10.5	16	14	17.5	19.5	17.5	15.5	14.5

Table D4a: New Wall Cluster Data Set

Interior Walls Feeder Station (For 1 Wall)

Activity Number	Activity Decription	1	2	3	4	5	6	7	8	9	Average
1	Bring Floor Assembly with Bathroom Fixtures in Interior Walls Station	0.7	0.8	0.8	0.6	0.6	0.5	0.2	0.8	0.5	0.611111
2	Attach Lumbers to construct Interior Wall Frames	1.8	1.8	2.4	1.5	1.6	1.4	2.5	2.6	1.9	1.944444
3	Allign and Attach Drywall on one side of Interior Wall Frame	1.2	1.5	1.5	1.4	1.1	1.6	1.9	2	1	1.466667
4	Cut the Drywall for Interior Doors and Windows Openings	1.9	1.8	2.05	1.3	1.5	1	1.3	2.8	1.2	1.65
5	Transfer the Interior Wall to the Electric Hoist	0.5	0.3	0.3	0.8	0.4	0.3	0.4	0.4	0.5	0.433333

Table D4b: New Wall Cluster Data Set

Interior Walls Main Station (Times are for 1 section)

Activity Number	Activity Decription	1	2	3	4	5	6	7	8	9	Average
6	Transfer the Interior Wall to the Floor Assembly/Chassis	0.7	0.5	0.6	0.8	0.9	0.5	0.4	0.5	0.7	0.622222
7	Cut Holes in Interior Walls for Wiring	2.3	5.5	1.8	1.6	2.7	2.4	6	3	8	3.7
8	Attach the Interior Walls to the Floor	6.8	4.2	2.8	3.5	2.4	2.7	6.6	7.8	5.6	4.711111
9	Attach the Interior Walls to other Interior Walls	6.2	4.8	6.6	7.8	8.6	6	12	10	15	8.555556
10	Attach Drywall on the other side of Interior Wall Frame	20	16	15	24	18	16	15	12	21	17.44444
11	Move the Floor with Interior Walls to the Exterior Walls Station	2	3	4	3	2	1	2	3	5	2.777778

Table D4c: New Wall Cluster Data Set

Side Walls Feeder Station (For 1 Wall)

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
13	Attach Lumbers to construct Side Wall Frames	0.8	0.7	0.4	0.7	0.4	0.4	0.6	0.5	0.4	0.544444
14	Spread Insulation on Side Wall	1.1	1.5	2.5	1.1	1.6	0.9	1.7	1	1.2	1.4
15	Allign and Attach Drywall on one side of Side Wall Frame	0.9	0.5	1	0.7	0.8	0.4	0.6	0.6	0.7	0.688889
16	Cut the Side Drywall for Doors and Windows Openings	9	14	17	9	8	17	12	5	10	11.22222
17	Transfer the Side Wall to the Floor Assembly with Interior Walls	1.7	2	1.6	1.4	1.5	1.7	1.8	1.5	1.5	1.633333

Table D4d: New Wall Cluster Data Set

End Walls Feeder Station (For 1 Wall)

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
18	Attach Lumbers to construct End Wall Frames	2.4	0.9	1.5	1.2	1.8	1.7	1.2	0.8	1.7	1.466667
19	Spread Insulation on End Wall	0.6	0.7	1.5	0.9	1.2	1.2	1	1.8	2	1.211111
20	Allign and Attach Drywall on one side of End Wall Frame	1.7	1.2	1	1.6	3	3	1.5	1.8	1.8	1.844444
21	Cut the End Drywall for Doors and Windows Openings	5	8	8	7	14	14	8	18	8	10
22	Transfer the End Wall to the Floor Assembly with Interior Walls	2	2	6	2	2	3	3	4	5	3.222222

Table D4e: New Wall Cluster Data Set

Marriage Walls Feeder Station (For 1 Wall)

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
23	Attach Lumbers to construct Marriage Walls Frames	0.9	1.5	0.8	1.4	1	8	1.5	1	1.8	1.988889
24	Allign and Attach Drywall on one side of Marriage Wall Frame	1.1	4.1	1.4	1.4	1.8	1.5	2.1	1.8	1.4	1.844444
25	Cut the Marriage Drywall for Doors and Windows Openings	14	6	18	6	9	10	16	9	18	11.77778
26	Transfer the Marriage Wall to the Floor Assembly with Interior Walls	1.7	1.8	4	2.5	3.6	1.9	1.8	1.8	2.4	2.388889

Table D4f: New Wall Cluster Data Set

Exterior Walls Main Assembly Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
12	Bring the Floor with Interior Walls into the Exterior Walls Station	1.2	1.1	1.2	1.6	1.2	1.5	1	0.9	0.7	1.155556
27	Bring the Side Wall to the Floor Assembly with Interior Walls	2	4	5	3	2	1.5	2	2	3	2.722222
30	Attach the Side Walls to the Floor Assembly with Interior Walls	14	10	12	16	22	14	16	10	13	14.11111
28	Bring the End Wall to the Floor Assembly with Interior Walls	3	4	6	8	5	5	6	5	4	5.111111
31	Attach the End Walls to the Floor Assembly with Interior Walls	18	10	8	9	25	28	13	12	17	15.55556
29	Bring the Marriage Wall to the Floor Assembly with Interior Walls	2	2	2	1.5	3	4	2	2	1	2.166667
32	Attach the Marriage Walls to the Floor Assembly with Interior Walls	10	8	7	14	18	22	12	18	16	13.88889
33	Attach Side Walls, End Walls and Marriage Walls	10	11.5	8	8	10.5	14	16	12	14	11.55556
34	Move the Section With Wall Assembly to the Marriage Wall Station	1.2	1.5	1.2	0.9	0.5	0.6	0.6	0.4	1	0.877778

Table D4g: New Wall Cluster Data Set

Marriage Walls Main Assembly Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
35	Bring the Section with Wall Assembly to the Marriage Station	2	3	3	3	5	6	2	4	5	3.666667
36	Attach the Two Floor Sections of a House	20.5	26	20	19	22.5	18	23	27	16	21.33333
37	Move the House to the Roofing Station	3	4	5	4	5	6	5	4	3	4.333333

Table D4h: New Wall Cluster Data Set

Roofing Assembly Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
38	Bring the House to the Roofing Assembly Station	2.5	3.6	1.8	2.5	1.7	2	3.5	2.7	1.5	2.422222
39	Install Electrical Work in Walls	15	12	15	15	18	19	16	18	26	17.11111
40	Install Wall Sheathing	28	32	35	30	22	31	33	30	37	30.88889
41	Install Siding	26	28	23	21	23	25	26	33	31	26.22222
42	Transfer the Roof Assembly from Feeder Station to Main Station										
43	Attach the Roof Assembly to End and Side Walls										
44	Spread Insulation on Roof Assembly										
45	Attach Roof Decking										
46	Cover the Roof Decking with SGL Underlayment Paper										
47	Install Shingles										
48	Separate the House into Two Sections	10	15	12	9	6	15	14	13	15	12.11111
49	Move the Completed Section from the Roofing Station to Finishes Station	2	3	4	2	3	3	4	5	5	3.444444

Table D4i: New Wall Cluster Data Set

Finishes Station

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
50	Bring the Section into Finshes Station	2	3	7	5	2	2	3	4	7	3.888889
51	Final Drywall Finishing (Sanding and Painting)	25.5	20	21	23	29	29.5	22.5	22.5	26	24.33333
52	Cleaning	7.5	12.5	10.5	16	14	17.5	19.5	17.5	15.5	14.5

Table D4j: New Wall Cluster Data Set

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
P1	Primary Dryall Finishing at Interior Walls Main Station	5.75	5.3125	4.625	5.9375	4.3125	6.0625	5.5	5.0625	4.875	5.270833
P2	Primary Drywall Finishing at Side Walls Feeder Station	5.75	5.3125	4.625	5.9375	4.3125	6.0625	5.5	5.0625	4.875	5.270833
P3	Primary Drywall Finishing at End Walls Feeder Station	5.75	5.3125	4.625	5.9375	4.3125	6.0625	5.5	5.0625	4.875	5.270833
P4	Primary Drywall Finishing at Marriage Walls Feeder Station	5.75	5.3125	4.625	5.9375	4.3125	6.0625	5.5	5.0625	4.875	5.270833

Table D4k: New Wall Cluster Data Set

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
S1	Secondary Dryall Finishing at Interior Walls Main Station	10.5	12	14	12.25	16.25	11.25	13	13.75	11.5	12.72222
S2	Secondary Drywall Finishing at Side Walls Feeder Station	10.5	12	14	12.25	16.25	11.25	13	13.75	11.5	12.72222
S3	Secondary Drywall Finishing at End Walls Feeder Station	10.5	12	14	12.25	16.25	11.25	13	13.75	11.5	12.72222
S4	Secondary Drywall Finishing at Marriage Walls Feeder Station	10.5	12	14	12.25	16.25	11.25	13	13.75	11.5	12.72222

Table D4I: New Wall Cluster Data Set

Activity Number	Activity Description	1	2	3	4	5	6	7	8	9	Average
W1	Install Windows on Side Wall	20	21.3333	30	28	24	24.6667	21.3333	16	26	23.48148
W2	Install Window on End Wall	10	10.6667	15	14	12	12.3333	10.6667	8	13	11.74074

APPENDIX-E

DISTANCE-COST REPORT FOR THE CASE STUDY FACTORY

Product Name	Part	Distance (ft.)	Cost	Intensity (trip)
House	Volume per Day: 5.00			
	27" Overhead Assembly			
	Station 4	455.63	$0.60	5.00
	Subtotal for 27" Overhead Assembly:	**455.63**	**$0.60**	**5.00**
	Adapter			
	Storage 15	50.96	$0.03	0.05
	Station 6A1	769.91	$0.03	5.00
	Station 2E	384.50	$0.03	0.63
	Subtotal for Adapter:	**1,205.36**	**$0.09**	**5.68**
	Adapter Cleanout			
	Station 2E	2,050.64	$0.01	3.33
	Subtotal for Adapter Cleanout:	**2,050.64**	**$0.01**	**3.33**
	Adapter-A			
	Station 2E	1,537.98	$0.48	2.50
	Subtotal for Adapter-A:	**1,537.98**	**$0.48**	**2.50**
	Adapter-B			
	Station 2E	128.17	$0.03	0.21
	Subtotal for Adapter-B:	**128.17**	**$0.03**	**0.21**
	Adapter-C			
	Station 2E	128.17	$0.03	0.21
	Subtotal for Adapter-C:	**128.17**	**$0.03**	**0.21**
	Adapter-D			
	Station 2E	128.17	$0.03	0.21
	Subtotal for Adapter-D:	**128.17**	**$0.03**	**0.21**
	Adapter-E			
	Station 2E	128.17	$0.03	0.21
	Subtotal for Adapter-E:	**128.17**	**$0.03**	**0.21**
	Adapter-Swivel Trap			
	Station 2E	1,537.98	$0.00	2.50
	Subtotal for Adapter-Swivel Trap:	**1,537.98**	**$0.00**	**2.50**
	Axle			
	Storage 1	164.24	$0.01	1.07
	Station 1A	154.08	$0.01	1.07
	Storage 1	109.49	$0.00	0.71
	Station 1A	102.72	$0.00	0.71
	Subtotal for Axle:	**530.52**	**$0.02**	**3.57**
	Backsocket			
	Storage 4B	3.73	$0.00	0.01
	Station 4B	302.24	$0.06	5.00
	Storage 4B	11.18	$0.00	0.02
	Station 4B	302.24	$0.12	5.00
	Storage 4B	3.73	$0.00	0.01
	Station 4B	302.24	$0.06	5.00
	Storage 4B	11.18	$0.00	0.02
	Station 4B	302.24	$0.12	5.00

Storage 4B	3.73	$0.00	0.01
Station 4B	302.24	$0.06	5.00
Storage 4B	7.46	$0.00	0.01
Station 4B	302.24	$0.09	5.00
Subtotal for Backsocket:	**1,854.42**	**$0.51**	**30.06**
Bar Base Cabinet Assembly			
Station 4	455.63	$0.60	5.00
Subtotal for Bar Base Cabinet Assembly:	**455.63**	**$0.60**	**5.00**
Bar Overhead Cabinet Assembly			
Station 4	455.63	$0.60	5.00
Subtotal for Bar Overhead Cabinet Assembly:	**455.63**	**$0.60**	**5.00**
Base			
Storage 4B	3,355.04	$0.06	5.00
Station 4B	302.24	$0.06	5.00
Subtotal for Base:	**3,657.27**	**$0.12**	**10.00**
Base Assembly 19"			
Station 4	455.63	$0.60	5.00
Subtotal for Base Assembly 19":	**455.63**	**$0.60**	**5.00**
Base Assembly 6"			
Station 4	455.63	$0.60	5.00
Subtotal for Base Assembly 6":	**455.63**	**$0.60**	**5.00**
Base Cabinet Assembly			
Station 4	455.63	$0.60	5.00
Subtotal for Base Cabinet Assembly:	**455.63**	**$0.60**	**5.00**
Batten 7/8 B			
Storage 21	23.71	$0.01	0.05
Station 26	959.31	$0.29	5.00
Subtotal for Batten 7/8 B:	**983.02**	**$0.31**	**5.05**
Batten 7/8 C			
Storage 21	14.23	$0.01	0.03
Station 26	959.31	$0.19	5.00
Subtotal for Batten 7/8 C:	**973.54**	**$0.19**	**5.03**
Batten 7/8 D			
Storage 21	104.60	$0.13	0.23
Station 26	959.31	$1.21	5.00
Subtotal for Batten 7/8 D:	**1,063.91**	**$1.34**	**5.23**
Batten 7/8 E			
Storage 21	691.73	$0.88	1.55
Station 26	959.31	$7.84	5.00
Subtotal for Batten 7/8 E:	**1,651.04**	**$8.72**	**6.55**
Batten 7/8 F			
Storage 21	435.12	$0.20	0.98
Station 26	959.31	$4.94	5.00
Subtotal for Batten 7/8 F:	**1,394.43**	**$5.15**	**5.98**
Batten 7/8 G			
Storage 21	2,009.73	$1.77	4.50
Station 26	959.31	$42.06	5.00
Subtotal for Batten 7/8 G:	**2,969.05**	**$43.83**	**9.50**

Batten-7/8 A			
Storage 21	23.71	$0.03	0.05
Station 26	959.31	$0.29	5.00
Subtotal for Batten-7/8 A:	**983.02**	**$0.32**	**5.05**
Bolt Closet			
Storage 4A	1,139.87	$0.14	1.67
Station 4A	379.82	$0.15	5.00
Subtotal for Bolt Closet:	**1,519.69**	**$0.29**	**6.67**
Bolt Shakle			
Storage 1	0.11	$0.03	0.00
Station 1A	719.02	$0.03	5.00
Storage 1	0.11	$0.03	0.00
Station 1A	719.02	$0.03	5.00
Subtotal for Bolt Shakle:	**1,438.26**	**$0.13**	**10.00**
Boot			
Storage 2D	55.07	$0.06	0.42
Station 2B	339.91	$0.09	5.00
Storage 2D	55.07	$0.06	0.42
Station 2B	339.91	$0.09	5.00
Subtotal for Boot:	**789.97**	**$0.30**	**10.83**
Boot Registar			
Storage 2D	165.22	$0.19	1.25
Station 2B	339.91	$0.21	5.00
Storage 2D	165.22	$0.19	1.25
Station 2B	339.91	$0.21	5.00
Subtotal for Boot Registar:	**1,010.26**	**$0.81**	**12.50**
Bottom Board			
Storage 2C	882.97	$1.10	4.50
Station 2B	500.54	$1.10	5.00
Storage 2C	882.97	$1.10	4.50
Station 2B	500.54	$1.10	5.00
Subtotal for Bottom Board:	**2,767.01**	**$4.41**	**18.99**
Bowl Tank			
Storage 4A	1,709.80	$0.08	2.50
Station 4A	379.82	$0.09	5.00
Subtotal for Bowl Tank:	**2,089.63**	**$0.17**	**7.50**
Bowl Toilet			
Storage 4A	854.90	$0.04	1.25
Station 4A	379.82	$0.06	5.00
Subtotal for Bowl Toilet:	**1,234.72**	**$0.10**	**6.25**
Box plastic Round			
Storage 15	424.64	$0.47	0.42
Station 6A1	769.91	$0.49	5.00
Storage 15	254.78	$0.47	0.25
Station 6A1	769.91	$0.49	5.00
Subtotal for Box plastic Round:	**2,219.24**	**$1.92**	**10.67**
Box White Plumbing			
Storage 4A	569.93	$0.07	0.83

Station 4A	379.82	$0.09	5.00
Subtotal for Box White Plumbing:	**949.76**	**$0.16**	**5.83**
Box-1 Gang			
Storage 15	285.36	$0.87	0.28
Station 6A1	769.91	$0.90	5.00
Storage 15	285.36	$0.87	0.28
Station 6A1	769.91	$0.90	5.00
Subtotal for Box-1 Gang:	**2,110.53**	**$3.54**	**10.56**
Box-2 Gang			
Storage 15	254.78	$0.25	0.25
Station 6A1	769.91	$0.27	5.00
Storage 15	254.78	$0.25	0.25
Station 6A1	769.91	$0.27	5.00
Subtotal for Box-2 Gang:	**2,049.38**	**$1.05**	**10.50**
Brackets-End Shelving			
Storage 28	690.46	$0.01	2.50
Station 30	1,100.20	$0.34	5.00
Storage 28	690.46	$0.04	2.50
Station 29	913.54	$0.34	5.00
Subtotal for Brackets-End Shelving:	**3,394.66**	**$0.73**	**15.00**
Brackets-U Clamp			
Storage 28	345.23	$0.07	1.25
Station 30	2,200.39	$0.68	10.00
Storage 28	345.23	$0.07	1.25
Station 29	1,827.08	$0.67	10.00
Subtotal for Brackets-U Clamp:	**4,717.93**	**$1.49**	**22.50**
Breaker-A			
Storage 15	50.96	$0.03	0.05
Station 6A1	769.91	$0.06	5.00
Subtotal for Breaker-A:	**820.87**	**$0.09**	**5.05**
Breaker-B			
Storage 15	50.96	$0.03	0.05
Station 6A1	769.91	$0.06	5.00
Subtotal for Breaker-B:	**820.87**	**$0.09**	**5.05**
Breaker-C			
Storage 15	50.96	$0.03	0.05
Station 6A1	769.91	$0.06	5.00
Subtotal for Breaker-C:	**820.87**	**$0.09**	**5.05**
Breaker-D			
Storage 15	50.96	$0.03	0.05
Station 6A1	769.91	$0.06	5.00
Subtotal for Breaker-D:	**820.87**	**$0.09**	**5.05**
Breaker-E			
Storage 15	50.96	$0.03	0.05
Station 6A1	769.91	$0.06	5.00
Subtotal for Breaker-E:	**820.87**	**$0.09**	**5.05**
Bushing-A			
Station 2E	192.25	$0.00	0.31

Subtotal for Bushing-A:	**192.25**	**$0.00**	**0.31**
Bushing-B			
Station 2E	256.33	$0.01	0.42
Subtotal for Bushing-B:	**256.33**	**$0.01**	**0.42**
Cab Crown			
Storage 28	153.44	$0.14	0.56
Station 30	1,100.20	$1.27	5.00
Subtotal for Cab Crown:	**1,253.63**	**$1.41**	**5.56**
Cabinet Assembly			
Station 5	1,017.64	$0.01	5.00
Subtotal for Cabinet Assembly:	**1,017.64**	**$0.01**	**5.00**
Cabinet Door			
Storage 15	636.96	$0.00	0.63
Station 6A1	769.91	$0.06	5.00
Storage 4B	559.17	$0.00	0.83
Station 4B	302.24	$0.09	5.00
Storage 4B	279.59	$0.00	0.42
Station 4B	302.24	$0.06	5.00
Storage 4B	559.17	$0.00	0.83
Station 4B	302.24	$0.09	5.00
Storage 4B	838.76	$0.00	1.25
Station 4B	302.24	$0.12	5.00
Storage 4B	838.76	$0.00	1.25
Station 4B	302.24	$0.12	5.00
Storage 4B	838.76	$0.00	1.25
Station 4B	302.24	$0.12	5.00
Storage 4B	559.17	$0.00	0.83
Station 4B	302.24	$0.09	5.00
Storage 4B	279.59	$0.00	0.42
Station 4B	302.24	$0.06	5.00
Storage 4B	1,118.35	$0.01	1.67
Station 4B	302.24	$0.15	5.00
Storage 4B	279.59	$0.00	0.42
Station 4B	302.24	$0.06	5.00
Storage 4B	279.59	$0.00	0.42
Station 4B	302.24	$0.06	5.00
Subtotal for Cabinet Door:	**11,161.95**	**$1.09**	**70.21**
Cabinet Panel 1/4"			
Storage 4B	587.13	$0.00	0.88
Station 4B	302.24	$0.09	5.00
Storage 4B	1,509.77	$0.01	2.25
Station 4B	302.24	$0.20	5.00
Storage 4B	587.13	$0.00	0.88
Station 4B	302.24	$0.09	5.00
Storage 4B	894.68	$0.00	1.33
Station 4B	302.24	$0.13	5.00
Subtotal for Cabinet Panel 1/4":	**4,787.65**	**$0.52**	**25.33**
Cabinet Panel 1/4" 2 sided			

Storage 4B	70.46	$0.01	0.11
Station 4B	124.45	$0.14	2.06
Storage 4B	2,236.69	$0.01	3.33
Station 4B	302.24	$0.28	5.00
Storage 4B	1,174.26	$0.01	1.75
Station 4B	302.24	$0.16	5.00
Storage 4B	3,466.87	$0.02	5.17
Station 4B	302.24	$0.42	5.00
Storage 4B	559.17	$0.00	0.83
Station 4B	302.24	$0.09	5.00
Storage 4B	894.68	$0.00	1.33
Station 4B	302.24	$0.13	5.00
Storage 4B	559.17	$0.00	0.83
Station 4B	302.24	$0.09	5.00
Storage 4B	1,509.77	$0.01	2.25
Station 4B	302.24	$0.20	5.00
Storage 4B	1,537.73	$0.01	2.29
Station 4B	302.24	$0.20	5.00
Storage 4B	894.68	$0.00	1.33
Station 4B	322.38	$0.13	5.33
Storage 4B	3,075.45	$0.02	4.58
Station 4B	302.24	$0.37	5.00
Storage 4B	559.17	$0.00	0.83
Station 4B	302.24	$0.09	5.00
Subtotal for Cabinet Panel 1/4" 2 sided:	**20,007.30**	**$2.36**	**82.04**
Cabinet Panel 1/8 B			
Storage 18B	133.29	$0.04	0.13
Station 17	1,367.69	$0.98	5.00
Subtotal for Cabinet Panel 1/8 B:	**1,500.98**	**$1.02**	**5.13**
Cabinet Panel 1/8 C			
Storage 18B	94.40	$0.03	0.09
Station 17	1,367.69	$0.70	5.00
Subtotal for Cabinet Panel 1/8 C:	**1,462.08**	**$0.73**	**5.09**
Cabinet Panel 1/8"			
Storage 4B	18.45	$0.00	0.03
Station 4B	302.24	$0.06	5.00
Storage 4B	16.78	$0.00	0.03
Station 4B	302.24	$0.06	5.00
Storage 4B	75.49	$0.01	0.11
Station 4B	302.24	$0.17	5.00
Storage 4B	95.62	$0.01	0.14
Station 4B	302.24	$0.20	5.00
Storage 4B	4,976.64	$0.02	7.42
Station 4B	302.24	$0.59	5.00
Storage 4B	229.82	$0.02	0.34
Station 4B	302.24	$0.46	5.00
Storage 4B	169.43	$0.01	0.25
Station 4B	302.24	$0.34	5.00

Storage 4B	1,957.11	$0.01	2.92
Station 4B	302.24	$0.25	5.00
Storage 4B	323.76	$0.03	0.48
Station 4B	302.24	$0.63	5.00
Storage 4B	95.62	$0.01	0.14
Station 4B	302.24	$0.20	5.00
Storage 4B	23.49	$0.00	0.04
Station 4B	302.24	$0.07	5.00
Storage 4B	221.43	$0.02	0.33
Station 4B	302.24	$0.44	5.00
Storage 4B	10,400.62	$0.05	15.50
Station 4B	302.24	$1.20	5.00
Storage 4B	184.53	$0.01	0.28
Station 4B	302.24	$0.37	5.00
Subtotal for Cabinet Panel 1/8":	**23,020.08**	**$5.23**	**98.00**
Cabinet Panel 1/8A			
Storage 18B	21.85	$0.01	0.02
Station 17	1,367.69	$0.18	5.00
Subtotal for Cabinet Panel 1/8A:	**1,389.54**	**$0.19**	**5.02**
Cabinet Shelf			
Storage 4B	1,174.26	$0.00	1.75
Station 4B	302.24	$0.14	5.00
Storage 4B	93.94	$0.01	0.14
Station 4B	302.24	$0.20	5.00
Storage 4B	187.88	$0.01	0.28
Station 4B	302.24	$0.38	5.00
Storage 4B	771.66	$0.00	1.15
Station 4B	302.24	$0.10	5.00
Storage 4B	26.84	$0.00	0.04
Station 4B	302.24	$0.08	5.00
Storage 4B	150.98	$0.01	0.23
Station 4B	302.24	$0.31	5.00
Storage 4B	1,945.92	$0.01	2.90
Station 4B	302.24	$0.21	5.00
Subtotal for Cabinet Shelf:	**6,467.13**	**$1.46**	**41.49**
Cabinet Shelf mdf			
Storage 4B	176.14	$0.01	0.26
Station 4B	302.24	$0.36	5.00
Storage 4B	73.81	$0.01	0.11
Station 4B	302.24	$0.16	5.00
Storage 4B	107.36	$0.01	0.16
Station 4B	302.24	$0.23	5.00
Subtotal for Cabinet Shelf mdf:	**1,264.02**	**$0.77**	**15.53**
Cabinet Shelf-mdf			
Storage 4B	171.11	$0.01	0.26
Station 4B	302.24	$0.35	5.00
Storage 4B	48.65	$0.00	0.07
Station 4B	302.24	$0.12	5.00

Storage 4B	1,409.12	$0.01	2.10
Station 4B	302.24	$0.16	5.00
Storage 4B	13,755.66	$0.06	20.50
Station 4B	302.24	$1.32	5.00
Subtotal for Cabinet Shelf-mdf:	**16,593.47**	**$2.02**	**42.93**
Cabinet-Door slab china			
Storage 4B	1,677.52	$0.01	2.50
Station 4B	302.24	$0.15	5.00
Subtotal for Cabinet-Door slab china:	**1,979.76**	**$0.16**	**7.50**
Carpet			
Storage 3	1,218.01	$0.22	3.05
Station 3	292.71	$21.01	5.00
Storage 3	1,218.01	$0.22	3.05
Station 3	292.71	$21.01	5.00
Subtotal for Carpet:	**3,021.43**	**$42.46**	**16.10**
Carpet Pad			
Storage 3	1,218.01	$0.22	3.05
Station 3	292.71	$21.01	5.00
Storage 3	1,218.01	$0.22	3.05
Station 3	292.71	$21.01	5.00
Subtotal for Carpet Pad:	**3,021.43**	**$42.46**	**16.10**
Ceiling Board			
Storage 9A	2,414.38	$1.54	4.89
Station 8A	432.63	$36.52	4.89
Storage 9B	2,369.84	$4.17	4.89
Station 9A	571.97	$36.52	4.89
Subtotal for Ceiling Board:	**5,788.82**	**$78.75**	**19.55**
Ceiling Light			
Storage 22	760.12	$0.03	1.67
Station 32	13,915.26	$0.48	40.00
Storage 22	760.12	$0.03	1.67
Station 31	11,948.74	$0.48	40.00
Subtotal for Ceiling Light:	**27,384.25**	**$1.03**	**83.33**
Ceiling Type A			
Station 10	346.32	$0.01	5.00
Subtotal for Ceiling Type A:	**346.32**	**$0.01**	**5.00**
Ceiling Type A Stage 1			
Station 8B	554.68	$7.64	5.00
Subtotal for Ceiling Type A Stage 1:	**554.68**	**$7.64**	**5.00**
Ceiling Type A Stage 2			
Station 8	1,037.20	$7.67	5.00
Subtotal for Ceiling Type A Stage 2:	**1,037.20**	**$7.67**	**5.00**
Ceiling Type B			
Station 11	350.00	$0.01	5.00
Subtotal for Ceiling Type B:	**350.00**	**$0.01**	**5.00**
Ceiling Type B Stage 1			
Station 9B	184.39	$7.61	5.00
Subtotal for Ceiling Type B Stage 1:	**184.39**	**$7.61**	**5.00**

Ceiling Type B Stage 2			
Station 9	984.17	$7.67	5.00
Subtotal for Ceiling Type B Stage 2:	**984.17**	**$7.67**	**5.00**
Clamp Ground			
Station 2E	768.99	$0.10	1.25
Subtotal for Clamp Ground:	**768.99**	**$0.10**	**1.25**
Closed Plasric Stand			
Storage 24	1,907.43	$0.54	3.75
Station 32	1,976.37	$0.20	5.00
Storage 24	1,907.43	$0.54	3.75
Station 31	1,764.85	$0.20	5.00
Subtotal for Closed Plasric Stand:	**7,556.08**	**$1.47**	**17.50**
Collar Start			
Storage 2D	27.54	$0.06	0.21
Station 2B	339.91	$0.09	5.00
Storage 2D	55.07	$0.06	0.42
Station 2B	339.91	$0.09	5.00
Subtotal for Collar Start:	**762.43**	**$0.30**	**10.63**
Conduit			
Storage 15	127.39	$0.16	0.13
Station 6A1	769.91	$0.18	5.00
Storage 15	127.39	$0.16	0.13
Station 6A1	769.91	$0.18	5.00
Subtotal for Conduit:	**1,794.60**	**$0.68**	**10.25**
Connector			
Station 2E	256.33	$0.06	0.42
Subtotal for Connector:	**256.33**	**$0.06**	**0.42**
Connector Gas - 1/2x18"			
Station 2E	3,075.96	$0.00	5.00
Subtotal for Connector Gas - 1/2x18":	**3,075.96**	**$0.00**	**5.00**
Connector Gas - 1/2x36"			
Station 2E	3,075.96	$0.00	5.00
Subtotal for Connector Gas - 1/2x36":	**3,075.96**	**$0.00**	**5.00**
Connector Romex			
Storage 15	229.30	$0.28	0.23
Station 6A1	769.91	$0.31	5.00
Storage 15	229.30	$0.28	0.23
Station 6A1	769.91	$0.31	5.00
Subtotal for Connector Romex:	**1,998.43**	**$1.18**	**10.45**
Connector-Crossover			
Storage 15	305.74	$0.10	0.30
Station 6A1	769.91	$0.12	5.00
Storage 15	305.74	$0.10	0.30
Station 6A1	769.91	$0.12	5.00
Subtotal for Connector-Crossover:	**2,151.30**	**$0.43**	**10.60**
Corner Base Cabinet Assembly			
Station 4	455.63	$0.60	5.00
Subtotal for Corner Base Cabinet Assembly:	**455.63**	**$0.60**	**5.00**

Corner Brace Shelving			
Storage 28	13.81	$0.00	0.05
Station 30	1,100.20	$0.09	5.00
Storage 28	13.81	$0.01	0.05
Station 29	913.54	$0.09	5.00
Subtotal for Corner Brace Shelving:	**2,041.36**	**$0.19**	**10.10**
Corner Overhead Cabinet Assembly			
Station 4	455.63	$0.60	5.00
Subtotal for Corner Overhead Cabinet Assembly:	**455.63**	**$0.60**	**5.00**
Counter Top			
Storage 4B	3.36	$0.00	0.01
Station 4B	302.24	$0.03	5.00
Storage 4B	234.85	$0.02	0.35
Station 4B	302.24	$0.47	5.00
Storage 4B	387.51	$0.03	0.58
Station 4B	302.24	$0.75	5.00
Storage 4B	234.85	$0.02	0.35
Station 4B	302.24	$0.47	5.00
Storage 4B	206.33	$0.02	0.31
Station 4B	302.24	$0.41	5.00
Storage 4B	234.85	$0.02	0.35
Station 4B	302.24	$0.47	5.00
Subtotal for Counter Top:	**3,115.17**	**$2.70**	**31.94**
Coupling			
Storage 15	25.48	$0.03	0.03
Station 6A1	769.91	$0.06	5.00
Station 2E	3,075.96	$0.06	5.00
Storage 15	25.48	$0.03	0.03
Station 6A1	769.91	$0.06	5.00
Subtotal for Coupling:	**4,666.74**	**$0.24**	**15.05**
Coupling-A			
Station 2E	1,537.98	$0.39	2.50
Subtotal for Coupling-A:	**1,537.98**	**$0.39**	**2.50**
Coupling-B			
Station 2E	512.66	$0.13	0.83
Subtotal for Coupling-B:	**512.66**	**$0.13**	**0.83**
Cover Waterproof Receptacle			
Storage 22	190.03	$0.01	0.42
Station 32	1,739.41	$0.09	5.00
Subtotal for Cover Waterproof Receptacle:	**1,929.44**	**$0.10**	**5.42**
Crimp Ring-A			
Station 2E	615.19	$3.74	1.00
Subtotal for Crimp Ring-A:	**615.19**	**$3.74**	**1.00**
Crimp Ring-B			
Station 2E	256.33	$1.56	0.42
Subtotal for Crimp Ring-B:	**256.33**	**$1.56**	**0.42**
Curtain Rod-A			
Storage 27	63.29	$0.01	0.21

Station 32	952.65	$0.09	5.00
Storage 27	63.29	$0.01	0.21
Station 31	732.11	$0.09	5.00
Subtotal for Curtain Rod-A:	**1,811.34**	**$0.19**	**10.42**
Curtain Rod-B			
Storage 27	158.23	$0.02	0.52
Station 32	952.65	$0.18	5.00
Storage 27	158.23	$0.02	0.52
Station 31	732.11	$0.18	5.00
Subtotal for Curtain Rod-B:	**2,001.21**	**$0.41**	**11.04**
Diverter			
Storage 4A	569.93	$0.07	0.83
Station 4A	379.82	$0.09	5.00
Subtotal for Diverter:	**949.76**	**$0.16**	**5.83**
Door			
Storage 28	276.18	$0.01	1.00
Station 30	6,601.18	$0.35	30.00
Storage 28	276.18	$0.02	1.00
Station 29	5,481.24	$0.35	30.00
Subtotal for Door:	**12,634.79**	**$0.73**	**62.00**
Door Hinge			
Storage 28	12.43	$0.03	0.05
Station 30	1,100.20	$0.31	5.00
Storage 28	12.43	$0.03	0.05
Station 29	913.54	$0.31	5.00
Subtotal for Door Hinge:	**2,038.59**	**$0.68**	**10.09**
Door Jamb			
Storage 28	1,408.54	$0.37	5.10
Station 30	1,100.20	$3.20	5.00
Storage 28	1,408.54	$0.37	5.10
Station 29	913.54	$3.20	5.00
Subtotal for Door Jamb:	**4,830.82**	**$7.13**	**20.20**
Door Stop			
Storage 28	70.43	$0.18	0.26
Station 30	1,100.20	$1.61	5.00
Storage 27	101.27	$0.04	0.33
Station 32	476.32	$0.33	2.50
Storage 27	101.27	$0.04	0.33
Station 31	366.05	$0.33	2.50
Storage 28	70.43	$0.18	0.26
Station 29	913.54	$1.61	5.00
Subtotal for Door Stop:	**3,199.50**	**$4.32**	**16.18**
Door-Front SD			
Storage 11A	386.14	$0.00	0.63
Station 13	879.21	$0.06	5.00
Subtotal for Door-Front SD:	**1,265.35**	**$0.06**	**5.63**
Door-Rear SD			
Storage 11A	386.14	$0.00	0.63

Station 12	886.88	$0.06	5.00
Subtotal for Door-Rear SD:	**1,273.02**	**$0.06**	**5.63**
Drain			
Storage 4A	569.93	$0.07	0.83
Station 4A	379.82	$0.09	5.00
Subtotal for Drain:	**949.76**	**$0.16**	**5.83**
Drain Water Vent Assembly			
Station 2B	580.50	$0.01	5.00
Subtotal for Drain Water Vent Assembly:	**580.50**	**$0.01**	**5.00**
Drapes			
Storage 25	306.85	$0.00	0.83
Station 32	1,300.13	$0.06	5.00
Storage 25	306.85	$0.00	0.83
Station 31	1,150.49	$0.06	5.00
Subtotal for Drapes:	**3,064.32**	**$0.13**	**11.67**
Drawe Guide 22"			
Storage 4B	0.52	$0.09	0.00
Station 4B	302.24	$0.12	5.00
Storage 4B	0.52	$0.09	0.00
Station 4B	302.24	$0.12	5.00
Storage 4B	0.17	$0.03	0.00
Station 4B	302.24	$0.06	5.00
Storage 4B	0.17	$0.03	0.00
Station 4B	302.24	$0.06	5.00
Storage 4B	0.17	$0.03	0.00
Station 4B	302.24	$0.06	5.00
Storage 4B	0.35	$0.06	0.00
Station 4B	302.24	$0.09	5.00
Subtotal for Drawe Guide 22":	**1,815.33**	**$0.84**	**30.00**
Drawer Front			
Storage 4B	209.69	$0.00	0.31
Station 4B	302.24	$0.12	5.00
Storage 4B	69.90	$0.00	0.10
Station 4B	302.24	$0.06	5.00
Storage 4B	251.63	$0.00	0.38
Station 4B	302.24	$0.14	5.00
Storage 4B	209.69	$0.00	0.31
Station 4B	302.24	$0.12	5.00
Storage 4B	69.90	$0.00	0.10
Station 4B	302.24	$0.06	5.00
Storage 4B	209.69	$0.00	0.31
Station 4B	302.24	$0.12	5.00
Storage 4B	69.90	$0.00	0.10
Station 4B	302.24	$0.06	5.00
Subtotal for Drawer Front:	**3,206.04**	**$0.69**	**36.63**
Drawer Front&Back			
Storage 4B	73.81	$0.00	0.11
Station 4B	302.24	$0.09	5.00

Storage 4B	150.98	$0.01	0.23
Station 4B	302.24	$0.17	5.00
Storage 4B	352.28	$0.01	0.53
Station 4B	302.24	$0.36	5.00
Storage 4B	73.81	$0.00	0.11
Station 4B	302.24	$0.09	5.00
Subtotal for Drawer Front&Back:	**1,859.82**	**$0.74**	**20.97**
Drawer Side			
Storage 4B	82.48	$0.01	0.12
Station 4B	302.24	$0.21	5.00
Storage 4B	48.93	$0.00	0.07
Station 4B	302.24	$0.14	5.00
Storage 4B	111.83	$0.01	0.17
Station 4B	302.24	$0.28	5.00
Storage 4B	111.83	$0.01	0.17
Station 4B	302.24	$0.28	5.00
Storage 4B	48.93	$0.00	0.07
Station 4B	302.24	$0.14	5.00
Storage 4B	176.14	$0.02	0.26
Station 4B	302.24	$0.42	5.00
Subtotal for Drawer Side:	**2,393.56**	**$1.51**	**30.86**
Drip Edge			
Storage 16	455.83	$0.53	0.47
Station 10	864.66	$4.75	5.00
Storage 16	455.83	$0.63	0.47
Station 11	816.33	$4.75	5.00
Subtotal for Drip Edge:	**2,592.64**	**$10.66**	**10.94**
Dust Cap			
Station 2E	128.17	$0.03	0.21
Station 2E	6.15	$0.00	0.01
Subtotal for Dust Cap:	**134.32**	**$0.03**	**0.22**
Dw 28std			
Storage 9A	2,418.50	$0.06	4.90
Station 8A	442.59	$1.49	5.00
Storage 9A	120.92	$0.06	0.24
Station 9A	530.38	$1.49	5.00
Subtotal for Dw 28std:	**3,512.40**	**$3.10**	**15.14**
E-Gasket			
Storage 4A	569.93	$0.07	0.83
Station 4A	379.82	$0.09	5.00
Subtotal for E-Gasket:	**949.76**	**$0.16**	**5.83**
Elbow			
Station 2E	128.17	$0.03	0.21
Station 2E	320.41	$0.01	0.52
Subtotal for Elbow:	**448.58**	**$0.04**	**0.73**
Elbow-A			
Station 2E	2,435.14	$0.62	3.96
Station 2E	30.76	$0.00	0.05

Subtotal for Elbow-A:	**2,465.90**	**$0.62**	**4.01**
Elbow-B			
Station 2E	768.99	$0.19	1.25
Station 2E	30.76	$0.00	0.05
Subtotal for Elbow-B:	**799.75**	**$0.20**	**1.30**
Elbow-C			
Station 2E	128.17	$0.03	0.21
Station 2E	30.76	$0.00	0.05
Subtotal for Elbow-C:	**158.92**	**$0.03**	**0.26**
Elbow-D			
Station 2E	61.52	$0.00	0.10
Subtotal for Elbow-D:	**61.52**	**$0.00**	**0.10**
Elbow-E			
Station 2E	61.52	$0.00	0.10
Subtotal for Elbow-E:	**61.52**	**$0.00**	**0.10**
Elbow-F			
Station 2E	153.80	$0.01	0.25
Station 2E	123.04	$0.01	0.20
Subtotal for Elbow-F:	**276.84**	**$0.01**	**0.45**
Elbow-G			
Station 2E	215.32	$0.01	0.35
Subtotal for Elbow-G:	**215.32**	**$0.01**	**0.35**
Electrical Assembly - A1			
Station 6	1,381.26	$0.06	5.00
Subtotal for Electrical Assembly - A1:	**1,381.26**	**$0.06**	**5.00**
Electrical Assembly - A2			
Station 12	1,820.77	$0.06	5.00
Subtotal for Electrical Assembly - A2:	**1,820.77**	**$0.06**	**5.00**
Electrical Assembly - A3			
Station 32	0.00	$0.06	5.00
Subtotal for Electrical Assembly - A3:	**0.00**	**$0.06**	**5.00**
Electrical Assembly - B1			
Station 6	1,381.26	$0.06	5.00
Subtotal for Electrical Assembly - B1:	**1,381.26**	**$0.06**	**5.00**
Electrical Assembly - B2			
Station 13	1,929.69	$0.06	5.00
Subtotal for Electrical Assembly - B2:	**1,929.69**	**$0.06**	**5.00**
Electrical Assembly - B3			
Station 31	0.00	$0.06	5.00
Subtotal for Electrical Assembly - B3:	**0.00**	**$0.06**	**5.00**
End Wall A			
Station 8	190.00	$0.01	5.00
Subtotal for End Wall A:	**190.00**	**$0.01**	**5.00**
End Wall B			
Station 9	350.00	$0.01	5.00
Subtotal for End Wall B:	**350.00**	**$0.01**	**5.00**
End Wall Type1			
Station 7	763.55	$0.60	5.00

Station 7	763.55	$0.60	5.00
Subtotal for End Wall Type1:	**1,527.10**	**$1.21**	**10.00**
End Wall Type2			
Station 7	763.55	$0.60	5.00
Station 7	763.55	$0.60	5.00
Subtotal for End Wall Type2:	**1,527.10**	**$1.21**	**10.00**
Exterior Finish Assembly A			
Station 14	350.00	$0.01	5.00
Station 16	350.00	$0.01	5.00
Station 17	190.00	$0.01	5.00
Subtotal for Exterior Finish Assembly A:	**890.00**	**$0.02**	**15.00**
Exterior Finish Assembly B			
Station 15	350.00	$0.01	5.00
Station 17	380.00	$0.01	5.00
Station 18	183.93	$0.01	5.00
Subtotal for Exterior Finish Assembly B:	**913.93**	**$0.02**	**15.00**
Exterior Jelly Jar Light			
Storage 22	95.02	$0.00	0.21
Station 32	1,739.41	$0.06	5.00
Storage 22	95.02	$0.00	0.21
Station 31	1,493.59	$0.06	5.00
Subtotal for Exterior Jelly Jar Light:	**3,423.03**	**$0.13**	**10.42**
Exterior Light Fixture			
Storage 22	95.02	$0.00	0.21
Station 32	1,739.41	$0.06	5.00
Storage 22	95.02	$0.00	0.21
Station 31	1,493.59	$0.06	5.00
Subtotal for Exterior Light Fixture:	**3,423.03**	**$0.13**	**10.42**
Exterior Roof Finish A			
Station 12	353.71	$0.01	5.00
Subtotal for Exterior Roof Finish A:	**353.71**	**$0.01**	**5.00**
Exterior Roof Finish B			
Station 13	350.00	$0.01	5.00
Subtotal for Exterior Roof Finish B:	**350.00**	**$0.01**	**5.00**
Fan			
Storage 22	190.03	$0.01	0.42
Station 32	1,739.41	$0.09	5.00
Storage 22	190.03	$0.00	0.42
Station 31	1,493.59	$0.09	5.00
Subtotal for Fan:	**3,613.06**	**$0.19**	**10.83**
Fascia White			
Storage 16	1,199.33	$0.19	1.23
Station 12	795.70	$4.63	5.00
Storage 16	1,199.33	$0.53	1.23
Station 13	813.11	$4.63	5.00
Subtotal for Fascia White:	**4,007.48**	**$9.98**	**12.47**
Fasteners			
Storage 26	13.22	$0.00	0.11

Station 34	12.37	$0.03	0.11
Storage 26	13.22	$0.00	0.11
Station 33	15.61	$0.03	0.11
Subtotal for Fasteners:	**54.42**	**$0.07**	**0.45**
Faucet			
Storage 4A	569.93	$0.04	0.83
Station 4A	379.82	$0.06	5.00
Subtotal for Faucet:	**949.76**	**$0.09**	**5.83**
Faucet-Lav			
Storage 4A	854.90	$0.10	1.25
Station 4A	379.82	$0.12	5.00
Subtotal for Faucet-Lav:	**1,234.72**	**$0.22**	**6.25**
Filler Garden tub			
Storage 4A	3,419.61	$0.01	5.00
Station 4A	379.82	$0.06	5.00
Subtotal for Filler Garden tub:	**3,799.43**	**$0.06**	**10.00**
Final Finish Assembly - A			
Station 34	748.22	$0.01	5.00
Station 33	750.00	$0.01	5.00
Subtotal for Final Finish Assembly - A:	**1,498.22**	**$0.01**	**10.00**
Finish Trim			
Storage 16	972.43	$0.05	1.00
Station 12	795.70	$1.27	5.00
Storage 16	972.43	$0.17	1.00
Station 13	813.11	$1.27	5.00
Subtotal for Finish Trim:	**3,553.68**	**$2.76**	**12.00**
Flange			
Station 2E	61.52	$0.00	0.10
Subtotal for Flange:	**61.52**	**$0.00**	**0.10**
Flange-Shower Rod			
Storage 27	63.29	$0.00	0.21
Station 32	952.65	$0.09	5.00
Subtotal for Flange-Shower Rod:	**1,015.94**	**$0.09**	**5.21**
Flashing Plastic			
Storage 16	202.59	$0.01	0.21
Station 10	864.66	$0.09	5.00
Storage 16	202.59	$0.01	0.21
Station 11	816.33	$0.09	5.00
Subtotal for Flashing Plastic:	**2,086.17**	**$0.19**	**10.42**
Flat A			
Storage 28	211.28	$0.54	0.77
Station 30	1,100.20	$4.79	5.00
Subtotal for Flat A:	**1,311.48**	**$5.33**	**5.77**
Flat B			
Storage 28	2,485.66	$0.13	9.00
Station 30	1,100.20	$1.15	5.00
Subtotal for Flat B:	**3,585.86**	**$1.28**	**14.00**
Flexduct-Insulated			

Storage 2D	39.65	$0.93	0.30
Station 2B	339.91	$0.97	5.00
Storage 2D	39.65	$0.93	0.30
Station 2B	339.91	$0.97	5.00
Subtotal for Flexduct-Insulated:	**759.13**	**$3.81**	**10.60**
Flexi Duct			
Storage 22	76.01	$0.07	0.17
Station 32	1,739.41	$0.65	5.00
Storage 22	76.01	$0.03	0.17
Station 31	1,493.59	$0.65	5.00
Subtotal for Flexi Duct:	**3,385.03**	**$1.40**	**10.33**
Floor Assembly A1			
Station 2A	619.74	$0.01	5.00
Station 2C	207.57	$0.01	5.00
Station 2D	693.71	$0.01	5.00
Subtotal for Floor Assembly A1:	**1,521.02**	**$0.02**	**15.00**
Floor Assembly A2			
Station 3	885.15	$0.01	5.00
Subtotal for Floor Assembly A2:	**885.15**	**$0.01**	**5.00**
Floor Assembly A3			
Station 4	862.68	$0.01	5.00
Station 5	1,017.64	$0.01	5.00
Subtotal for Floor Assembly A3:	**1,880.32**	**$0.01**	**10.00**
Floor Assembly B1			
Station 2A	619.74	$0.01	5.00
Station 2C	207.57	$0.01	5.00
Station 2D	693.71	$0.01	5.00
Subtotal for Floor Assembly B1:	**1,521.02**	**$0.02**	**15.00**
Floor Assembly B2			
Station 3	885.15	$0.01	5.00
Subtotal for Floor Assembly B2:	**885.15**	**$0.01**	**5.00**
Floor Assembly B3			
Station 4	862.68	$0.01	5.00
Station 5	1,017.64	$0.01	5.00
Subtotal for Floor Assembly B3:	**1,880.32**	**$0.01**	**10.00**
F-Moulding			
Storage 4A	284.97	$0.03	0.42
Station 4A	379.82	$0.06	5.00
Subtotal for F-Moulding:	**664.79**	**$0.09**	**5.42**
Frame Assembly A			
Station 1B	616.72	$0.01	5.00
Station 2A	1,495.00	$0.01	5.00
Station 2B	619.74	$0.01	5.00
Subtotal for Frame Assembly A:	**2,731.46**	**$0.02**	**15.00**
Frame Assembly B			
Station 1B	616.72	$0.01	5.00
Station 2A	1,495.00	$0.01	5.00
Station 2B	619.74	$0.01	5.00

Subtotal for Frame Assembly B:	**2,731.46**	**$0.02**	**15.00**
Frames-Triple,10"			
Storage 1	1,532.87	$0.01	10.00
Station 1B	1,016.04	$0.01	10.00
Station 1A	1,233.44	$0.01	10.00
Storage 1	1,532.87	$0.01	10.00
Station 1B	1,016.04	$0.01	10.00
Station 1A	1,233.44	$0.01	10.00
Subtotal for Frames-Triple,10":	**7,564.69**	**$0.09**	**60.00**
Furnace			
Storage 2D	660.87	$0.01	5.00
Station 2B	339.91	$0.06	5.00
Storage 2D	660.87	$0.01	5.00
Station 2B	339.91	$0.06	5.00
Subtotal for Furnace:	**2,001.57**	**$0.13**	**20.00**
Fuse Panel Door Assembly			
Station 12	1,820.77	$0.06	5.00
Subtotal for Fuse Panel Door Assembly:	**1,820.77**	**$0.06**	**5.00**
Gas Assembly			
Station 2B	580.50	$0.01	5.00
Subtotal for Gas Assembly:	**580.50**	**$0.01**	**5.00**
Glass-China door			
Storage 4B	1,677.52	$0.01	2.50
Station 4B	302.24	$0.15	5.00
Subtotal for Glass-China door:	**1,979.76**	**$0.16**	**7.50**
Globe Fluted Ball			
Storage 22	760.12	$0.01	1.67
Station 32	6,957.63	$0.37	20.00
Storage 22	760.12	$0.01	1.67
Station 31	5,974.37	$0.37	20.00
Subtotal for Globe Fluted Ball:	**14,452.25**	**$0.75**	**43.33**
Ground Strap			
Storage 2D	235.80	$0.01	0.42
Station 2B	339.91	$0.09	5.00
Storage 2D	235.80	$0.01	0.42
Station 2B	339.91	$0.09	5.00
Subtotal for Ground Strap:	**1,151.42**	**$0.19**	**10.83**
Gypsum Vinyl Moroccan Sand			
Storage 28	265.83	$0.82	0.96
Station 30	1,100.20	$7.30	5.00
Storage 28	265.83	$0.82	0.96
Station 29	913.54	$7.30	5.00
Storage 5	285.43	$0.19	0.30
Station 5A	848.43	$4.51	5.00
Subtotal for Gypsum Vinyl Moroccan Sand:	**3,679.25**	**$20.94**	**17.23**
Gypsum Vinyl Morroccan Sand			
Storage 27	8.35	$0.03	0.03
Station 32	952.65	$0.71	5.00

Storage 27	8.35	$0.08	0.03
Station 31	732.11	$0.71	5.00
Subtotal for Gypsum Vinyl Morroccan Sand:	**1,701.46**	**$1.53**	**10.06**
Gypsum Vinyl Sussex			
Storage 7A	558.07	$0.17	0.53
Station 6B	764.10	$4.01	5.00
Storage 6	238.50	$0.09	0.22
Station 6A	698.85	$3.36	5.00
Storage 5	76.11	$0.04	0.08
Station 5A	848.43	$1.02	5.00
Storage 5	22.00	$0.01	0.02
Station 5A	848.43	$0.37	5.00
Storage 5	178.23	$0.07	0.19
Station 5A	848.43	$1.77	5.00
Storage 5	106.24	$0.07	0.11
Station 5A	710.56	$1.69	4.19
Storage 5	107.04	$0.07	0.11
Station 5A	848.43	$1.71	5.00
Storage 5	131.61	$0.09	0.14
Station 5A	848.43	$2.09	5.00
Storage 7A	279.03	$0.45	0.27
Station 6B	764.10	$4.01	5.00
Storage 6	477.01	$0.09	0.45
Station 6A	698.85	$3.36	5.00
Storage 5	126.86	$0.13	0.13
Station 5A	327.50	$1.01	1.93
Storage 5	217.24	$0.23	0.23
Station 5A	848.43	$1.73	5.00
Subtotal for Gypsum Vinyl Sussex:	**11,572.46**	**$27.64**	**58.60**
Gypsum-end rafters			
Storage 8	306.74	$0.01	0.52
Station 8A	136.33	$0.18	5.00
Storage 9C	196.00	$0.01	0.52
Station 9A	1,110.36	$0.18	5.00
Subtotal for Gypsum-end rafters:	**1,749.44**	**$0.38**	**11.04**
Heat Duct Aluminium			
Storage 2D	377.28	$0.28	0.67
Station 2B	339.91	$2.55	5.00
Storage 2D	377.28	$0.33	0.67
Station 2B	339.91	$2.55	5.00
Subtotal for Heat Duct Aluminium:	**1,434.38**	**$5.71**	**11.33**
Hinge			
Storage 15	16.99	$0.00	0.02
Station 6A1	769.91	$0.09	5.00
Storage 4B	108.23	$0.01	0.16
Station 4B	302.24	$0.15	5.00
Storage 4B	54.11	$0.00	0.08
Station 4B	302.24	$0.09	5.00

Storage 4B	108.23	$0.01	0.16
Station 4B	302.24	$0.15	5.00
Storage 4B	54.11	$0.00	0.08
Station 4B	302.24	$0.09	5.00
Storage 4B	54.11	$0.00	0.08
Station 4B	302.24	$0.09	5.00
Storage 4B	135.28	$0.01	0.20
Station 4B	302.24	$0.18	5.00
Storage 4B	162.34	$0.01	0.24
Station 4B	302.24	$0.21	5.00
Storage 4B	324.68	$0.02	0.48
Station 4B	302.24	$0.40	5.00
Storage 4B	108.23	$0.01	0.16
Station 4B	302.24	$0.15	5.00
Storage 4B	378.79	$0.02	0.56
Station 4B	302.24	$0.47	5.00
Storage 4B	162.34	$0.01	0.24
Station 4B	302.24	$0.21	5.00
Storage 4B	216.45	$0.01	0.32
Station 4B	302.24	$0.28	5.00
Subtotal for Hinge:	**6,280.64**	**$2.66**	**67.80**
House			
Station 36	2,948.33	$0.84	5.00
Subtotal for House:	**2,948.33**	**$0.84**	**5.00**
Insualtion r19			
Storage 9B	444.47	$0.39	0.92
Station 8B	532.91	$3.49	5.00
Storage 7A	1,141.94	$0.25	1.18
Station 7A	671.28	$5.95	5.00
Storage 7A	1,141.94	$0.25	1.18
Station 7A	671.28	$5.95	5.00
Storage 6	1,049.41	$0.36	1.11
Station 6A	698.85	$14.01	5.00
Storage 2D	340.35	$16.24	2.58
Station 2B	339.91	$16.25	5.00
Storage 9B	303.05	$0.14	0.63
Station 9B	517.23	$3.49	5.00
Storage 7A	1,141.94	$0.67	1.18
Station 7A	671.28	$5.95	5.00
Storage 7A	456.77	$0.79	0.47
Station 7A	671.28	$5.95	5.00
Storage 6	1,049.41	$0.36	1.11
Station 6A	698.85	$14.01	5.00
Storage 2D	340.35	$16.24	2.58
Station 2B	339.91	$16.25	5.00
Subtotal for Insualtion r19:	**13,222.42**	**$126.97**	**62.91**
Insulation Cellulose			
Storage 9B	4,242.68	$0.10	8.75

Station 8B	746.08	$11.69	7.00
Storage 9B	424.27	$0.10	0.88
Station 9B	724.12	$11.69	7.00
Subtotal for Insulation Cellulose:	**6,137.15**	**$23.58**	**23.63**
Insulation r11			
Storage 2D	668.80	$31.90	5.06
Station 2B	339.91	$31.90	5.00
Storage 2D	74.02	$3.53	0.56
Station 2B	339.91	$3.55	5.00
Storage 2D	668.80	$31.90	5.06
Station 2B	339.91	$31.90	5.00
Storage 2D	74.02	$3.53	0.56
Station 2B	339.91	$3.55	5.00
Subtotal for Insulation r11:	**2,845.29**	**$141.78**	**31.24**
Interior Partition A			
Station 6	176.24	$0.01	5.00
Subtotal for Interior Partition A:	**176.24**	**$0.01**	**5.00**
Interior Partition B			
Station 6	176.24	$0.01	5.00
Subtotal for Interior Partition B:	**176.24**	**$0.01**	**5.00**
Interior Partition-A1			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-A1:	**485.72**	**$0.60**	**5.00**
Interior Partition-A2			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-A2:	**485.72**	**$0.60**	**5.00**
Interior Partition-A3			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-A3:	**485.72**	**$0.60**	**5.00**
Interior Partition-A4			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-A4:	**485.72**	**$0.60**	**5.00**
Interior Partition-A5			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-A5:	**485.72**	**$0.60**	**5.00**
Interior Partition-A6			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-A6:	**485.72**	**$0.60**	**5.00**
Interior Partition-A7			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-A7:	**485.72**	**$0.60**	**5.00**
Interior Partition-B1			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-B1:	**485.72**	**$0.60**	**5.00**
Interior Partition-B2			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-B2:	**485.72**	**$0.60**	**5.00**
Interior Partition-B3			

Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-B3:	**485.72**	**$0.60**	**5.00**
Interior Partition-B4			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-B4:	**485.72**	**$0.60**	**5.00**
Interior Partition-B5			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-B5:	**485.72**	**$0.60**	**5.00**
Interior Partition-B6			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-B6:	**485.72**	**$0.60**	**5.00**
Interior Partition-B7			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-B7:	**485.72**	**$0.60**	**5.00**
Interior Partition-B8			
Station 5	485.72	$0.60	5.00
Subtotal for Interior Partition-B8:	**485.72**	**$0.60**	**5.00**
J Block			
Storage 16	72.93	$0.01	0.08
Station 12	795.70	$0.12	5.00
Storage 16	72.93	$0.01	0.08
Station 13	813.11	$0.12	5.00
Subtotal for J Block:	**1,754.68**	**$0.26**	**10.15**
J Channel			
Storage 16	972.43	$0.14	1.00
Station 12	795.70	$1.27	5.00
Storage 16	972.43	$0.17	1.00
Station 13	813.11	$1.27	5.00
Subtotal for J Channel:	**3,553.68**	**$2.85**	**12.00**
Kitchen Counter Tops			
Station 4	455.63	$0.60	5.00
Subtotal for Kitchen Counter Tops:	**455.63**	**$0.60**	**5.00**
Knob-Chrome Cabinet			
Storage 4B	124.26	$0.13	0.19
Station 4B	302.24	$0.15	5.00
Storage 4B	93.20	$0.09	0.14
Station 4B	302.24	$0.12	5.00
Storage 4B	62.13	$0.06	0.09
Station 4B	302.24	$0.09	5.00
Storage 4B	62.13	$0.06	0.09
Station 4B	302.24	$0.09	5.00
Storage 4B	155.33	$0.16	0.23
Station 4B	302.24	$0.18	5.00
Storage 4B	62.13	$0.06	0.09
Station 4B	302.24	$0.09	5.00
Storage 4B	62.13	$0.06	0.09
Station 4B	302.24	$0.09	5.00
Storage 4B	93.20	$0.09	0.14

Station 4B	302.24	$0.12	5.00
Storage 4B	31.06	$0.03	0.05
Station 4B	302.24	$0.06	5.00
Storage 4B	279.59	$0.28	0.42
Station 4B	302.24	$0.31	5.00
Storage 4B	62.13	$0.06	0.09
Station 4B	302.24	$0.09	5.00
Storage 4B	93.20	$0.09	0.14
Station 4B	302.24	$0.12	5.00
Subtotal for Knob-Chrome Cabinet:	**4,807.30**	**$2.69**	**61.76**
Lag			
Storage 2D	928.10	$0.43	1.64
Station 2B	339.91	$10.36	5.00
Storage 2D	928.10	$1.17	1.64
Station 2B	339.91	$10.36	5.00
Subtotal for Lag:	**2,536.03**	**$22.31**	**13.28**
Lav			
Storage 4A	854.90	$0.10	1.25
Station 4A	379.82	$0.12	5.00
Subtotal for Lav:	**1,234.72**	**$0.22**	**6.25**
Linoleum			
Storage 3	808.68	$0.15	2.03
Station 3	292.71	$14.04	5.00
Storage 3	808.68	$0.15	2.03
Station 3	292.71	$14.04	5.00
Subtotal for Linoleum:	**2,202.77**	**$28.36**	**14.05**
Load Center-100amp			
Storage 15	25.48	$0.03	0.03
Station 6A1	769.91	$0.06	5.00
Subtotal for Load Center-100amp:	**795.39**	**$0.09**	**5.03**
Lock Nut			
Storage 1	15.33	$0.03	0.10
Station 1A	119.84	$0.76	0.83
Storage 1	15.33	$0.03	0.10
Station 1A	119.84	$0.76	0.83
Subtotal for Lock Nut:	**270.33**	**$1.58**	**1.87**
Lockset			
Storage 28	27.62	$0.02	0.10
Station 30	110.02	$0.19	0.50
Storage 28	27.62	$0.02	0.10
Station 29	91.35	$0.19	0.50
Subtotal for Lockset:	**256.61**	**$0.43**	**1.20**
Lug			
Storage 15	101.91	$0.03	0.10
Station 6A1	769.91	$0.06	5.00
Storage 15	101.91	$0.03	0.10
Station 6A1	769.91	$0.06	5.00
Subtotal for Lug:	**1,743.64**	**$0.18**	**10.20**

Lug Ground			
Station 2E	256.33	$0.03	0.42
Subtotal for Lug Ground:	**256.33**	**$0.03**	**0.42**
Lumber - 2x6x12			
Storage 2C	335.85	$0.01	1.50
Station 2B	500.54	$0.02	5.00
Storage 2C	335.85	$0.01	1.50
Station 2B	500.54	$0.02	5.00
Subtotal for Lumber - 2x6x12:	**1,672.77**	**$0.07**	**13.00**
Lumber - 2x6x14			
Storage 2C	268.68	$0.01	1.20
Station 2B	500.54	$0.02	5.00
Subtotal for Lumber - 2x6x14:	**769.22**	**$0.03**	**6.20**
Lumber - 2x6x157			
Storage 2C	1,522.51	$0.06	6.80
Station 2B	500.54	$0.09	5.00
Storage 2C	1,522.51	$0.06	6.80
Station 2B	500.54	$0.24	5.00
Subtotal for Lumber - 2x6x157:	**4,046.10**	**$0.45**	**23.60**
Lumber - 2x6x16			
Station 2F	551.13	$0.00	1.33
Station 2F	551.13	$0.00	1.33
Subtotal for Lumber - 2x6x16:	**1,102.27**	**$0.01**	**2.67**
Lumber - 2x6x19			
Storage 2C	44.78	$0.00	0.20
Station 2B	500.54	$0.09	5.00
Storage 2C	44.78	$0.00	0.20
Station 2B	500.54	$0.09	5.00
Subtotal for Lumber - 2x6x19:	**1,090.63**	**$0.18**	**10.40**
Lumber - 2x6x29			
Storage 2C	1,164.27	$0.04	5.20
Station 2B	520.56	$0.19	5.20
Subtotal for Lumber - 2x6x29:	**1,684.83**	**$0.23**	**10.40**
Lumber - 2x6xRL			
Station 2F	661.36	$0.03	1.60
Station 2F	661.36	$0.03	1.60
Subtotal for Lumber - 2x6xRL:	**1,322.72**	**$0.05**	**3.20**
Lumber 1x3xRL (cut from 12)			
Storage 7A	162.19	$0.05	0.16
Station 6B	764.10	$1.18	5.00
Storage 7A	81.09	$0.05	0.08
Station 6B	764.10	$1.18	5.00
Subtotal for Lumber 1x3xRL (cut from 12):	**1,771.47**	**$2.46**	**10.23**
Lumber 1x3xRL (cut from 14)			
Storage 18B	174.81	$0.11	0.17
Station 17	1,367.69	$1.02	5.00
Storage 7A	244.15	$0.07	0.23
Station 6B	764.10	$1.77	5.00

Storage 18B	87.40	$0.11	0.08
Station 18	1,393.30	$1.02	5.00
Storage 7A	122.08	$0.07	0.12
Station 6B	764.10	$1.77	5.00
Subtotal for Lumber 1x3xRL (cut from 14):	**4,917.62**	**$5.96**	**20.60**
Lumber 1x4xRL (cut from 14)			
Storage 18B	174.81	$0.04	0.17
Station 17	1,367.69	$1.02	5.00
Storage 18B	87.40	$0.11	0.08
Station 18	1,393.30	$1.02	5.00
Subtotal for Lumber 1x4xRL (cut from 14):	**3,023.20**	**$2.20**	**10.25**
Lumber 2x3x106 stud fj west			
Storage 7A	1,961.96	$0.05	1.88
Station 6B	764.10	$1.15	5.00
Storage 7A	735.73	$0.05	0.70
Station 6B	764.10	$1.15	5.00
Subtotal for Lumber 2x3x106 stud fj west:	**4,225.89**	**$2.39**	**12.58**
Lumber 2x3x22 (cut from 14)			
Storage 7A	3,051.94	$0.07	2.92
Station 6B	764.10	$1.77	5.00
Storage 7A	1,144.48	$0.07	1.09
Station 6B	764.10	$1.77	5.00
Subtotal for Lumber 2x3x22 (cut from 14):	**5,724.60**	**$3.68**	**14.01**
Lumber 2x3x8 stud			
Storage 8	736.17	$0.02	1.25
Station 8A	136.33	$0.40	5.00
Storage 9B	303.05	$0.04	0.63
Station 9A	585.14	$0.40	5.00
Subtotal for Lumber 2x3x8 stud:	**1,760.69**	**$0.86**	**11.88**
Lumber 2x3xRL (cut from 14)			
Storage 7A	326.99	$0.10	0.31
Station 6B	764.10	$2.36	5.00
Storage 7A	163.50	$0.27	0.16
Station 6B	764.10	$2.36	5.00
Subtotal for Lumber 2x3xRL (cut from 14):	**2,018.68**	**$5.08**	**10.47**
Lumber 2x6x10			
Storage 7A	639.18	$0.01	0.57
Station 7A	671.28	$0.37	5.00
Storage 7A	639.18	$0.01	0.57
Station 7A	671.28	$0.37	5.00
Storage 7A	122.72	$0.05	0.11
Station 7A	671.28	$0.37	5.00
Storage 7A	639.18	$0.04	0.57
Station 7A	671.28	$0.37	5.00
Subtotal for Lumber 2x6x10:	**4,725.42**	**$1.59**	**21.83**
Lumber 2x6x81			
Storage 7A	3,835.10	$0.09	3.44
Station 7A	671.28	$2.08	5.00

Storage 7A	3,835.10	$0.09	3.44
Station 7A	671.28	$2.08	5.00
Storage 7A	736.34	$0.23	0.66
Station 7A	671.28	$2.08	5.00
Storage 7A	3,835.10	$0.24	3.44
Station 7A	671.28	$2.08	5.00
Subtotal for Lumber 2x6x81:	**14,926.79**	**$8.96**	**30.97**
Lumber 2x6xRL (cut from 16)			
Storage 7A	576.80	$0.07	0.52
Station 7A	671.28	$1.63	5.00
Storage 7A	576.80	$0.07	0.52
Station 7A	671.28	$1.63	5.00
Storage 7A	576.80	$0.18	0.52
Station 7A	671.28	$1.63	5.00
Storage 7A	288.40	$0.07	0.26
Station 7A	671.28	$1.63	5.00
Subtotal for Lumber 2x6xRL (cut from 16):	**4,703.94**	**$6.92**	**21.81**
Lumber Closed Up			
Storage 26	21.32	$0.16	0.18
Station 34	544.46	$1.41	5.00
Storage 26	21.32	$0.16	0.18
Station 33	686.84	$1.41	5.00
Subtotal for Lumber Closed Up:	**1,273.94**	**$3.14**	**10.37**
Lumber LVL			
Storage 8	122.70	$0.00	0.21
Station 8A	136.33	$0.09	5.00
Storage 9A	102.91	$0.01	0.21
Station 9A	530.38	$0.09	5.00
Subtotal for Lumber LVL:	**892.33**	**$0.19**	**10.42**
Lumber, 3/4 #3btr			
Storage 4B	314.53	$0.12	0.47
Station 4B	272.01	$2.86	4.50
Storage 4B	143.29	$0.05	0.21
Station 4B	302.24	$1.32	5.00
Storage 4B	76.89	$0.03	0.11
Station 4B	302.24	$0.72	5.00
Storage 4B	148.53	$0.06	0.22
Station 4B	302.24	$1.36	5.00
Storage 4B	171.95	$0.06	0.26
Station 4B	302.24	$1.57	5.00
Storage 4B	188.72	$0.07	0.28
Station 4B	302.24	$1.73	5.00
Storage 4B	88.77	$0.03	0.13
Station 4B	302.24	$0.83	5.00
Storage 4B	71.99	$0.03	0.11
Station 4B	302.24	$0.67	5.00
Storage 4B	48.58	$0.02	0.07
Station 4B	302.24	$0.46	5.00

Storage 4B	112.18	$0.04	0.17
Station 4B	302.24	$1.04	5.00
Storage 4B	95.76	$0.04	0.14
Station 4B	302.24	$0.89	5.00
Storage 4B	234.15	$0.09	0.35
Station 4B	302.24	$2.14	5.00
Storage 4B	117.78	$0.04	0.18
Station 4B	302.24	$1.09	5.00
Storage 4B	26.21	$0.01	0.04
Station 4B	302.24	$0.26	5.00
Subtotal for Lumber, 3/4 #3btr:	**6,040.40**	**$17.62**	**72.24**
Lumber, mill room			
Storage 4B	31.45	$0.01	0.05
Station 4B	302.24	$0.31	5.00
Storage 4B	10.48	$0.00	0.02
Station 4B	302.24	$0.12	5.00
Storage 4B	149.58	$0.06	0.22
Station 4B	302.24	$1.37	5.00
Storage 4B	42.99	$0.02	0.06
Station 4B	302.24	$0.41	5.00
Subtotal for Lumber, mill room:	**1,443.45**	**$2.30**	**20.35**
Lumber-1x3xRL (cut from 14)			
Storage 5	16.85	$0.01	0.02
Station 5A	848.43	$0.29	5.00
Storage 5	48.33	$0.03	0.05
Station 5A	848.43	$0.82	5.00
Storage 5	15.86	$0.01	0.02
Station 5A	848.43	$0.28	5.00
Storage 5	54.87	$0.02	0.06
Station 5A	848.43	$0.56	5.00
Storage 5	23.98	$0.02	0.03
Station 5A	848.43	$0.42	5.00
Storage 5	34.25	$0.02	0.04
Station 5A	848.43	$0.59	5.00
Storage 5	16.99	$0.02	0.02
Station 5A	848.43	$0.15	5.00
Storage 5	35.39	$0.02	0.04
Station 5A	848.43	$0.60	5.00
Storage 5	24.64	$0.02	0.03
Station 5A	848.43	$0.21	5.00
Storage 5	16.99	$0.01	0.02
Station 5A	848.43	$0.15	5.00
Storage 5	25.91	$0.02	0.03
Station 5A	848.43	$0.22	5.00
Subtotal for Lumber-1x3xRL (cut from 14):	**9,646.75**	**$4.49**	**55.33**
Lumber-1x3xRL back (cut from 12)			
Storage 5	4.56	$0.00	0.00
Station 5A	848.43	$0.10	5.00

Storage 5	14.27	$0.01	0.02
Station 5A	848.43	$0.21	5.00
Storage 5	7.33	$0.00	0.01
Station 5A	848.43	$0.14	5.00
Storage 5	15.86	$0.01	0.02
Station 5A	848.43	$0.28	5.00
Storage 5	34.29	$0.02	0.04
Station 5A	848.43	$0.56	5.00
Storage 5	44.40	$0.03	0.05
Station 5A	848.43	$0.72	5.00
Storage 5	70.56	$0.07	0.07
Station 5A	848.43	$0.58	5.00
Storage 5	33.30	$0.02	0.04
Station 5A	848.43	$0.55	5.00
Storage 5	107.43	$0.11	0.11
Station 5A	848.43	$0.87	5.00
Storage 5	7.14	$0.00	0.01
Station 5A	848.43	$0.08	5.00
Storage 5	7.14	$0.01	0.01
Station 5A	848.43	$0.08	5.00
Storage 5	79.00	$0.08	0.08
Station 5A	848.43	$0.60	5.00
Storage 5	76.51	$0.03	0.08
Station 5A	848.43	$0.63	5.00
Storage 5	80.08	$0.07	0.08
Station 5A	848.43	$0.65	5.00
Subtotal for Lumber-1x3xRL back (cut from 12):	**12,459.85**	**$6.54**	**70.61**
Lumber-1x3xRL back (cut from 14)			
Storage 5	48.33	$0.03	0.05
Station 5A	848.43	$0.82	5.00
Storage 5	17.13	$0.01	0.02
Station 5A	848.43	$0.31	5.00
Storage 5	107.89	$0.03	0.11
Station 5A	848.43	$0.82	5.00
Storage 5	107.04	$0.11	0.11
Station 5A	848.43	$0.87	5.00
Subtotal for Lumber-1x3xRL back (cut from 14):	**3,674.09**	**$3.00**	**20.29**
Lumber-1x4xRL (cut from 14)			
Storage 5	11.42	$0.01	0.01
Station 5A	848.43	$0.21	5.00
Storage 5	34.40	$0.03	0.04
Station 5A	848.43	$0.28	5.00
Subtotal for Lumber-1x4xRL (cut from 14):	**1,742.68**	**$0.53**	**10.05**
Lumber-1x6xRL			
Storage 6	294.23	$0.07	0.28
Station 6A	698.85	$2.76	5.00
Storage 6	588.46	$0.07	0.55
Station 6A	698.85	$2.76	5.00

Subtotal for Lumber-1x6xRL:	**2,280.38**	**$5.67**	**10.83**
Lumber-2x3x8 stud			
Storage 5	130.08	$0.01	0.14
Station 5A	848.43	$0.25	5.00
Storage 5	95.14	$0.01	0.10
Station 5A	3,393.71	$0.23	20.00
Storage 5	37.17	$0.00	0.04
Station 5A	848.43	$0.09	5.00
Storage 5	74.33	$0.01	0.08
Station 5A	848.43	$0.15	5.00
Storage 5	74.33	$0.01	0.08
Station 5A	848.43	$0.15	5.00
Storage 5	111.50	$0.01	0.12
Station 5A	848.43	$0.22	5.00
Storage 5	99.11	$0.01	0.10
Station 5A	848.43	$0.09	5.00
Storage 5	247.77	$0.02	0.26
Station 5A	848.43	$0.18	5.00
Storage 5	74.33	$0.01	0.08
Station 5A	848.43	$0.15	5.00
Storage 5	99.11	$0.00	0.10
Station 5A	1,696.85	$0.12	10.00
Storage 5	99.11	$0.01	0.10
Station 5A	848.43	$0.09	5.00
Storage 5	346.87	$0.03	0.36
Station 5A	848.43	$0.25	5.00
Subtotal for Lumber-2x3x8 stud:	**15,063.67**	**$2.07**	**81.56**
Lumber-2x3x9 stud fj west			
Storage 5	63.43	$0.01	0.07
Station 5A	3,393.71	$0.23	20.00
Storage 5	74.33	$0.01	0.08
Station 5A	848.43	$0.15	5.00
Storage 5	37.17	$0.00	0.04
Station 5A	848.43	$0.09	5.00
Storage 5	445.98	$0.04	0.47
Station 5A	848.43	$0.31	5.00
Storage 5	99.11	$0.01	0.10
Station 5A	848.43	$0.09	5.00
Subtotal for Lumber-2x3x9 stud fj west:	**7,507.43**	**$0.93**	**40.76**
Lumber-2x3xRL (cut from 14)			
Storage 5	9.51	$0.01	0.01
Station 5A	848.43	$0.15	5.00
Storage 5	22.36	$0.02	0.02
Station 5A	848.43	$0.17	5.00
Storage 5	53.52	$0.05	0.06
Station 5A	848.43	$0.42	5.00
Subtotal for Lumber-2x3xRL (cut from 14):	**2,630.67**	**$0.82**	**15.09**
Lumber-2x4x8 stud			

Storage 5	23.79	$0.00	0.03
Station 5A	848.43	$0.06	5.00
Storage 5	247.77	$0.02	0.26
Station 5A	848.43	$0.18	5.00
Subtotal for Lumber-2x4x8 stud:	**1,968.41**	**$0.26**	**10.29**
Lumber-2x4x9 stud			
Storage 5	99.11	$0.00	0.10
Station 5A	848.43	$0.09	5.00
Subtotal for Lumber-2x4x9 stud:	**947.53**	**$0.09**	**5.10**
Lumber-2x4x9 stud fj west			
Storage 5	47.57	$0.00	0.05
Station 5A	848.43	$0.09	5.00
Storage 5	198.21	$0.02	0.21
Station 5A	848.43	$0.15	5.00
Subtotal for Lumber-2x4x9 stud fj west:	**1,942.64**	**$0.26**	**10.26**
Lumber-2x6x11			
Storage 7A	581.08	$0.01	0.52
Station 7A	671.28	$0.34	5.00
Storage 7A	581.08	$0.01	0.52
Station 7A	671.28	$0.34	5.00
Storage 5	89.20	$0.01	0.09
Station 6A	438.48	$0.49	5.00
Storage 7A	111.57	$0.04	0.10
Station 7A	671.28	$0.34	5.00
Storage 7A	581.08	$0.04	0.52
Station 7A	671.28	$0.34	5.00
Storage 5	89.20	$0.01	0.09
Station 6A	438.48	$0.49	5.00
Subtotal for Lumber-2x6x11:	**5,595.29**	**$2.45**	**31.85**
Lumber-2x6x14			
Storage 7A	232.43	$0.01	0.21
Station 7A	671.28	$0.15	5.00
Storage 7A	232.43	$0.01	0.21
Station 7A	671.28	$0.15	5.00
Storage 6	80.24	$0.01	0.08
Station 6A	698.85	$0.40	5.00
Storage 7A	44.63	$0.01	0.04
Station 7A	671.28	$0.15	5.00
Storage 7A	232.43	$0.01	0.21
Station 7A	671.28	$0.15	5.00
Storage 6	80.24	$0.01	0.08
Station 6A	698.85	$0.40	5.00
Subtotal for Lumber-2x6x14:	**4,985.24**	**$1.46**	**30.81**
Lumber-2x6x30			
Storage 7A	232.43	$0.01	0.21
Station 7A	671.28	$0.15	5.00
Storage 7A	232.43	$0.01	0.21
Station 7A	671.28	$0.15	5.00

Storage 6	40.12	$0.00	0.04
Station 6A	139.77	$0.19	1.00
Storage 7A	111.57	$0.02	0.10
Station 7A	671.28	$0.15	5.00
Storage 7A	232.43	$0.01	0.21
Station 7A	671.28	$0.15	5.00
Storage 6	40.12	$0.00	0.04
Station 6A	139.77	$0.19	1.00
Subtotal for Lumber-2x6x30:	**3,853.78**	**$1.04**	**22.80**
Lumber-2x6x44			
Storage 6	13.37	$0.00	0.01
Station 6A	698.85	$0.15	5.00
Storage 6	26.75	$0.00	0.03
Station 6A	698.85	$0.15	5.00
Subtotal for Lumber-2x6x44:	**1,437.81**	**$0.31**	**10.04**
Lumber-2x6x46			
Storage 7A	116.22	$0.00	0.10
Station 7A	61.03	$0.06	0.45
Storage 7A	116.22	$0.00	0.10
Station 7A	61.03	$0.06	0.45
Storage 6	13.37	$0.00	0.01
Station 6A	698.85	$0.15	5.00
Storage 7A	55.78	$0.01	0.05
Station 7A	61.03	$0.06	0.45
Storage 7A	116.22	$0.01	0.10
Station 7A	61.03	$0.06	0.45
Storage 6	26.75	$0.00	0.03
Station 6A	698.85	$0.15	5.00
Subtotal for Lumber-2x6x46:	**2,086.35**	**$0.59**	**12.22**
Lumber-2x6x7			
Storage 6	127.05	$0.02	0.12
Station 6A	698.85	$0.62	5.00
Storage 6	127.05	$0.02	0.12
Station 6A	698.85	$0.62	5.00
Subtotal for Lumber-2x6x7:	**1,651.80**	**$1.26**	**10.24**
Lumber-2x6x81			
Storage 6	441.34	$0.05	0.41
Station 6A	698.85	$2.08	5.00
Storage 6	441.34	$0.05	0.41
Station 6A	698.85	$2.08	5.00
Subtotal for Lumber-2x6x81:	**2,280.38**	**$4.27**	**10.83**
Lumber-2x6xRL			
Storage 6	294.23	$0.07	0.28
Station 6A	698.85	$2.76	5.00
Storage 6	588.46	$0.07	0.55
Station 6A	698.85	$2.76	5.00
Subtotal for Lumber-2x6xRL:	**2,280.38**	**$5.67**	**10.83**
Lumber-2x6xRL back			

Storage 7A	203.05	$0.02	0.18
Station 7A	671.28	$0.59	5.00
Storage 7A	203.05	$0.06	0.18
Station 7A	671.28	$0.59	5.00
Subtotal for Lumber-2x6xRL back:	**1,748.67**	**$1.27**	**10.36**
Lumber-3/4"			
Storage 6	111.27	$0.09	0.10
Station 6A	698.85	$3.26	5.00
Storage 6	111.27	$0.09	0.10
Station 6A	698.85	$3.26	5.00
Subtotal for Lumber-3/4":	**1,620.24**	**$6.69**	**10.21**
Mating Wall A			
Station 7	0.00	$0.01	5.00
Subtotal for Mating Wall A:	**0.00**	**$0.01**	**5.00**
Mating Wall B			
Station 7	0.00	$0.01	5.00
Subtotal for Mating Wall B:	**0.00**	**$0.01**	**5.00**
Mating Wall Stage A1			
Station 7	781.16	$0.60	5.00
Subtotal for Mating Wall Stage A1:	**781.16**	**$0.60**	**5.00**
Mating Wall Stage B1			
Station 7	781.16	$0.60	5.00
Subtotal for Mating Wall Stage B1:	**781.16**	**$0.60**	**5.00**
Mini Blind-A			
Storage 24	211.94	$0.00	0.42
Station 32	1,976.37	$0.06	5.00
Storage 24	211.94	$0.00	0.42
Station 31	1,764.85	$0.06	5.00
Subtotal for Mini Blind-A:	**4,165.09**	**$0.13**	**10.83**
Mini Blind-B			
Storage 24	1,059.68	$0.01	2.08
Station 32	1,976.37	$0.19	5.00
Storage 24	1,059.68	$0.02	2.08
Station 31	1,764.85	$0.19	5.00
Subtotal for Mini Blind-B:	**5,860.59**	**$0.40**	**14.17**
Mini Blind-C			
Storage 24	635.81	$0.01	1.25
Station 32	1,976.37	$0.12	5.00
Storage 24	635.81	$0.01	1.25
Station 31	1,764.85	$0.12	5.00
Subtotal for Mini Blind-C:	**5,012.84**	**$0.27**	**12.50**
Mirror Std			
Storage 27	379.75	$0.00	1.25
Station 32	2,857.94	$0.17	15.00
Storage 27	379.75	$0.01	1.25
Station 31	2,196.32	$0.17	15.00
Subtotal for Mirror Std:	**5,813.76**	**$0.36**	**32.50**
Mud			

Storage 9B	630.34	$0.00	1.30
Station 8B	532.91	$0.11	5.00
Storage 9B	350.19	$0.00	0.72
Station 9B	517.23	$0.11	5.00
Subtotal for Mud:	**2,030.67**	**$0.22**	**12.02**
Mud-g			
Storage 9B	775.80	$0.06	1.60
Station 8B	532.91	$0.52	5.00
Storage 9B	26.94	$0.02	0.06
Station 9B	517.23	$0.52	5.00
Subtotal for Mud-g:	**1,852.89**	**$1.12**	**11.66**
Novodeck-48x168			
Storage 2C	522.43	$0.09	2.33
Station 2D	379.52	$0.09	5.00
Storage 2C	1,119.50	$0.47	5.00
Station 2D	379.52	$0.09	5.00
Subtotal for Novodeck-48x168:	**2,400.97**	**$0.75**	**17.33**
Novodeck-96x168			
Storage 2C	5,224.31	$0.92	23.33
Station 2D	3,795.22	$0.92	50.00
Storage 2C	11,194.95	$4.71	50.00
Station 2D	3,795.22	$0.92	50.00
Subtotal for Novodeck-96x168:	**24,009.69**	**$7.47**	**173.33**
Nut			
Storage 4A	13.68	$0.12	0.02
Station 4A	31.65	$0.13	0.42
Subtotal for Nut:	**45.33**	**$0.25**	**0.44**
Nut-Ballock			
Station 2E	3.08	$0.06	0.01
Subtotal for Nut-Ballock:	**3.08**	**$0.06**	**0.01**
OSB Board			
Storage 23	70.90	$0.13	0.15
Station 32	1,803.26	$1.15	5.00
Storage 16	259.32	$0.23	0.27
Station 12	795.70	$2.02	5.00
Storage 23	70.90	$0.13	0.15
Station 31	1,567.84	$1.15	5.00
Storage 16	259.32	$0.27	0.27
Station 13	813.11	$2.02	5.00
Subtotal for OSB Board:	**5,640.34**	**$7.08**	**20.83**
OSB Board 7/16			
Storage 9C	2,861.12	$4.77	5.59
Station 10	2,300.25	$1.76	5.59
Storage 9C	2,861.12	$5.61	5.59
Station 11	2,311.43	$1.76	5.59
Subtotal for OSB Board 7/16:	**10,333.92**	**$13.90**	**22.37**
Outside Corner			
Storage 16	20.26	$0.01	0.02

Station 12	795.70	$0.15	5.00
Storage 16	20.26	$0.01	0.02
Station 13	813.11	$0.15	5.00
Subtotal for Outside Corner:	**1,649.33**	**$0.33**	**10.04**
Overhead Range Cabinet Assembly			
Station 4	455.63	$0.60	5.00
Subtotal for Overhead Range Cabinet Assembly:	**455.63**	**$0.60**	**5.00**
Pantry Shelf Assembly			
Station 4	455.63	$0.60	5.00
Subtotal for Pantry Shelf Assembly:	**455.63**	**$0.60**	**5.00**
Paper Roller			
Storage 24	211.94	$0.01	0.42
Station 32	1,976.37	$0.09	5.00
Subtotal for Paper Roller:	**2,188.31**	**$0.10**	**5.42**
Part A (Toilet & Kitchen)			
Station 35	657.93	$0.82	5.00
Subtotal for Part A (Toilet & Kitchen):	**657.93**	**$0.82**	**5.00**
Part B			
Station 35	656.08	$0.82	5.00
Subtotal for Part B:	**656.08**	**$0.82**	**5.00**
Pipe A			
Station 2E	3,291.28	$0.07	5.35
Subtotal for Pipe A:	**3,291.28**	**$0.07**	**5.35**
Pipe B			
Station 2E	307.60	$0.01	0.50
Subtotal for Pipe B:	**307.60**	**$0.01**	**0.50**
Pipe C			
Station 2E	892.03	$0.04	1.45
Subtotal for Pipe C:	**892.03**	**$0.04**	**1.45**
Pipe-1"			
Station 2E	76.90	$0.03	0.13
Subtotal for Pipe-1":	**76.90**	**$0.03**	**0.13**
Pipe-1/2"			
Station 2E	538.29	$0.03	0.88
Subtotal for Pipe-1/2":	**538.29**	**$0.03**	**0.88**
Pipe-3/4"			
Station 2E	51.27	$0.00	0.08
Subtotal for Pipe-3/4":	**51.27**	**$0.00**	**0.08**
Pipe-Range Hood			
Storage 26	581.54	$0.01	5.00
Station 32	339.96	$0.06	5.00
Subtotal for Pipe-Range Hood:	**921.50**	**$0.06**	**10.00**
Plate-Nail			
Storage 22	75.25	$0.04	0.17
Station 32	1,739.41	$1.07	5.00
Storage 22	75.25	$0.04	0.17
Station 31	1,493.59	$1.07	5.00
Subtotal for Plate-Nail:	**3,383.50**	**$2.22**	**10.33**

Plenum			
Storage 2D	55.07	$0.03	0.42
Station 2B	339.91	$0.06	5.00
Storage 2D	55.07	$0.03	0.42
Station 2B	339.91	$0.06	5.00
Subtotal for Plenum:	**789.97**	**$0.18**	**10.83**
Plug Cap			
Station 2E	123.04	$0.03	0.20
Subtotal for Plug Cap:	**123.04**	**$0.03**	**0.20**
Plug Cleanout			
Storage 4A	854.90	$0.10	1.25
Station 4A	379.82	$0.12	5.00
Station 2E	492.15	$0.13	0.80
Subtotal for Plug Cleanout:	**1,726.88**	**$0.35**	**7.05**
Plug Lift			
Storage 4A	569.93	$0.07	0.83
Station 4A	379.82	$0.09	5.00
Subtotal for Plug Lift:	**949.76**	**$0.16**	**5.83**
Plumbing Assembly			
Station 4	450.73	$0.01	5.00
Station 5	1,017.64	$0.01	5.00
Subtotal for Plumbing Assembly:	**1,468.37**	**$0.01**	**10.00**
P-Trap-A			
Station 2E	9,227.89	$0.19	15.00
Subtotal for P-Trap-A:	**9,227.89**	**$0.19**	**15.00**
P-Trap-B			
Station 2E	9,227.89	$0.19	15.00
Subtotal for P-Trap-B:	**9,227.89**	**$0.19**	**15.00**
P-Trap-C			
Station 2E	12,303.86	$0.26	20.00
Subtotal for P-Trap-C:	**12,303.86**	**$0.26**	**20.00**
Range Gas			
Storage 26	581.54	$0.00	5.00
Station 32	339.96	$0.06	5.00
Subtotal for Range Gas:	**921.50**	**$0.06**	**10.00**
Range Hood			
Storage 26	581.54	$0.00	5.00
Station 32	339.96	$0.06	5.00
Subtotal for Range Hood:	**921.50**	**$0.06**	**10.00**
Receptacle-dryer			
Storage 15	101.91	$0.03	0.10
Station 6A1	769.91	$0.06	5.00
Subtotal for Receptacle-dryer:	**871.82**	**$0.09**	**5.10**
Receptacle-duplex			
Storage 15	254.78	$0.78	0.25
Station 6A1	769.91	$0.81	5.00
Storage 15	254.78	$0.78	0.25
Station 6A1	769.91	$0.81	5.00

Subtotal for Receptacle-duplex:	**2,049.38**	**$3.19**	**10.50**
Receptacle-GFI			
Storage 15	305.74	$0.10	0.30
Station 6A1	769.91	$0.12	5.00
Storage 15	305.74	$0.10	0.30
Station 6A1	769.91	$0.12	5.00
Subtotal for Receptacle-GFI:	**2,151.30**	**$0.43**	**10.60**
Refer, 16f			
Storage 26	581.54	$0.00	5.00
Station 32	339.96	$0.06	5.00
Subtotal for Refer, 16f:	**921.50**	**$0.06**	**10.00**
Reference Shelf			
Station 4	455.63	$0.60	5.00
Subtotal for Reference Shelf:	**455.63**	**$0.60**	**5.00**
Refrigerators			
Storage 26	581.54	$0.00	5.00
Station 32	339.96	$0.06	5.00
Subtotal for Refrigerators:	**921.50**	**$0.06**	**10.00**
Register			
Storage 2D	220.29	$0.26	1.67
Station 2B	339.91	$0.27	5.00
Storage 2D	220.29	$0.26	1.67
Station 2B	339.91	$0.27	5.00
Subtotal for Register:	**1,120.41**	**$1.06**	**13.33**
Return Air Grill			
Storage 26	581.54	$0.01	5.00
Station 32	679.92	$0.11	10.00
Subtotal for Return Air Grill:	**1,261.46**	**$0.12**	**15.00**
Ring Wax			
Storage 4A	142.48	$0.06	0.21
Station 4A	379.82	$0.09	5.00
Subtotal for Ring Wax:	**522.31**	**$0.15**	**5.21**
Roof Cement			
Storage 16	1,021.05	$0.01	1.05
Station 10	864.66	$0.09	5.00
Storage 16	1,021.05	$0.01	1.05
Station 11	816.33	$0.09	5.00
Subtotal for Roof Cement:	**3,723.09**	**$0.20**	**12.10**
Roof Jack			
Storage 2D	660.87	$0.06	5.00
Station 2B	339.91	$0.06	5.00
Storage 2D	660.87	$0.06	5.00
Station 2B	339.91	$0.06	5.00
Subtotal for Roof Jack:	**2,001.57**	**$0.23**	**20.00**
Roof Vent			
Storage 16	1,620.72	$0.03	1.67
Station 10	3,458.62	$0.36	20.00
Storage 16	1,620.72	$0.03	1.67

Station 11	3,265.32	$0.36	20.00
Subtotal for Roof Vent:	**9,965.39**	**$0.78**	**43.33**
Seat Toilet			
Storage 4A	1,139.87	$0.07	1.67
Station 4A	759.65	$0.11	10.00
Subtotal for Seat Toilet:	**1,899.51**	**$0.19**	**11.67**
Self Edge			
Storage 4B	397.01	$0.02	0.59
Station 4B	302.24	$0.47	5.00
Storage 4B	343.89	$0.02	0.51
Station 4B	302.24	$0.41	5.00
Storage 4B	69.90	$0.00	0.10
Station 4B	302.24	$0.10	5.00
Storage 4B	83.88	$0.00	0.13
Station 4B	302.24	$0.12	5.00
Subtotal for Self Edge:	**2,103.62**	**$1.15**	**21.33**
SGL Underlayment			
Storage 16	2,285.22	$6.68	2.35
Station 10	8,127.76	$59.47	47.00
Storage 16	2,285.22	$7.85	2.35
Station 11	7,673.51	$59.47	47.00
Subtotal for SGL Underlayment:	**20,371.71**	**$133.47**	**98.70**
Sheathing Goldguard			
Storage 16	1,335.88	$3.91	1.37
Station 12	437.24	$34.21	2.75
Storage 16	1,335.88	$3.91	1.37
Station 13	446.80	$34.21	2.75
Subtotal for Sheathing Goldguard:	**3,555.80**	**$76.23**	**8.24**
Sheathing-Goldguard			
Storage 9B	81.82	$0.05	0.17
Station 8B	532.91	$1.29	5.00
Storage 9B	81.82	$0.14	0.17
Station 9B	517.23	$1.29	5.00
Subtotal for Sheathing-Goldguard:	**1,213.79**	**$2.77**	**10.34**
Shelving-Wire Closet			
Storage 28	36.32	$0.03	0.13
Station 30	110.02	$0.83	0.50
Storage 28	36.32	$0.09	0.13
Station 29	91.35	$0.83	0.50
Subtotal for Shelving-Wire Closet:	**274.01**	**$1.79**	**1.26**
Shingles			
Storage 16	3,525.07	$0.02	3.63
Station 10	12,537.51	$0.84	72.50
Storage 16	3,525.07	$0.06	3.63
Station 11	11,836.80	$0.84	72.50
Subtotal for Shingles:	**31,424.44**	**$1.76**	**152.25**
Shower Curtain Ring			
Storage 27	15.19	$0.02	0.05

Station 32	952.65	$0.40	5.00
Subtotal for Shower Curtain Ring:	**967.84**	**$0.42**	**5.05**
Shower Door			
Storage 4A	427.45	$0.00	0.63
Station 4A	379.82	$0.06	5.00
Subtotal for Shower Door:	**807.27**	**$0.06**	**5.63**
Shower Fiberglass			
Storage 4A	3,419.61	$0.00	5.00
Station 4A	379.82	$0.06	5.00
Subtotal for Shower Fiberglass:	**3,799.43**	**$0.06**	**10.00**
Shower Head			
Storage 4A	3,419.61	$0.06	5.00
Station 4A	379.82	$0.06	5.00
Subtotal for Shower Head:	**3,799.43**	**$0.12**	**10.00**
Shower Head-Kit Chrome			
Storage 4A	569.93	$0.04	0.83
Station 4A	379.82	$0.06	5.00
Subtotal for Shower Head-Kit Chrome:	**949.76**	**$0.09**	**5.83**
Shower Liner			
Storage 27	15.19	$0.00	0.05
Station 32	952.65	$0.06	5.00
Subtotal for Shower Liner:	**967.84**	**$0.06**	**5.05**
Shower Rod			
Storage 27	31.65	$0.00	0.10
Station 32	952.65	$0.06	5.00
Subtotal for Shower Rod:	**984.29**	**$0.06**	**5.10**
Side Floor Joists			
Station 2B	3,516.08	$0.17	20.00
Station 2B	3,516.08	$0.17	20.00
Subtotal for Side Floor Joists:	**7,032.16**	**$0.34**	**40.00**
Side Wall A			
Station 7	163.76	$0.01	5.00
Subtotal for Side Wall A:	**163.76**	**$0.01**	**5.00**
Side Wall B			
Station 7	163.76	$0.01	5.00
Subtotal for Side Wall B:	**163.76**	**$0.01**	**5.00**
Side Wall Stage-1			
Station 6	784.02	$0.60	5.00
Station 6	784.02	$0.60	5.00
Subtotal for Side Wall Stage-1:	**1,568.05**	**$1.21**	**10.00**
Siding Double			
Storage 16	2,820.05	$0.04	2.90
Station 12	795.70	$0.39	5.00
Storage 16	2,820.05	$0.04	2.90
Station 13	813.11	$0.39	5.00
Subtotal for Siding Double:	**7,248.92**	**$0.86**	**15.80**
Sink Base Cabinet Assembly			
Station 4	455.63	$0.60	5.00

Subtotal for Sink Base Cabinet Assembly:	**455.63**	**$0.60**	**5.00**
Sink Kit			
Storage 4A	3,419.61	$0.06	5.00
Station 4A	379.82	$0.06	5.00
Subtotal for Sink Kit:	**3,799.43**	**$0.12**	**10.00**
Skylite lip moulding			
Storage 28	93.90	$0.24	0.34
Station 30	1,100.20	$2.17	5.00
Storage 28	93.90	$0.24	0.34
Station 29	913.54	$2.17	5.00
Subtotal for Skylite lip moulding:	**2,201.54**	**$4.82**	**10.68**
SleeveWire			
Storage 22	18.24	$0.05	0.04
Station 32	1,739.41	$1.29	5.00
Storage 22	18.24	$0.05	0.04
Station 31	1,493.59	$1.29	5.00
Subtotal for SleeveWire:	**3,269.49**	**$2.68**	**10.08**
Smoke Detector			
Storage 23	393.91	$0.00	0.83
Station 32	1,803.26	$0.06	5.00
Subtotal for Smoke Detector:	**2,197.16**	**$0.06**	**5.83**
Soffit Receiver			
Storage 16	1,361.41	$0.50	1.40
Station 12	795.70	$4.38	5.00
Storage 16	1,361.41	$0.50	1.40
Station 13	813.11	$4.38	5.00
Subtotal for Soffit Receiver:	**4,331.62**	**$9.76**	**12.80**
Soffit Vented			
Storage 16	3,160.40	$0.46	3.25
Station 12	795.70	$4.07	5.00
Storage 16	632.08	$0.46	0.65
Station 13	813.11	$4.07	5.00
Subtotal for Soffit Vented:	**5,401.30**	**$9.07**	**13.90**
Sprinkler Head			
Station 2E	128.17	$0.03	0.21
Subtotal for Sprinkler Head:	**128.17**	**$0.03**	**0.21**
Starter Strip			
Storage 16	3,403.51	$0.50	3.50
Station 12	795.70	$4.38	5.00
Storage 16	680.70	$0.50	0.70
Station 13	813.11	$4.38	5.00
Subtotal for Starter Strip:	**5,693.03**	**$9.76**	**14.20**
Stile			
Storage 15	29.30	$0.01	0.03
Station 6A1	769.91	$0.24	5.00
Subtotal for Stile:	**799.21**	**$0.25**	**5.03**
Stile 2"			
Storage 4B	77.17	$0.02	0.12

Station 4B	302.24	$0.39	5.00
Storage 4B	30.87	$0.01	0.05
Station 4B	302.24	$0.17	5.00
Storage 4B	162.38	$0.03	0.24
Station 4B	302.24	$0.79	5.00
Storage 4B	235.52	$0.05	0.35
Station 4B	302.24	$1.13	5.00
Storage 4B	33.55	$0.01	0.05
Station 4B	302.24	$0.18	5.00
Storage 4B	58.38	$0.01	0.09
Station 4B	302.24	$0.30	5.00
Storage 4B	47.64	$0.01	0.07
Station 4B	302.24	$0.25	5.00
Storage 4B	101.32	$0.02	0.15
Station 4B	302.24	$0.50	5.00
Storage 4B	152.99	$0.03	0.23
Station 4B	302.24	$0.74	5.00
Storage 4B	24.16	$0.00	0.04
Station 4B	302.24	$0.14	5.00
Storage 4B	67.77	$0.01	0.10
Station 4B	302.24	$0.34	5.00
Storage 4B	106.02	$0.02	0.16
Station 4B	302.24	$0.52	5.00
Storage 4B	19.46	$0.00	0.03
Station 4B	302.24	$0.12	5.00
Subtotal for Stile 2":	**5,046.29**	**$5.79**	**66.67**
Stile 3"			
Storage 4B	47.64	$0.01	0.07
Station 4B	302.24	$0.25	5.00
Storage 4B	42.94	$0.01	0.06
Station 4B	302.24	$0.23	5.00
Storage 4B	85.22	$0.02	0.13
Station 4B	302.24	$0.42	5.00
Storage 4B	38.25	$0.01	0.06
Station 4B	302.24	$0.20	5.00
Storage 4B	25.50	$0.00	0.04
Station 4B	302.24	$0.14	5.00
Storage 4B	16.78	$0.00	0.03
Station 4B	302.24	$0.10	5.00
Storage 4B	13.42	$0.00	0.02
Station 4B	302.24	$0.09	5.00
Storage 4B	40.26	$0.01	0.06
Station 4B	302.24	$0.21	5.00
Storage 4B	35.56	$0.01	0.05
Station 4B	302.24	$0.19	5.00
Storage 4B	43.62	$0.01	0.07
Station 4B	302.24	$0.23	5.00
Storage 4B	50.33	$0.01	0.08

Station 4B	302.24	$0.26	5.00
Subtotal for Stile 3":	**3,764.10**	**$2.42**	**55.66**
Strainer Basket			
Storage 4A	569.93	$0.07	0.83
Station 4A	759.65	$0.11	10.00
Subtotal for Strainer Basket:	**1,329.58**	**$0.18**	**10.83**
Strainer Shower			
Storage 4A	854.90	$0.04	1.25
Station 4A	379.82	$0.06	5.00
Subtotal for Strainer Shower:	**1,234.72**	**$0.10**	**6.25**
Strapping steel			
Storage 2D	13.22	$0.01	0.10
Station 2B	169.96	$0.14	2.50
Storage 2D	13.22	$0.01	0.10
Station 2B	169.96	$0.14	2.50
Subtotal for Strapping steel:	**366.35**	**$0.28**	**5.20**
Support Shelf			
Storage 28	920.61	$0.03	3.33
Station 30	733.46	$0.27	3.33
Storage 28	55.24	$0.01	0.20
Station 29	609.03	$0.27	3.33
Subtotal for Support Shelf:	**2,318.34**	**$0.57**	**10.20**
Switch Ground Screw			
Storage 15	305.74	$0.47	0.30
Station 6A1	769.91	$0.50	5.00
Storage 15	305.74	$0.47	0.30
Station 6A1	769.91	$0.50	5.00
Subtotal for Switch Ground Screw:	**2,151.30**	**$1.94**	**10.60**
Switch Plate-A			
Storage 15	509.57	$0.16	0.50
Station 6A1	769.91	$0.18	5.00
Storage 15	509.57	$0.16	0.50
Station 6A1	769.91	$0.18	5.00
Subtotal for Switch Plate-A:	**2,558.95**	**$0.69**	**11.00**
Switch Plate-B			
Storage 15	1,936.35	$0.61	1.90
Station 6A1	769.91	$0.62	5.00
Storage 15	1,936.35	$0.61	1.90
Station 6A1	769.91	$0.62	5.00
Subtotal for Switch Plate-B:	**5,412.52**	**$2.46**	**13.80**
Switch Plate-C			
Storage 15	509.57	$0.16	0.50
Station 6A1	769.91	$0.18	5.00
Storage 15	509.57	$0.16	0.50
Station 6A1	769.91	$0.18	5.00
Subtotal for Switch Plate-C:	**2,558.95**	**$0.69**	**11.00**
Switch Plate-D			
Storage 15	305.74	$0.10	0.30

Station 6A1	769.91	$0.12	5.00
Subtotal for Switch Plate-D:	**1,075.65**	**$0.22**	**5.30**
Tank Toilet			
Storage 4A	6,839.21	$0.13	10.00
Station 4A	759.65	$0.11	10.00
Subtotal for Tank Toilet:	**7,598.86**	**$0.24**	**20.00**
Tape Mesh			
Storage 9B	2.18	$0.00	0.00
Station 8B	532.91	$0.05	5.00
Storage 9B	109.10	$0.00	0.23
Station 9B	517.23	$0.05	5.00
Subtotal for Tape Mesh:	**1,161.42**	**$0.11**	**10.23**
Tee			
Station 2E	128.17	$0.03	0.21
Station 2E	3,075.96	$0.06	5.00
Station 2E	256.33	$0.03	0.42
Subtotal for Tee:	**3,460.46**	**$0.13**	**5.63**
Tee-A			
Station 2E	1,281.65	$0.32	2.08
Station 2E	6,151.93	$0.13	10.00
Subtotal for Tee-A:	**7,433.58**	**$0.45**	**12.08**
Tee-B			
Station 2E	128.17	$0.03	0.21
Subtotal for Tee-B:	**128.17**	**$0.03**	**0.21**
Tee-C			
Station 2E	128.17	$0.03	0.21
Subtotal for Tee-C:	**128.17**	**$0.03**	**0.21**
Tee-D			
Station 2E	128.17	$0.03	0.21
Subtotal for Tee-D:	**128.17**	**$0.03**	**0.21**
Tee-E			
Station 2E	640.83	$0.16	1.04
Subtotal for Tee-E:	**640.83**	**$0.16**	**1.04**
Test Cap			
Station 2E	256.33	$0.06	0.42
Subtotal for Test Cap:	**256.33**	**$0.06**	**0.42**
Test Plug			
Station 2E	256.33	$0.06	0.42
Subtotal for Test Plug:	**256.33**	**$0.06**	**0.42**
Thermostat			
Storage 15	764.35	$0.94	0.75
Station 6A1	769.91	$0.96	5.00
Storage 15	764.35	$0.94	0.75
Station 6A1	769.91	$0.96	5.00
Subtotal for Thermostat:	**3,068.51**	**$3.80**	**11.50**
Tie Strap			
Storage 2D	13.22	$0.01	0.10
Station 2B	169.96	$0.14	2.50

Storage 2D	13.22	$0.01	0.10
Station 2B	169.96	$0.14	2.50
Subtotal for Tie Strap:	**366.35**	**$0.29**	**5.20**
Towel Bar			
Storage 27	63.29	$0.01	0.21
Station 32	952.65	$0.09	5.00
Subtotal for Towel Bar:	**1,015.94**	**$0.10**	**5.21**
Trim - A			
Station 32	877.13	$0.01	5.00
Subtotal for Trim - A:	**877.13**	**$0.01**	**5.00**
Trim - B			
Station 31	875.35	$0.01	5.00
Subtotal for Trim - B:	**875.35**	**$0.01**	**5.00**
Trim Stage A1			
Station 19B	878.79	$0.01	5.00
Station 20B	940.00	$0.01	5.00
Station 21B	940.00	$0.01	5.00
Station 22B	616.72	$0.01	5.00
Station 24	8,381.68	$0.88	5.00
Station 26	500.00	$0.82	5.00
Subtotal for Trim Stage A1:	**12,257.19**	**$1.73**	**30.00**
Trim Stage B1			
Station 19A	880.30	$0.01	5.00
Station 20A	940.00	$0.01	5.00
Station 21A	940.00	$0.01	5.00
Station 22A	615.69	$0.01	5.00
Station 23	8,499.09	$0.88	5.00
Station 25	497.85	$0.82	5.00
Subtotal for Trim Stage B1:	**12,372.93**	**$1.73**	**30.00**
Trim Stage A2			
Station 28	500.00	$0.82	5.00
Station 30	500.00	$0.82	5.00
Subtotal for Trim Stage A2:	**1,000.00**	**$1.65**	**10.00**
Trim Stage B2			
Station 27	501.40	$0.82	5.00
Station 29	498.60	$0.82	5.00
Subtotal for Trim Stage B2:	**1,000.00**	**$1.65**	**10.00**
Trusses			
Storage 8	299.42	$0.00	0.50
Station 8A	272.67	$0.08	10.00
Storage 9B	237.57	$0.00	0.50
Station 9A	1,170.27	$0.08	10.00
Subtotal for Trusses:	**1,979.93**	**$0.17**	**21.00**
Tub corner			
Storage 4A	3,419.61	$0.00	5.00
Station 4A	379.82	$0.06	5.00
Subtotal for Tub corner:	**3,799.43**	**$0.06**	**10.00**
Tub Fibreglass			

Storage 4A	3,419.61	$0.00	5.00
Station 4A	379.82	$0.06	5.00
Subtotal for Tub Fibreglass:	**3,799.43**	**$0.06**	**10.00**
Tube			
Storage 4A	284.97	$0.03	0.42
Station 4A	379.82	$0.06	5.00
Subtotal for Tube:	**664.79**	**$0.09**	**5.42**
Tubing-A			
Station 2E	236.85	$2.40	0.39
Subtotal for Tubing-A:	**236.85**	**$2.40**	**0.39**
Tubing-B			
Station 2E	258.38	$2.62	0.42
Subtotal for Tubing-B:	**258.38**	**$2.62**	**0.42**
Tubing-C			
Station 2E	178.41	$1.81	0.29
Subtotal for Tubing-C:	**178.41**	**$1.81**	**0.29**
Tubing-D			
Station 2E	89.20	$0.90	0.15
Subtotal for Tubing-D:	**89.20**	**$0.90**	**0.15**
Tyre			
Storage 1	229.93	$0.01	1.50
Station 1A	719.02	$0.02	5.00
Storage 1	229.93	$0.01	1.50
Station 1A	719.02	$0.02	5.00
Subtotal for Tyre:	**1,897.90**	**$0.05**	**13.00**
U-Channel			
Storage 27	172.16	$0.04	0.57
Station 32	952.65	$1.10	5.00
Storage 27	103.29	$0.12	0.34
Station 31	732.11	$1.10	5.00
Subtotal for U-Channel:	**1,960.20**	**$2.36**	**10.91**
Valve			
Storage 4A	284.97	$0.03	0.42
Station 4A	379.82	$0.06	5.00
Station 2E	256.33	$0.06	0.42
Subtotal for Valve:	**921.12**	**$0.16**	**5.83**
Valve-Gas Ball			
Station 2E	256.33	$0.06	0.42
Subtotal for Valve-Gas Ball:	**256.33**	**$0.06**	**0.42**
Vanity Cabinet Module-A			
Station 4	455.63	$0.60	5.00
Subtotal for Vanity Cabinet Module-A:	**455.63**	**$0.60**	**5.00**
Vanity Cabinet Module-B			
Station 4	455.63	$0.60	5.00
Subtotal for Vanity Cabinet Module-B:	**455.63**	**$0.60**	**5.00**
Vapor Barrier			
Storage 9B	71.03	$0.00	0.15
Station 8B	532.91	$0.12	5.00

Storage 9B	710.35	$0.01	1.47
Station 9B	517.23	$0.12	5.00
Subtotal for Vapor Barrier:	**1,831.52**	**$0.25**	**11.61**
Vent			
Station 2E	768.99	$0.01	1.25
Subtotal for Vent:	**768.99**	**$0.01**	**1.25**
Ventilaire			
Storage 2D	660.87	$0.06	5.00
Station 2B	339.91	$0.06	5.00
Storage 2D	660.87	$0.06	5.00
Station 2B	339.91	$0.06	5.00
Subtotal for Ventilaire:	**2,001.57**	**$0.23**	**20.00**
Vermin Proofer			
Storage 4A	427.45	$0.00	0.63
Station 4A	379.82	$0.09	5.00
Station 2E	6,151.93	$0.13	10.00
Subtotal for Vermin Proofer:	**6,959.20**	**$0.22**	**15.63**
Vermin Proofer-A			
Station 2E	1,281.65	$0.32	2.08
Subtotal for Vermin Proofer-A:	**1,281.65**	**$0.32**	**2.08**
Vermin Proofer-B			
Station 2E	384.50	$0.10	0.63
Subtotal for Vermin Proofer-B:	**384.50**	**$0.10**	**0.63**
Vermin Proofer-C			
Station 2E	512.66	$0.13	0.83
Subtotal for Vermin Proofer-C:	**512.66**	**$0.13**	**0.83**
Washer			
Storage 2D	1,607.21	$0.37	2.84
Station 2B	339.91	$0.37	5.00
Storage 2D	803.60	$1.19	1.42
Station 2B	339.91	$1.19	5.00
Subtotal for Washer:	**3,090.63**	**$3.12**	**14.26**
Waste Cont			
Storage 4A	3,419.61	$0.00	5.00
Station 4A	379.82	$0.06	5.00
Subtotal for Waste Cont:	**3,799.43**	**$0.06**	**10.00**
Water Heater			
Storage 4A	3,419.61	$0.00	5.00
Station 4A	379.82	$0.06	5.00
Subtotal for Water Heater:	**3,799.43**	**$0.06**	**10.00**
Water Supply Assembly			
Station 2D	728.81	$0.06	5.00
Subtotal for Water Supply Assembly:	**728.81**	**$0.06**	**5.00**
Window Metal-30x27			
Storage 16	607.77	$0.00	0.63
Station 12	795.70	$0.06	5.00
Subtotal for Window Metal-30x27:	**1,403.48**	**$0.06**	**5.63**
Window Metal-30x27 white storm			

Storage 16	607.77	$0.00	0.63
Station 12	795.70	$0.06	5.00
Subtotal for Window Metal-30x27 white storm:	**1,403.48**	**$0.06**	**5.63**
Window Metal-30x60			
Storage 16	3,038.85	$0.02	3.13
Station 12	795.70	$0.18	5.00
Subtotal for Window Metal-30x60:	**3,834.56**	**$0.20**	**8.13**
Window Metal-30x60 white storm			
Storage 16	3,038.85	$0.02	3.13
Station 12	795.70	$0.18	5.00
Subtotal for Window Metal-30x60 white storm:	**3,834.56**	**$0.20**	**8.13**
Window Metal-46x60			
Storage 16	1,823.31	$0.01	1.88
Station 12	795.70	$0.12	5.00
Storage 16	607.77	$0.01	0.63
Station 13	813.11	$0.12	5.00
Subtotal for Window Metal-46x60:	**4,039.89**	**$0.26**	**12.50**
Wire-A			
Storage 15	2,993.70	$21.96	2.94
Station 6A1	723.71	$22.23	4.70
Storage 15	2,993.70	$21.96	2.94
Station 6A1	723.71	$22.23	4.70
Subtotal for Wire-A:	**7,434.82**	**$88.38**	**15.28**
Wire-B			
Storage 15	997.90	$7.32	0.98
Station 6A1	769.91	$7.43	5.00
Storage 15	997.90	$7.32	0.98
Station 6A1	769.91	$7.43	5.00
Subtotal for Wire-B:	**3,535.62**	**$29.50**	**11.96**
Wire-C			
Storage 15	42.46	$0.31	0.04
Station 6A1	769.91	$0.34	5.00
Storage 15	42.46	$0.31	0.04
Station 6A1	769.91	$0.34	5.00
Subtotal for Wire-C:	**1,624.75**	**$1.31**	**10.08**
Wire-Copper			
Station 2E	0.43	$0.00	0.00
Subtotal for Wire-Copper:	**0.43**	**$0.00**	**0.00**
Wire-D			
Storage 15	50.96	$0.37	0.05
Station 6A1	769.91	$0.40	5.00
Storage 15	50.96	$0.37	0.05
Station 6A1	769.91	$0.40	5.00
Subtotal for Wire-D:	**1,641.73**	**$1.56**	**10.10**
Wire-E			
Storage 15	42.46	$0.31	0.04
Station 6A1	769.91	$0.34	5.00
Storage 15	42.46	$0.31	0.04

	Station 6A1	769.91	$0.34	5.00
	Subtotal for Wire-E:	**1,624.75**	**$1.31**	**10.08**
	Wire-Red			
	Storage 1	61.74	$0.15	0.40
	Station 1A	695.05	$3.68	4.83
	Storage 1	61.74	$0.15	0.40
	Station 1A	695.05	$3.68	4.83
	Subtotal for Wire-Red:	**1,513.59**	**$7.66**	**10.47**
	Wye A			
	Station 2E	768.99	$0.13	1.25
	Subtotal for Wye A:	**768.99**	**$0.13**	**1.25**
	Wye B			
	Station 2E	576.74	$0.10	0.94
	Subtotal for Wye B:	**576.74**	**$0.10**	**0.94**
	Wye C			
	Station 2E	576.74	$0.10	0.94
	Subtotal for Wye C:	**576.74**	**$0.10**	**0.94**
	Total for House:	**1,037,106.45**	**$1,385.01**	**5,058.61**
Grand Total:		**1,037,106.45**	**$1,385.01**	**5,058.61**

APPENDIX-F

EXISTING FLOOR CLUSTER PRODUCTION SIMULATION REPORT

ARENA Simulation Results
Dr. R.L. Tummala - License #9710524

Summary for Replication 1 of 1

Project: Floor Cluster Si Run execution date : 11/

1/2004
Analyst: Abhi Sabharwal Model revision date:

6/14/2004

Replication ended at time : 10287.3

TALLY VARIABLES

Identifier Average Half Width Minimum Maximum

Observations

_

Depart 1_Ta 6.6839 (Insuf) 6.0029 7.3665

201
Move Electric Hoist Up .00000 (Insuf) .00000 .00000

201
Spread Floor Decking o .00000 (Insuf) .00000 .00000

201
Spread glue over Joist .00000 (Insuf) .00000 .00000

201
Mark and Cut Holes for .00000 (Insuf) .00000 .00000

201
Attach HVAC ducts to f .00000 (Insuf) .00000 .00000

201
Put Glue over Band Joi .00000 (Insuf) .00000 .00000

201

Attach Lumber with Bra .00000 (Insuf) .00000 .00000

201
Attach Plastic Membran .00000 (Insuf) .00000 .00000

201
Delay 1_R_Q Queue Time 2900.0 (Insuf) .00000 5800.0

201
Run Basic Electrical_R 12.233 (Insuf) .00000 339.53

201
Attach Main Axle with .00411 (Insuf) .00000 .82665

201
Lower Chassis Frame ov .00000 (Insuf) .00000 .00000

201
Allign Band Joists at .00000 (Insuf) .00000 .00000

201
put Headers onto the C .00000 (Insuf) .00000 .00000

201
Delay 2_R_Q Queue Time 1983.9 (Insuf) .00000 3997.2

201
Attach PVC Linolium to .00000 (Insuf) .00000 .00000

201
Attach Floor Decking t .00000 (Insuf) .00000 .00000

201
get the Plumbing Out_R .00000 (Insuf) .00000 .00000

201
Put Rough Plumbing and .00000 (Insuf) .00000 .00000

201
Move Electric Hoist Up .00000 (Insuf) .00000 .00000

201
Delay 3_R_Q Queue Time .36106 (Insuf) .00000 13.835

201

Bring out HVAC_R_Q Que .00000 (Insuf) .00000 .00000

201
Attach joists Band joi .00000 (Insuf) .00000 .00000

201
Lower the Chassis Fram .00000 (Insuf) .00000 .00000

201
Load Chassis Frame on .00000 (Insuf) .00000 .00000

201
Bring Subfloor into th .00000 (Insuf) .00000 .00000

201
Spread joists over Cha .00000 (Insuf) .00000 .00000

201
Remove Chassis from St .44857 (Insuf) .00000 15.114

201
Spread Insulation_R_Q .00000 (Insuf) .00000 .00000

201
Set Insulation_R_Q Que .00000 (Insuf) .00000 .00000

201
Remove Subfloor from S .00000 (Insuf) .00000 .00000

201
Bring Chassis into Sta .00000 (Insuf) .00000 .00000

201
Spread Plastic Membran .00000 (Insuf) .00000 .00000

201
Attach Lumbers to Buil .00000 (Insuf) .00000 .00000

201
Attach Tires to Main A .03666 (Insuf) .00000 3.3974

201
Move the Floor to the .00000 (Insuf) .00000 .00000

201

Bring Chassis into Sub .00000 (Insuf) .00000 .00000

201

DISCRETE-CHANGE VARIABLES

Identifier Average Half Width Minimum Maximum Final

Value

_

______

Attach HVAC ducts to f .23714 .01244 .00000 1.0000

.00000
in Lower the Chassis .00000 (Insuf) .00000 .00000

.00000
Delay 1_R Busy .58616 (Insuf) .00000 1.0000

.00000
Lower Chassis Frame ov .03498 (Corr) .00000 1.0000

.00000
Mark and Cut Holes for 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Attach Lumbers to .00000 (Insuf) .00000 .00000

.00000
in Run Basic Electri .23902 (Insuf) .00000 12.000

.00000
Move Electric Hoist Up 1.0000 (Insuf) 1.0000 1.0000

1.0000
in put Headers onto .00000 (Insuf) .00000 .00000

.00000
Allign Band Joists at .02784 .00128 .00000 1.0000

.00000
Attach joists Band joi .11052 .00630 .00000 1.0000

.00000
Remove Chassis from St 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Remove Subfloor f .00000 (Insuf) .00000 .00000

.00000
Attach Lumber with Bra .16145 (Corr) .00000 1.0000

.00000
Remove Subfloor from S 1.0000 (Insuf) 1.0000 1.0000

1.0000
Bring Chassis into Sta 1.0000 (Insuf) 1.0000 1.0000

1.0000
Spread glue over Joist .06538 (Corr) .00000 1.0000

.00000
Attach Floor Decking t .24592 .01469 .00000 1.0000

.00000
in Attach Tires to M 7.1630E-04 (Insuf) .00000 1.0000

.00000
Move Electric Hoist Up 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Bring Chassis int .00000 (Insuf) .00000 .00000

.00000
Remove Subfloor from S .04978 .00223 .00000 1.0000

.00000
Lower the Chassis Fram .05467 (Corr) .00000 1.0000

.00000
Spread Insulation_R Av 1.0000 (Insuf) 1.0000 1.0000

1.0000
Attach PVC Linolium to 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Bring Chassis int .00000 (Insuf) .00000 .00000

.00000

Bring Subfloor into th 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Move Electric Hoi .00000 (Insuf) .00000 .00000

.00000
Attach Main Axle with 1.0000 (Insuf) 1.0000 1.0000

1.0000
Bring Chassis into Sub .04406 .00213 .00000 1.0000

.00000
Attach joists Band joi 1.0000 (Insuf) 1.0000 1.0000

1.0000
Run Basic Electrical_R 1.0000 (Insuf) 1.0000 1.0000

1.0000
put Headers onto the C 1.0000 (Insuf) 1.0000 1.0000

1.0000
put Headers onto the C .23948 (Corr) .00000 1.0000

.00000
Load Chassis Frame on .05467 (Corr) .00000 1.0000

.00000
Move the Floor to the .14283 (Corr) .00000 1.0000

.00000
in Bring out HVAC_R_ .00000 (Insuf) .00000 .00000

.00000
in Attach Main Axle 8.0356E-05 (Insuf) .00000 1.0000

.00000
in Spread Plastic Me .00000 (Insuf) .00000 .00000

.00000
in Spread joists ove .00000 (Insuf) .00000 .00000

.00000
Lower the Chassis Fram 1.0000 (Insuf) 1.0000 1.0000

1.0000

Spread Plastic Membran 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Spread Floor Deck .00000 (Insuf) .00000 .00000

.00000
Spread Floor Decking o .06735 .00605 .00000 1.0000

.00000
Attach Lumber with Bra 1.0000 (Insuf) 1.0000 1.0000

1.0000
Mark and Cut Holes for .12189 (Corr) .00000 1.0000

.00000
Allign Band Joists at 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Set Insulation_R_ .00000 (Insuf) .00000 .00000

.00000
in Move Electric Hoi .00000 (Insuf) .00000 .00000

.00000
Load Chassis Frame on 1.0000 (Insuf) 1.0000 1.0000

1.0000
in get the Plumbing .00000 (Insuf) .00000 .00000

.00000
get the Plumbing Out_R 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Delay 3_R_Q .00705 (Insuf) .00000 1.0000

.00000
Bring out HVAC_R Busy .23024 .01781 .00000 1.0000

.00000
Attach Floor Decking t 1.0000 (Insuf) 1.0000 1.0000

1.0000
Put Rough Plumbing and 1.0000 (Insuf) 1.0000 1.0000

1.0000

Attach Plastic Membran 1.0000 (Insuf) 1.0000 1.0000

1.0000
Bring Subfloor into th .05317 .00351 .00000 1.0000

.00000
Bring Chassis into Sta .05994 (Corr) .00000 1.0000

.00000
Run Basic Electrical_R .10167 (Corr) .00000 1.0000

.00000
Spread joists over Cha 1.0000 (Insuf) 1.0000 1.0000

1.0000
Set Insulation_R Busy .05503 .00405 .00000 1.0000

.00000
in Delay 2_R_Q 38.763 (Corr) .00000 80.000

.00000
Delay 3_R Available 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Attach PVC Linoli .00000 (Insuf) .00000 .00000

.00000
Attach PVC Linolium to .13060 (Corr) .00000 1.0000

.00000
in Move the Floor to .00000 (Insuf) .00000 .00000

.00000
in Attach joists Ban .00000 (Insuf) .00000 .00000

.00000
Put Rough Plumbing and .05208 .00233 .00000 1.0000

.00000
Spread glue over Joist 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Put Rough Plumbin .00000 (Insuf) .00000 .00000

.00000

in Attach Plastic Me .00000 (Insuf) .00000 .00000

.00000
in Delay 1_R_Q 56.661 (Corr) .00000 194.00

.00000
Delay 2_R Available 1.0000 (Insuf) 1.0000 1.0000

1.0000
Spread Plastic Membran .03664 .00144 .00000 1.0000

.00000
in Put Glue over Ban .00000 (Insuf) .00000 .00000

.00000
get the Plumbing Out_R .04130 (Corr) .00000 1.0000

.00000
Lower Chassis Frame ov 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Mark and Cut Hole .00000 (Insuf) .00000 .00000

.00000
Move Electric Hoist Up .04142 (Corr) .00000 1.0000

.00000
in Spread glue over .00000 (Insuf) .00000 .00000

.00000
Delay 1_R Available 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Remove Chassis fr .00876 (Insuf) .00000 4.0000

.00000
Bring Chassis into Sub 1.0000 (Insuf) 1.0000 1.0000

1.0000
Spread Insulation_R Bu .03435 .00197 .00000 1.0000

.00000
in Spread Insulation .00000 (Insuf) .00000 .00000

.00000

Put Glue over Band Joi .03986 (Corr) .00000 1.0000

.00000
in Attach Floor Deck .00000 (Insuf) .00000 .00000

.00000
Spread Floor Decking o 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Bring Subfloor in .00000 (Insuf) .00000 .00000

.00000
Attach Tires to Main A .16990 (Corr) .00000 1.0000

.00000
Attach Tires to Main A 1.0000 (Insuf) 1.0000 1.0000

1.0000
Attach HVAC ducts to f 1.0000 (Insuf) 1.0000 1.0000

1.0000
Move Electric Hoist Up .05246 (Corr) .00000 1.0000

.00000
Attach Plastic Membran .18752 .01022 .00000 1.0000

.00000
in Load Chassis Fram .00000 (Insuf) .00000 .00000

.00000
in Lower Chassis Fra .00000 (Insuf) .00000 .00000

.00000
in Attach HVAC ducts .00000 (Insuf) .00000 .00000

.00000
in Attach Lumber wit .00000 (Insuf) .00000 .00000

.00000
Bring out HVAC_R Avail 1.0000 (Insuf) 1.0000 1.0000

1.0000
in Allign Band Joist .00000 (Insuf) .00000 .00000

.00000

Remove Chassis from St .08951 (Corr) .00000 1.0000

.00000
Attach Main Axle with .19082 (Corr) .00000 1.0000

.00000
Set Insulation_R Avail 1.0000 (Insuf) 1.0000 1.0000

1.0000
Delay 3_R Busy .78154 (Corr) .00000 1.0000

.00000
Move the Floor to the 1.0000 (Insuf) 1.0000 1.0000

1.0000
Put Glue over Band Joi 1.0000 (Insuf) 1.0000 1.0000

1.0000
Spread joists over Cha .03924 .00250 .00000 1.0000

.00000
Attach Lumbers to Buil 1.0000 (Insuf) 1.0000 1.0000

1.0000
Attach Lumbers to Buil .09661 .00354 .00000 1.0000

.00000
Delay 2_R Busy .97693 (Insuf) .00000 1.0000

.00000

COUNTERS

Identifier	Count	Limit
Depart 1_C	201	Infinite

Simulation run time: 0.93 minutes.
Simulation run complete.

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