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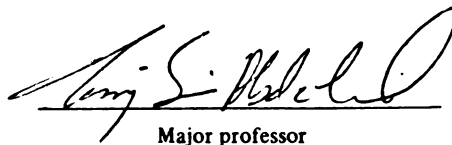
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**PERFORMANCE ASSESSMENT OF PLANNING PROCESSES DURING
MANUFACTURED HOUSING PRODUCTION OPERATIONS USING LEAN
PRODUCTION PRINCIPLES**

By

Vijaykrupal Reddy Chitla

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ABSTRACT

PERFORMANCE ASSESSMENT OF PLANNING PROCESSES DURING MANUFACTURED HOUSING PRODUCTION OPERATIONS USING LEAN PRODUCTION PRINCIPLES

By
Vijaykrupal Reddy Chitla

From the time of trailers of pre-World War II, used as recreational vehicles, to today's urban alternative for affordable housing, Manufactured Homes have come a long way. Built completely on an assembly line in a factory, 21.4 million Americans have chosen these Manufactured Homes as a housing option, in 1999. With a similar production style like the car manufacturing, Manufactured Housing industry has been building homes, which have improved in quality, size, and price. MH industry should undertake a critical examination of its *production planning processes* to identify opportunities for decreasing production costs while improving performance.

The goal of this research is to evaluate the plant production planning process in the manufacturing housing industry and to identify opportunities for improvement. Lean construction techniques, inspired and adopted from Lean Manufacturing principles of automobile industry are utilized to achieve the intended goal. Using Last Planner's Percent Plan Complete, a production control tool of Lean Construction, and Labor Utilization Factor results, using productivity ratings, a method to evaluate the performance of production planning process in a Manufactured Housing plant is developed. Techniques like Pareto Analysis and Fish Bone diagrams were used to identify process improvement opportunities, and provide guidelines to the industry.

Dedicated to My Wonderful Parents

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF TABLES	x
LIST OF FIGURES.....	xi
CHAPTER I – INTRODUCTION	1
I.1 Motivation.	2
I.2. Need Statement	4
I.3 Goal and Objectives.	7
I.4 Report Overview	8
CHAPTER II - LITERATURE REVIEW.....	9
2.1 Introduction	10
2.2 Manufactured Housing	10
2.2.1 Previous Research	11
2.2.2 Definitions.....	12
2.2.1.1 Factory-Built Housing.....	13
2.2.1.2 Site-Built Housing	13
2.2.1.3 Manufactured House	13
2.2.1.4 Single-Section House	13
2.2.1.5 Multi-Section House	14
2.2.1.6 Modular House	14
2.2.1.7 Panelized House	14
2.2.1.8 Pre-cut House	14

2.2.1.9 Mobile House	15
2.2.1.10 HUD Code	15
2.2.3 Production Process	15
2.3 Background Of Lean Production	18
2.3.1 Origin Of Lean Production	18
2.3.2 Types Of Production Processes	19
2.3.3 Construction From A Lean View	22
2.3.4 Lean Construction	23
2.3.4.1 Lean Project Delivery System.....	26
2.3.4.2 Lean Construction Principles	29
2.3.5 Research In Lean Construction	30
2.3.6 Traditional Project Control	31
2.3.6.1 Production Control	33
2.3.7 Last Planner	36
2.4 Summary	40
CHAPTER III – METHODS	41
3.1 Introduction	42
3.2 Methods And Tools For Objectives	43
3.3 Objective 1	43
3.3.1 Understanding Production Process in Manufactured Housing	44
3.3.2 Documenting Production Planning process	46
3.3.2.1 Data on Production Planning Process	46
3.4 OBJECTIVE 2	48

3.4.1 Last Planner	48
3.4.2 Work Sampling	50
3.4.3 Productivity Ratings	50
3.4.3.1 Sample Size	51
3.4.3.2 Classification of work	53
3.4.3.3 Labor-Utilization Factor	55
3.5 Objective 3	57
3.5.1 Constraint Analysis	57
3.5.2 Pareto Analysis	58
3.5.3 Cause-and-Effect Diagrams	59
3.6 Production Planning Process In Manufactured Housing Production Plants ...	61
3.6.1 Brief About The Production Plants	61
3.6.2 Production Process	62
3.6.2.1 Macro level planning	62
3.6.2.2 Problems in the production process planning	64
3.7 Summary	65
CHAPTER IV - DATA COLLECTION AND ANALYSIS	66
4.1 Introduction	67
4.2 Data Collection.....	67
4.3 Production Planning Process.....	68
4.3.1 Manufactured Housing Production Plant.....	68
4.3.1.1 Manufacturing Codes and Standards	69
4.3.1.2 Size and Capacity.....	71

4.3.1.3 Manufactured Housing Plant Assembly Line and Stations.....	72
4.3.2 Organizational Chart in a Manufactured Housing Plant Production.....	73
4.3.2.1 Hierarchical Planning.....	75
4.3.2.2 Production Planning System and Strategy	76
4.4 Production Planning Operations at a Manufactured Housing Production Plant.....	79
4.4.1 Cluster Operations.....	81
4.4.2 Daily and Weekly Operations.....	82
4.5 Summary.....	84
4.6 Percent Plan Complete.....	85
4.6.1 Production Planning.....	85
4.6.2 Production Planning at Two Plants.....	86
4.6.3 Percent Plan Complete Calculations.....	88
4.6.4 PPC Data and Calculations.....	90
4.7 Summary of PPC.....	99
4.8 Labor Utilization Factor.....	101
4.8.1 Labor Force.....	102
4.8.2 Production Rating Study.....	103
4.8.3 Labor Utilization Factor Data.....	105
4.9 Relation between LUF and PPC.....	107
4.10 Coefficient Determination.....	109
4.11 Summary.....	113

CHAPTER V – DESCRIPTION AND CONCLUSION.....	114
5.1 Introduction.....	115
5.2 Constraint Analysis.....	115
5.2.1 Pareto Analysis.....	118
5.2.2 Fish Bone Technique.....	119
5.3 Results And Contributions	123
5.4 Recommendations and Guidelines for the Industry.....	124
5.5 Limitations and Future Areas Of Research.....	126
5.6 Summary.....	127
APPENDICES.....	128
REFERENCES.....	138

LIST OF TABLES

Table 1.1	Manufactured Houses Sales Price.....	3
Table 2.1	Theory of production.....	25
Table 3.2	Sample format of PPC data collection.....	49
Table 3.3	Productivity ratings for several construction trades.....	54
Table 4.1	Manufactured housing stations and activities at each station.....	90
Table 4.2	PPC of roof truss building assignment/station crew.....	93
Table 4.3	PPC of Internal walls assignment/station crew.....	95
Table 4.4	PPC for External Walls assignment/station crew.....	96
Table 4.5	AM and PM LUF of individual crewmembers at the observed stations..	106
Table 4.6	PPC & LUF data of a single day for observing Correlation between LUF & PPC.....	109
Table 5.1	Percent of non-completed assignments.....	116
Table 5.2	Problems in production operations of a MH production plant.....	118

LIST OF FIGURES

Figure 1.1	Recent Home Buyers by Age.....	5
Figure 1.2	Expected demand for Manufactured Houses in different age groups.....	6
Figure 2.1	Production Process Layout of a Typical Manufactured Housing Plant....	17
Figure 2.2	Methodologies Based on Concepts and Principles.....	24
Figure 2.3	Lean Project Delivery System Model.....	26
Figure 2.4	Traditional Planning and Control System.	35
Figure 2.5	Last Planner Planning process.....	36
Figure 2.6	Construction Planning vs. Last Planner.....	38
Figure 3.1	Example of production operations in MH.....	44
Figure 3.2	Activity Definition Model for Roof Insulation activity.....	45
Figure 3.3	Comparison of Percent Plan Complete vs. Labor-utilization factor	56
Figure 3.4	General Format for a Pareto Chart.....	59
Figure 3.5	Cause-and-Effect Diagram (Fishbone Diagram).....	60
Figure 3.6	Organization Chart for Plant A.....	63
Figure 4.1	Manufactured Housing Production Plant Setup.....	69
Figure 4.2	Organization Hierarchies in a Manufactured Housing Production Plant.....	74
Figure 4.3	Hierarchical Planning Process.....	76
Figure 4.4	Required inputs to the Production Planning System.....	77
Figure 4.5	ADM diagram representation for Roof Shingles Station.....	83
Figure 4.6	Production Planning Strategies at Plant A and B.....	87

Figure 4.7	Percent plan complete for roof truss station crew.....	94
Figure 4.8	PPC for Internal walls station.....	95
Figure 4.9	Percent plan complete of exterior boards assignment/station crew.....	97
Figure 4.10	Percent plan complete of doors and windows installation station crew...	97
Figure 4.11	PPC for exterior siding and external finish assignment/station crews.....	98
Figure 4.12	PPC for paint ceiling, roof board, and shingles assignment/station crews.....	99
Figure 4.13	Average crew PPC of all observed stations.....	100
Figure 4.14	Average LUF of all observed station crews.....	107
Figure 4.15	LUF Vs. PPC for all the observed stations.....	108
Figure 4.16	Scattered Plot of LUF vs. PPC for all the Observed stations.....	110
Figure 5.1	Pareto analysis chart depicting the factors responsible for problems.....	119

Chapter One

Introduction

I. INTRODUCTION

I.1 Motivation

Every man's basic necessities are food, shelter, and clothing. Shelter apart, both food and clothing are very much affordable and man can acquire these with some effort and work. The third basic need of having a place to live has come a long way from caves to modern luxury houses. Not every one can afford such houses, but to fulfill a common man's dream, the industry has come up with manufactured houses.

Manufactured houses have come a long way from its earlier form of trailer coaches of pre-world war II. These trailer coaches were built to serve the American traveler. In the 1930s and 1940s, mobile homes were viewed as recreational housing and as such very highly mobile. Though the original intention of manufacturers was to provide temporary and recreational housing, many units were used as permanent houses. Housing shortages after World War II increased the use of mobile homes as permanent housing.

Mobile homes had a very high demand in the 1960s and 1970s. These mobile homes then transformed into manufactured houses in 1974, after Congress passed the National Mobile Home Construction and Safety Standards Act, also known as the HUD Code.

The HUD Code came into effect in 1976 and it was designed to more clearly define mobile homes as buildings, rather than vehicles. The houses were being

manufactured in bigger spans, growing from 8 to 16 feet. Soon double wide and multi-section houses were being manufactured along with single section houses, and the manufactured housing industry has grown to a booming industry. Sales have increased along with the size and production of manufactured houses. According to the Manufactured Housing Institute, “In the year 1999, 21.4 million Americans (about 7.6 percent of the US population) lived full time in 8.9 million manufactured homes” (MHI 2000).

Manf. Houses	1993	1994	1995	1996	1997	1998	1999
Avg. Sales Price	\$30,500	\$32,900	\$35,400	\$37,400	\$40,000	\$41,900	\$43,600
Avg. Sq. Footage	1,295	1,335	1,360	1,385	1,420	1,455	1,480
Cost/Sq foot	\$23.55	\$24.64	\$26.03	\$27.00	\$28.17	\$28.80	\$29.46
Site Built Houses	1993	1994	1995	1996	1997	1998	1999
Avg. Sales Price	\$147,700	\$154,100	\$158,700	\$166,400	\$176,200	\$181,900	\$195,800
Land Price	\$36,925	\$38,525	\$34,574	\$35,250	\$37,750	\$39,775	\$42,375
Price of Structure	\$110,775	\$115,575	\$124,125	\$131,150	\$138,450	\$142,125	\$153,425
Avg. Sq. Footage	2,095	2,115	2,050	2,090	2,140	2,170	2,230
Cost/Sq foot	\$52.88	\$54.65	\$60.55	\$62.75	\$64.70	\$65.50	\$68.80

Table 1.1: Manufactured Houses Sales Price
(Source: MHI Fast Facts, 1999-2001)

With the increase in demand for housing over the years and the cost of site-built housing relatively rising, manufactured houses have come out to be an affordable option

to site-built housing. The average cost per square foot of manufactured houses was \$29.46 based on data from 1999, as shown in Table 1.1. In comparison, the average cost per square foot of a site built house, excluding land cost, is \$68.80 (Manufactured Housing Institute, 2000). Hence, manufactured housing (MH) costs 57% less than site-built housing. Information from Table 1.1 also indicates an increase of about \$6 (25%) in the cost per square foot from the year 1993 to 1999 for manufactured houses as compared to approximately \$16 (30%) increase for site-built over the same period.

So not only the site-built houses are more expensive as compared to manufactured houses; the increase in the overall cost of this form of housing is higher. Data in these figures cast little doubt that MH are more affordable compared to site-built.

Due to its affordability, manufactured housing is now one of the nation's fastest growing housing segments (Perkins 1999). With the past trends and future predicted trends, it is clear that manufactured housing is an affordable option for the households in America.

I.2. Need Statement

Increasing household rates in America help in growth of the housing market, including manufactured housing. The household growth is expected to continue steadily and will increase more rapidly by the year 2010 (Vermeer and Louie 1997). The baby-boom generation, which is expected to move into prime household formation years, will be a prime market for manufactured housing.

Over the years, manufactured houses have improved both in quality, size and price. Figure 1.1 shows that manufactured housing is a desirable and attractive product to homebuyers. Figure 1.2 shows the expected demand for Manufactured Housing by the year 2010 in different age groups. From Figure 1.2, it can be seen that the age group of 35-64 years would be a primary market for the manufactured housing industry. There is also an increasing demand in other age groups.

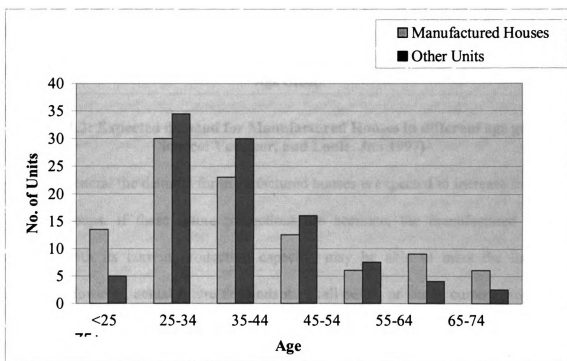


Figure 1.1 Recent Home Buyers by Age
(Source: Vermeer, and Louie. Jan 1997)

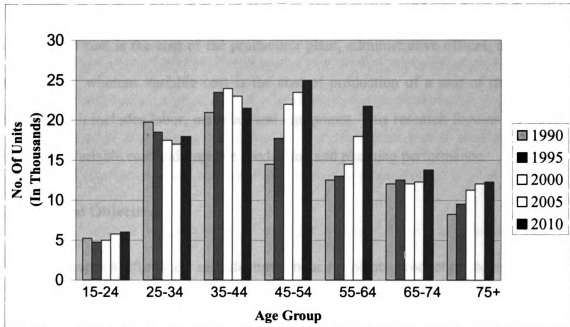


Figure 1.2: Expected demand for Manufactured Houses in different age groups
(Source: Vermeer, and Louie. Jan 1997)

In general the demand for manufactured houses is expected to increase in most of the age groups. If these future projections are accurate, the manufactured housing industry, with its current production capacity, may be able to meet the increasing demands. However, actual future demands may fall below or above current projections. In the case of over projections, manufactured housing plants production capacity will exceed demands resulting in cost increase to offset the imbalance. In the case of under-projections, manufactured housing plants will not be able to meet the demand. In either scenario, the manufactured housing production companies stand to loose. Clearly, the MH industry should undertake a critical examination of its *production planning processes* to identify opportunities for decreasing production costs while improving performance.

The cost for a Manufactured Housing plant consists of both *fixed* and *variable costs*. Fixed cost is the cost of the production plant, administrative offices, and material warehouses, whereas variable cost is the cost of production of a unit of manufactured house, which includes labor, material, and equipment. This research focuses on ways to reduce the variable cost and improve production and planning performance.

I.3 Goal and Objectives

Previous research efforts on manufactured housing plants production operations have focused on removing inefficiencies and variability in performance using process mapping and operations simulation (Senghore 2001). Another way to investigate manufactured housing plants production operations is to determine the effectiveness with which operations are executed.

The goal of this research is to evaluate the plant production planning process in the manufacturing housing industry and to identify opportunities for improvement. To reach this goal, the following objectives are undertaken:

1. Documenting the currently utilized production planning process in a Manufactured Housing plant.
2. Assessing and quantifying the production planning process performance using lean construction principles.
3. Identifying causes of off-target performance through constraint analysis techniques and suggesting opportunities for production planning process improvement.

I.4 Report Overview

This thesis report is divided into five chapters. In Chapter I, an overview of the evolution of manufactured houses was introduced. Concerns to the manufactured housing industry, stemming mainly from increased demands, were discussed and a problem statement formulated. The research goal and objectives were also presented.

In Chapter II, a background of lean production, production processes, and lean construction will be discussed. This chapter will also look at traditional project and production control and concludes with a description of the last planner technique. Chapter III will outline the methods and tools that will be used to achieve the set goal in this chapter. Detailed methodology and approach for each objective will be outlined. Chapter IV reports on the data collection process and analysis using the methods and tools described in chapter III. Chapter V presents the findings and conclusions of the research.

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter details the related literature used for this research. The literature review is used to brief the reader about the manufactured housing industry, lean production, and lean construction. The manufactured housing industry terms and production procedures are explained first. Lean production and lean construction concepts, and the last planner technique are explained next.

2.2 MANUFACTURED HOUSING

Manufactured housing is a relatively new industry in terms of its presence in the market and in the world of academic research. Evolving from a trailer industry, manufactured houses have not been recognized in the construction industry until the 1970s. The creation of the HUD code in 1976 has catapulted the mobile homes industry and its image in the eyes of the public and soon the name Manufactured Housing emerged. To this date manufactured housing struggles to make its own mark and place in the construction industry because of its unconventional method of building houses.

The academic world is making an effort to play its role in helping the manufactured housing industry both in terms of production improvement and as well as overall improvement of the industry.

2.2.1 PREVIOUS RESEARCH

Manufactured housing has been explored by a handful of researchers. Previous research efforts in the manufactured housing industry have focused on finding ways to improve productivity, zoning and regulatory issues, and other aspects of the production process.

One important source on the subject is a master's thesis submitted by Senghore (2001) in the Construction Management program at Michigan State University. His research titled "*Production and Material Flow Process Model for Manufactured Housing*" outlines a detailed study of the production process in a manufactured housing plant. The research developed a production process model for the plant and extensive data collection on productivity in the production process. This data was used to simulate the production process at certain stations along the assembly line. The goal of the research was to develop a tool to improve the production process by identifying the bottlenecks in the process. The work focuses on improving the production process based on the simulation results and by recommending scenarios to remove the bottlenecks. This work serves as a reference for manufactured housing literature on production process and production flow.

The data from Senghore's (2001) work will be used in later chapters for a comparative analysis with the results from data collected in this research. To do this, data in this research work will be collected from the same stations as in Senghore's (2001) work.

Another important research work in the area of manufactured housing is that by Mehrotra (2002) at Michigan State University. Her work titled “*Facilities Design Process of a Manufactured Housing Production Plant*” looks at the spatial aspects of the assembly layout in a manufactured housing plant. The work considered the production process details to define the spatial and proximity-based requirements between stations, and also among the subassembly stations and feeder stations. Factory PLAN, plant layout software was used to create different layout patterns and to arrive at alternative layouts based on the requirements and specific production process.

No prior research could be found that considers the planning of operations in a manufactured housing plant. Moreover, being closer to a manufacturing facility than a construction site, it is apt to look at the production planning aspects from a lean production perspective, as lean production has evolved from the manufacturing of vehicles.

The following sections present brief literature on definitions used in industry and in the academic literature of manufactured housing, followed by a short description of the production process.

2.2.2 DEFINITIONS

A good source of manufactured housing terminology is the Manufactured Housing Institute (MHI). MHI is a nonprofit national trade association representing all segments of the manufactured housing industry, including manufactured home producers; retailers; developers; community owners and managers; suppliers; insurers and financial service

providers. The following definitions are introduced by MHI to help potential customers have a better understanding of terms used in the industry.

2.2.2.1 Factory-Built Housing

A house built partially or totally in a controlled environment like a factory. Many types of structures are built in the factory and designed for long-term residential use. There are different types of factory-built housing namely, manufactured houses, modular houses, panelized houses, pre-cut houses, and mobile houses.

2.2.2.2 Site-Built Housing

Site-built housing is the traditional method of constructing a house where the entire house is built on the home site.

2.2.2.3 Manufactured House

“These are homes built entirely in the factory under a federal building code administered by the U.S. Department of Housing and Urban Development (HUD). The Federal Manufactured Home Construction and Safety Standards (commonly known as the HUD Code) went into effect June 15, 1976. Manufactured homes may be single or multi-section and are transported to the site and installed. On-site additions, such as garages, decks and porches, often add to the attractiveness of manufactured homes and must be built to local, state or regional building codes” (Manufactured Housing Institute).

2.2.2.4 Single-Section House

A manufactured house built on a permanent chassis in single section. The width of the section is regulated by the width of the road on which it is to be transported. The usual width of the single-section house ranges from 8 feet to 16 feet. Average area of single-section homes is 1,130 square feet.

2.2.2.5 Multi-Section House

A manufactured house built and delivered to the site in two or three single sections. The average square footage is 1,640 square feet, with houses manufactured up to 2,400 square feet. Additional attachments like garages are built on the site where installation will take place.

2.2.2.6 Modular House

Modular houses are built in a factory under ideal conditions, structurally engineered to be built in sections (modules). Modules are transported to the site and installed. These are built to the state, local or regional code where the home will be located.

2.2.2.7 Panelized House

These are factory-built homes in which panels - a whole wall with windows, doors, wiring and outside siding - are transported to the site and assembled. The homes must meet state or local building codes where they are sited.

2.2.2.8 Pre-cut House

This is the name for factory-built housing in which building materials are factory-cut to design specifications, transported to the site and assembled. Pre-cut homes include kit, log and dome homes. These homes must meet local, state or regional building codes (MHI).

2.2.2.9 Mobile House

This is the term used for factory-built homes produced prior to June 15, 1976, when the HUD Code went into effect. By 1970, these homes were built to voluntary industry standards that were eventually enforced by 45 of the 48 contiguous states (MHI).

2.2.2.10 HUD Code

Federal construction standards for manufactured housing, enforced by the Department of Housing and Urban Development (HUD). Commonly known as HUD code, it regulates the design and construction, and sets stringent performance standards for the utilities of a manufactured house. The federal standards regulate manufactured housing design and construction, strength and durability, transportability, fire resistance, energy efficiency and quality. The HUD Code also sets performance standards for the heating, plumbing, air-conditioning, thermal and electrical systems. It is the only federally regulated national building code.

2.2.3 PRODUCTION PROCESS

Manufactured housing is an exceptional sector of the construction industry. It is a different kind of manufacturing and less sophisticated in comparison to other

manufacturing industries. Though large numbers of sections are produced each day in a manufactured housing factory, some customization is required depending on customer needs.

The manufactured housing industry as mentioned earlier is a different kind of 'construction' or rather manufacturing of houses. Unlike site-built construction, the manufactured house is built in a factory on an assembly line, as shown in Figure 2.1, where house sections move from one station to another with work done on each station.

A typical manufactured housing plant assembly line will have 12-18 main stations depending upon the complexity of houses the plant manufactures. Most of the production takes place at these stations. All manufactured houses are built on a steel base frame called chassis.

Some parts of the house are pre-assembled at sub-assembly stations located along the main assembly line and adjacent to the main stations. The sub-assembly stations fabricate and manufacture major parts of the house, like the roof truss assembly, interior walls, cabinets, etc. Workers are assigned to each station to work on a specific job. Feeder stations either along the assembly line or at some fixed positions supply the necessary material for the work to the main stations and the sub-assembly stations.

An example of a main station is the roof truss station, which has a fixed crew, feeder stations, and subassembly station in its proximity. The major activities at this main station are placing the pre-assembled roof truss, roof insulation, and at the same time,

work takes place in the lower part of the house such as installing doors and windows, exterior boards, and siding.

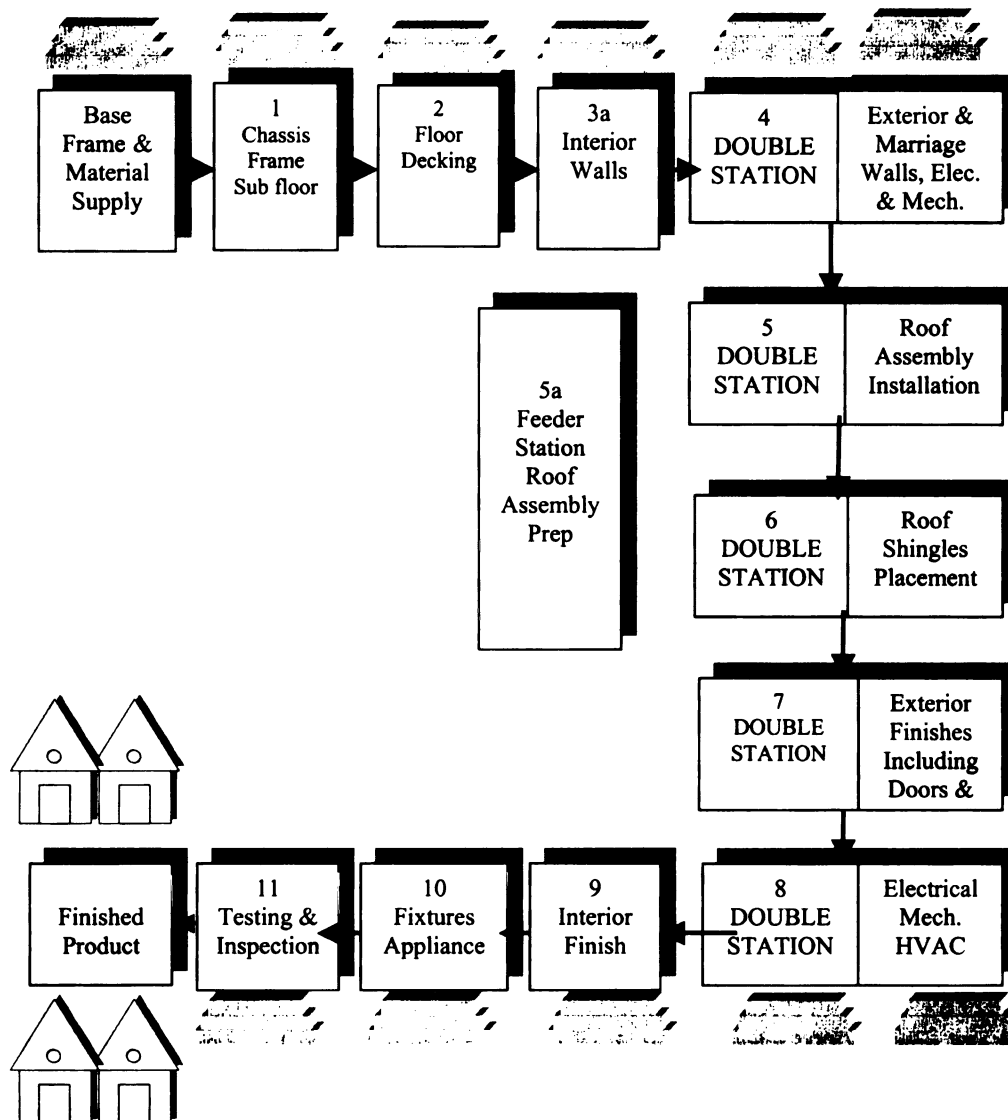


Figure 2.1 Production Process Layout of a Typical Manufactured Housing Plant
(Modified from: Senghore, 2001)

Completed units are shipped to site for installation on previously prepared site foundations. The final assembly of the units and additional activities like landscaping,

fencing and garage units take place at the site. This form of manufacturing houses provides an affordable option with a growing market.

The previous sections provide a brief overview of manufactured housing, terms and definitions used, and plant production processes. More details can be found in Senghore (2001) and Mehrotra (2002). The remaining sections of Chapter II will present lean production, lean construction, and then give a background on project control in construction and manufactured housing.

2.3 BACKGROUND OF LEAN PRODUCTION

The second part of this literature review introduces the lean production concept in detail, starting with its origin, different types of production processes, lean construction, principles of lean construction, traditional project control, lean production control, and finally the last planner system of production control as conceived under lean construction.

2.3.1 Origin of Lean Production

From the early days of manufacturing, dating back to the early 1900s, there has been a persistent effort aimed at improving production. The industrial revolution in the late 19th century coupled with new techniques of manufacturing fueled these efforts. More recently, a number of new approaches to production management have emerged. Just In Time (JIT), Total Quality Management (TQM), value based management, process reengineering, world-class manufacturing, and concurrent engineering are some of them (Koskela, 1993).

When analyzed closely, all of the above management approaches seem to have a common core, but perspectives vary. For instance, JIT stresses the elimination of wait times, whereas TQM aims at the removal of non-value adding activities; however both try to improve the flow of work, material and information (Koskela, 1993).

Generalizing these approaches led to a new production philosophy called lean production, which is modeled after the successful Japanese automobile manufacturer Toyota. The concept of Lean was developed by Toyota, led by engineer Ohno, to cut waste and improve efficiency.

The three objectives observed by Toyota engineer Ohno for a lean production system are (Kaufman Consulting Group, LLC, 2000):

1. Delivery of product that meets the requirement of customer
2. Produce with zero waste
3. Maintain minimum inventory

American researchers studying the production practice of Toyota coined the term “lean”. Lean identifies customer value, understanding how it is delivered, applying pull systems (systems release material or information into a system based on the state of the system), and assures system transparency and zero waste. Reorganizing work to cut costs is at the heart of lean production.

2.3.2 Types Of Production Processes

The world of manufacturing/production has seen many types of production processes over the past two centuries. Two of the successful kinds of production techniques were craft and mass production. The 19th century and early 20th century have witnessed craft production and then came Henry Ford's Mass Production after the industrial revolution.

Lean production is the newest type of production. Lean production has also evolved in the car manufacturing industry and lean applications have shown tremendous results in the manufacturing sector, revolutionizing the production systems and forcing manufacturers to reassess their current production systems. This innovative production system is better understood in contrast with the other two kinds of productions (Craft and Mass production) that human beings have devised to make things.

Craft production uses highly skilled workers and simple but flexible tools to make exactly what the customer ask for—one item at a time. For example exotic sports cars and custom furniture provide current day examples. Anyone would like the idea of craft production, but the problem with it is obvious: Goods produced by the craft method cost too much for most of us to afford. So, mass production was developed at the beginning of the twentieth century as an alternative (Womack 1990).

Mass-production uses narrowly skilled professionals to design products to be mentioned using expensive single-purpose machines. Due to the high costs of machinery, mass production designs are standardized such that higher volumes are produced at lower

costs but at the expense of variety. This means of producing goods is monotonous and uninspiring to workers.

Lean production combines the best features of craft production (high-quality, individualized, custom-made products) and mass production (manufacturing at great quantities to satisfy broad consumer needs at lower prices). Lean uses multi-skilled workers at all levels of the organization. Flexible and increasingly automated machines are used to produce volumes of products with reasonable variety.

Lean principles have been applied successfully worldwide in the automobile industry. Manufacturers like Toyota have strived to work towards the ideal, which is 100% value added work with zero (or minimum) waste. These lean principles are being increasingly employed in many other industrial sectors with a lot of success. The best results can be obtained when used in a repetitive or continuous production environment.

A general characteristic of most industries is the drive to improve performance for competitive advantage (Porter 1985). Performance can be measured against value, i.e., meeting the customer's needs. Improving performance has two key components: doing it more effectively and efficiently (Horman & Kenley 1995). Effectiveness refers to maximizing value of the output, whereas efficiency refers to minimizing or eliminating non value-adding items in production. Performance is therefore described in terms of attaining value effectively and efficiently. Lean principles strive for the same kind of performance. Using lean production techniques most industries would be able to tailor their processes to achieve this performance and meet the unique customer requirements.

As mentioned above, best results of lean production process can be obtained when used in a repetitive or continuous production environment like manufactured housing production. Principles of lean production have been applied in site-built construction and have shown good results. These principles when applied in a controlled environment like the manufactured housing plant would give tremendous results and improve the performance.

In recent years, a handful of construction companies have embarked on a lean conversion path. Guided by research efforts to tailor concepts of lean production to fit the construction industry, these companies are observing good returns on their investments, specifically in the areas of waste reduction in on-site production activities.

2.3.3 Construction from a Lean View

The construction industry is unique for its on-site production environment, and temporary multi-organization for each project. Projects in the construction industry vary considerably in terms of sector they serve. In addition, projects can also be characterized as slow and quick, simple and complex, and certain and uncertain (Ballard and Howell, 1998).

For the small, simple and certain kind of projects a manufacturing strategy is appropriate; i.e., making construction more like manufacturing through initiatives such as standardization. However, for dynamic and uncertain projects, a manufacturing strategy is insufficient. The uncertain, complex, and quick nature of construction projects must be

handled within the characteristic construction conditions of on-site production, and temporary organization (Ballard and Howell, 1998).

Site-built construction is a combination of fabrication and assembly. Industrialization should help to simplify site construction to final assembly and testing. This would help shift much of the work to the shop conditions where it can be done more efficiently. The final assembly, which is always done on site, can vary with the stage of development and the facility being assembled.

The following section looks at the research efforts in the construction industry involving lean applications.

2.3.4 Lean Construction

Lean construction is in its formative stages as a new project management philosophy to handle construction projects. According to Koskela, and general consensus in the literature, methods/tools for designing, planning, controlling, and analyzing are based on principles that are in turn based on concepts. Koskela used Figure 2.2 to depict the relation between concepts, principles, and methodologies/tools.

Koskela states that the production concepts used in various industries are of three main types (Koskela 2000):

1. Transformation view – Concept of transforming inputs to outputs.
2. Flow view – Materials and information flow in a production process.

3. Value generation view – Process where the value for customer is created through fulfillment of his/her requirements.

Each of these three views has introduced various principles, methods, and tools. Koskela believes the integration of these three partial theories will create a unified theory of production in construction, namely the TFV theory. Table 2.1 gives an overview of the integrated TFV theory (Koskela et al 2000).

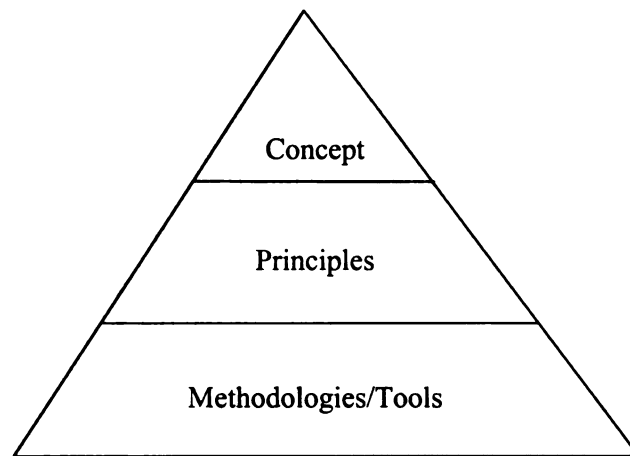


Figure 2.2 Methodologies based on concepts and principles
(Source: Koskela, 2000)

In this research, the focus will be on Last Planner system shown in Table 2.1 as a method of production control under the flow view. The Last Planner focuses management's control functions on production processes versus on overall activities. A main feature of Last planner is to allow the last person in the authority line to plan and decide the assignments to be done. To assess the quality of assignments made, a simple metric is used. This metric is termed as Percent Plan Complete (PPC).

	Transformation view	Flow view	Value generation view
Concept of production	Transformation of inputs to outputs	Flow of material and information, composed of transformation, inspection, moving and waiting	Process where value for the customer is created through fulfillment of his/her requirements
Main principle	Getting production realized efficiently	Elimination of waste i.e., non-value adding activities	Elimination of value loss (achieved value in relation to best possible value)
Methods and practices	WBS, Material Requirements Planning (MRP), Organizational responsibility chart	Continuous flow, Pull techniques, Production Control (Last Planner system) Continuous Improvement, JIT	Method for requirement capture, Quality Function Deployment

**Table 2.1 Theory of production
(Modified from Koskela et al 2000)**

PPC is calculated by expressing the number of completed assignments as a ratio of the total number of assignments planned for a particular production unit along the assembly line in a given week or any other period over which assignments are typically made. PPC can take on values from 0 to 100%, with the latter being the best case. If PPC is less than 100%, there is a failure in the production planning process. Understanding the reasons for the failure will enable future improvement of the planning process. By improving the quality of assignments, PPC will increase reflecting a more reliable planning system.

2.3.4.1 Lean Project Delivery System

The Lean Project Delivery System is “a set of interdependent functions, rules of decision-making, procedures for execution of functions, and as implementation aids and tools, including software when appropriate” (Ballard 2000). The intersection of projects and production systems forms the domain for LPDS, which is called the project-based production system (Ballard 2000).

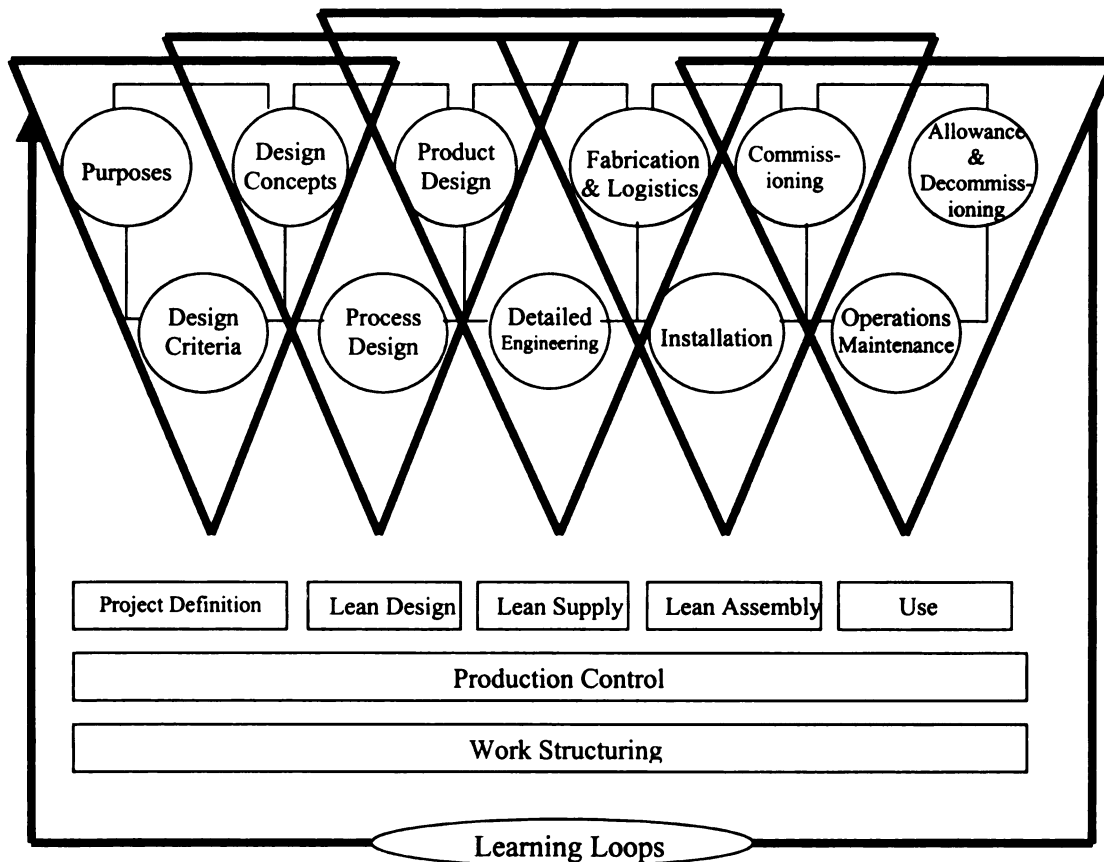


Figure 2.3 Lean Project Delivery System Model
(Modified from LPDS, Ballard, 2000)

Essential features of LPDS are as follows (Ballard 2000):

- Structure and management of a project is aimed at creating value.

- Cross-functional teams, involved in front end planning and design, include members from all the areas of a production process.
- Project control would be a tool executed throughout the project as opposed to reliance on after-the-fact variance detection.
- Optimization efforts are focused on making work flow reliable and not to focus on improving productivity.
- Pull techniques are used to govern the flow of materials and information.
- Capacity and inventory buffers are used to absorb variability in the production process.
- Feedback loops incorporated at every level, are aimed at a rapid system adjustment and learning.

Work Structuring

Work structuring is a fundamental level of process design in the Lean Project Delivery System. The purpose of work structuring is to make work flow more reliable and quick while delivering value to the customer.

Production Control

Production control governs execution of plans and extends throughout the project. Last Planner is the system of production control in Lean Construction. It consists of workflow control and production unit control. Workflow control is accomplished primarily through the lookahead process, which is explained later in this chapter, while production unit control is accomplished primarily through weekly work planning. Production control

extends through all phases of LPDS. The different phases of Lean Project Delivery System are Project definition, Lean design, Lean supply, Lean assembly and Use.

Project Definition

This phase, managed by the project manager responsible for the project, includes both designing and building of the project. Traditional sources are used as inputs and are integrated with post-occupancy evaluation. Design criteria for both product and process will be produced in this phase.

Lean Design

This phase develops the conceptual design from Project definition into Product and Process design, consistent with the design criteria produced in Project definition.

Lean Supply

Lean supply phase consists of detailed engineering of the product design produced in Lean Design, then fabrication or purchasing of components and materials, and the logistics management of deliveries and inventories.

Lean Assembly & Use

Lean assembly and Use are the last two phases of LPDS. Lean assembly begins with the first delivery of tools, labor, and components to the site and ends when the keys are turned over to the client. Use phase is to handle the stages after the client is handled the

product. Operations and maintenance, commissioning and decommissioning are parts of this phase.

The application of LPDS can be on a full range of projects, but would be more appropriate to temporary production systems. After knowing, the kind of project delivery system and to what types of projects LPDS can be applicable, the following lean construction principles can be outlined.

2.3.4.2 Lean Construction Principles

The Lean Construction Institute (LCI) has developed through its extensive research a Lean Project Delivery System (LPDS) as shown in Figure 2.3 intended as a template for applying lean construction to the industry. A lean approach to manage construction projects is different from the traditional method. Lean construction has the following essential features (Howell 1999) and (LCI 2001):

1. Clear set of objectives to be established for the delivery process. Customer needs and requirements are well understood.
2. A cross-functional team designs product and process concurrently, to give more value to the customer needs - this process of parallel design helps positive iteration within the process and negative iteration is reduced.
3. Shifting design work along the supply chain to reduce the variation and match the work content.

4. Work structuring of the entire process increases value and reduces waste at the project delivery level. Efforts to improve performance at the planning level increases performance at project level.

“Making things happen” rather than “monitoring results” is lean production control. Measuring and improving the performance of production control systems improves the project performance and hence value to the customer is achieved. Production control is applied from design to delivery.

2.3.5 Research In Lean Construction

Various research projects have focused on tailoring lean concepts to the construction industry. Most of have been concerned with applying the lean production principles in the site-built construction. The Lean Construction Institute, commonly known as LCI, is an active research institute working to adopt lean principles and develop this innovative project management approach. LCI has developed a new project delivery system for the construction industry based on these lean construction principles. *“Last Planner System of Production Control”* by Glenn Ballard, is a part of this model and is developed specifically to be used a production control technique for construction projects. Parts of the Last Planner concepts are utilized in this research.

Research efforts in applying the lean production principles in construction industry have shown excellent results. Various projects were executed as part of the research work conducted by the Lean Construction Institute researchers in the site-built construction. Most of the projects were commercial and large-scale projects. In spite of

the heavy complexity and uncertainty in such projects, they have shown good results using the lean approach. Such results are always an encouragement and the same results are driving many construction companies to become lean.

Research paper by Amarjit Singh (2002) titled “*Lean Engineering for Mass Housing – Design, Manufacture and Site Erection*” at University of Hawaii at Manoa, talks about the tremendous shortage of housing in the world and how lean construction can help to overcome such shortages. The paper discusses an innovative approach for fast and low-cost erection of mass housing units that have architectural flexibility, manufacturing flexibility, and erection flexibility (Singh 2002). It explores the flexibility of design, manufacture, and erection in mass housing and presents an innovative housing system using lean concepts, like reducing waste, product innovation, and agile production.

Production control is of primary interest to this research because it is an essential tool in coordinating work assignments and workflow. To understand clearly the production control system for project delivery, the sections below describe traditional project control versus production control followed by the Last Planner system of production control.

2.3.6 TRADITIONAL PROJECT CONTROL

To deliver a project according to customers’ needs every project must exercise a form of planning and control. *Project controls*, as commonly known in the traditional construction industry and other industries using contemporary project management, play

an important role along with planning of the production process in any construction project. In general, the objective of project controls in traditional construction project management setting is to detect negative variances or deviations from target or baselines, and then to develop corrective actions.

The main objects of traditional project control are time and cost. Time control checks on production output or progress, while cost control is primarily concerned with tracking actual productivity rates and comparing to the rates used in project budgeting. This function is performed using different tools/methods to control time and cost in a construction project in the traditional methods. The basis of all these tools/methods is the Work Breakdown Structure (WBS).

The WBS is one key element of traditional project management. “The WBS provides the framework for defining the project from top all the way down to its smallest components and for accumulating the costs associated with each piece. In doing so, the WBS provides a data base from which problem areas can be identified, forecasts made, and corrective action can be taken (Diekmann and Thrush 1986).”

The traditional system of project control focuses more on keeping track of time and cost, with corrective actions taken after the system is off-track. “Without corrective actions a project control system becomes merely a cost/schedule reporting system (Diekmann and Thrush 1986)”. Traditional project control systems assume that causes of deviation are apparent and corrective actions will be taken accordingly.

2.3.6.1 Production Control

This control approach is different from the concept of controls under a project management paradigm. ‘Production’ is most commonly understood as either ‘manufacturing’ or ‘making’ where many copies of a single design are manufactured. “Within the world of construction, manufacturing in this sense is approached most closely by manufactured housing” (Ballard, 2000). The construction industry’s production cannot run through an assembly setting as the assembled product eventually becomes too large to move. So, most of the making, production or construction takes place on the site, which makes it fixed position manufacturing. Manufactured housing plants are the only construction sector where ‘production’ can be viewed as a moving assembly-line process.

Reviews of lean production literature and prior research done in designing a production control system suggest the following guidelines and criteria for an effective design of a production control system (Ballard 2000):

1. Variability in a system should be reduced and the remaining variability must be managed.
2. All the assignments should be sound in regard to the prerequisite work.
3. Completion of assignments is measured and monitored.
4. Causes for failure in realization of such assignments are identified and removed.
5. A buffer of sound assignments is maintained for each crew or production unit.
6. Prerequisite work for upcoming assignments is actively made ready.

7. Pull systems replace the traditional push technique¹.
8. Production control facilitates work flow and value generation.
9. The project is conceived as a temporary production system.
10. Decision-making is distributed in production control systems.

Several applications of the production control concepts to the AEC industry have been implemented over the years. The focus of a production control system would be appreciated when contrasted with the existing project control system.

Under traditional project management, the work is planned mainly with design information and project objectives. After initial planning, a schedule of “Should be done” activities are identified and committed to by executors. As shown in Figure 2.4, these “Should be done” activities are then performed using available or ‘pushed’ resources. Performed work is tracked as the ‘Did’ activities. The control process is responsible for determining the differential between the “Shoulds” and the “Dids” and responding to eliminate it.

Using the lean-based production control concepts mentioned earlier, a new production planning and control system called Last Planner system was developed by Ballard (2000). When included in the current planning system, the Last Planner system would first transform what “SHOULD” be done into what “CAN” be done. Then, from

¹ **Push Systems:** In this system materials or information are pushed or supplied based on scheduled milestones that take into account customer demand not plant or site status. The current system of construction scheduling follows Push mechanism.

Pull Systems: Suppliers are “authorized” to release material or information on certain dates based on plant or site status.

the “CANs”, a weekly work plan of “WILL” be done activities can be formed. The assignments that “WILL” be done are a commitment of the Last Planner to perform this work. The Last Planner is the person or group of people who have the skill and authority to make daily assignments.

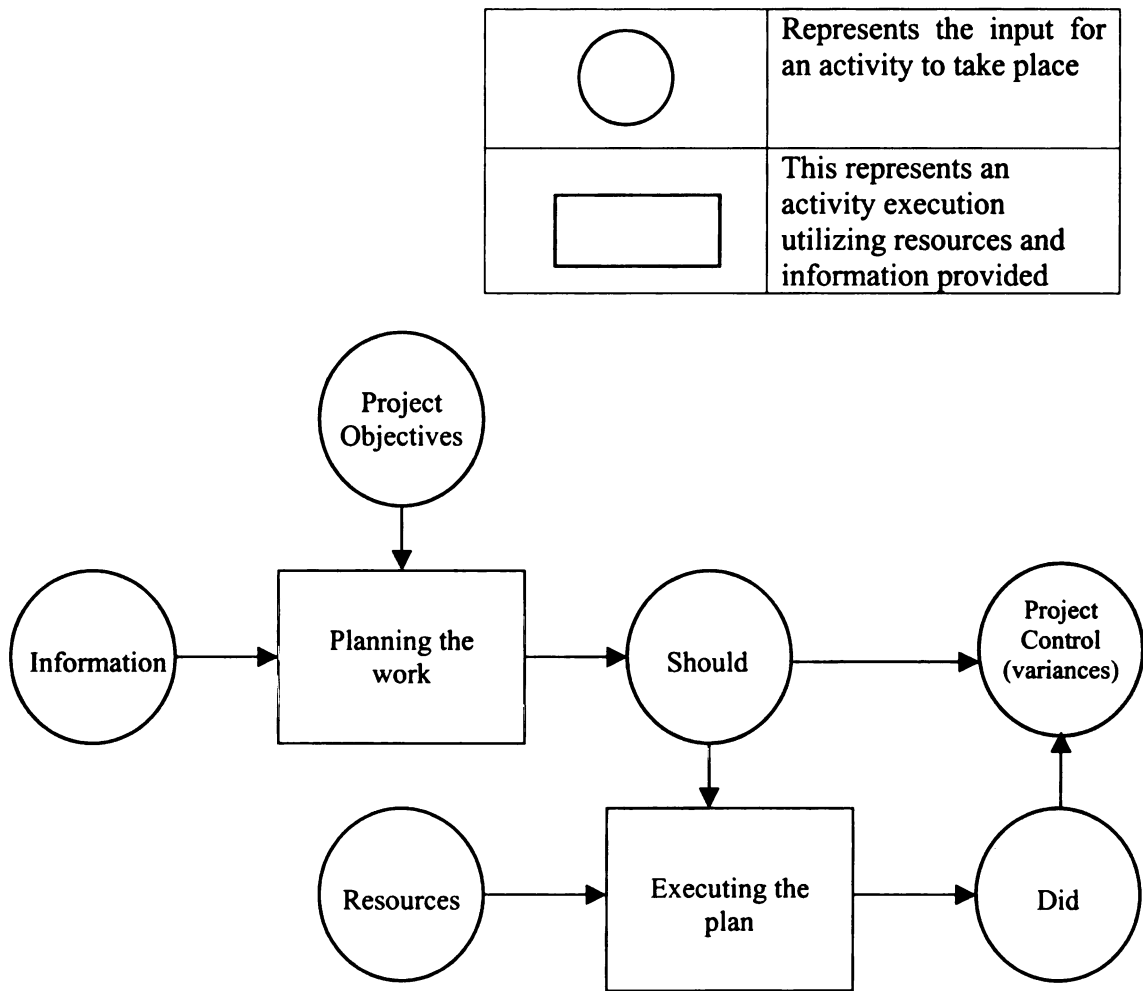


Fig 2.4: Traditional Planning and Control System (Source: Ballard, 2000)

Figure 2.5 represents the Last Planner planning process which makes the “SHOULD” and “CAN” assignments to “WILL” in the form of weekly or daily work

packages ready to be executed with all the prerequisite work done. The production control process compares, usually on a weekly basis, the “WILLs” to the “DIDs”. The “DIDs” are expressed as a percentage of the “WILLs” and this percentage is called Percent Plan Complete (PPC). The Last Planner system of production planning and control will be explained in detail in the following sections.

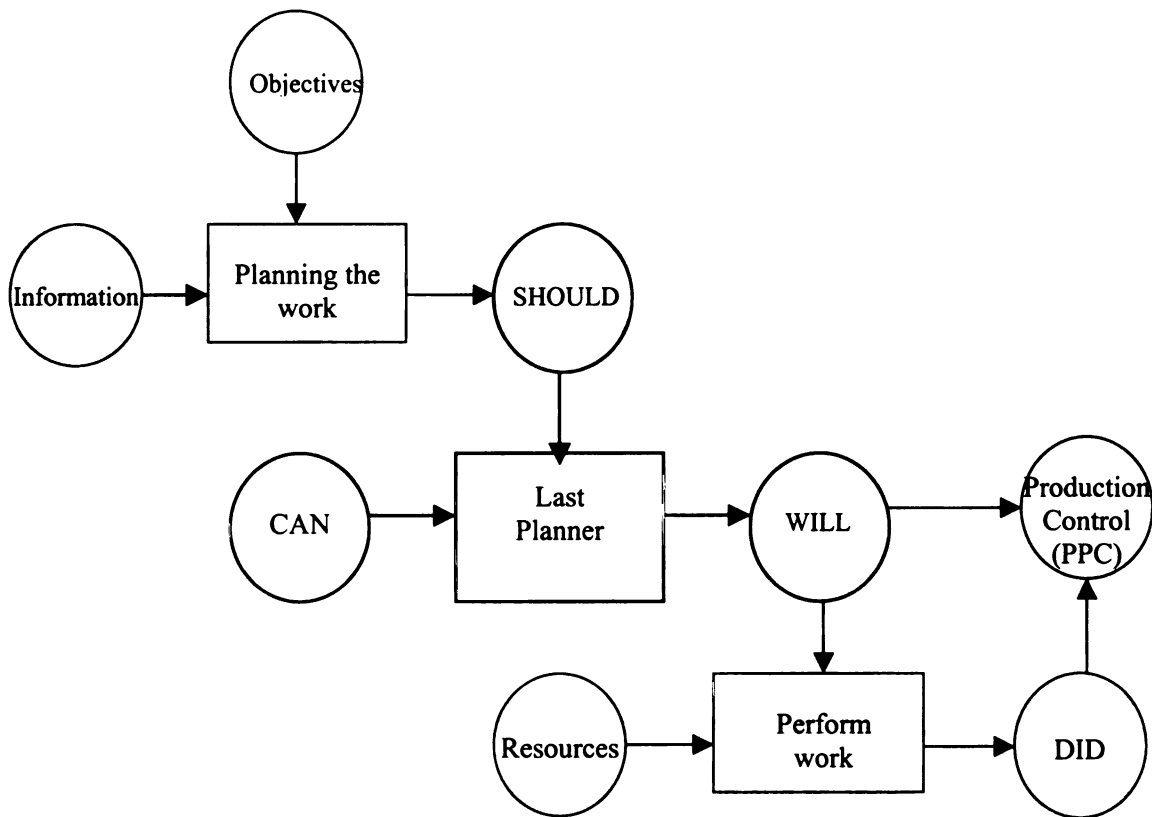


Fig 2.5 Last Planner Planning Process (Source: Ballard, 2000)

2.3.7 LAST PLANNER

Manufacturing a product requires proper planning to deliver goods in time and quality. There is a lot of decision making in the production process where the product moves from one stage to the other. A person who decides last, if the work is ready to be

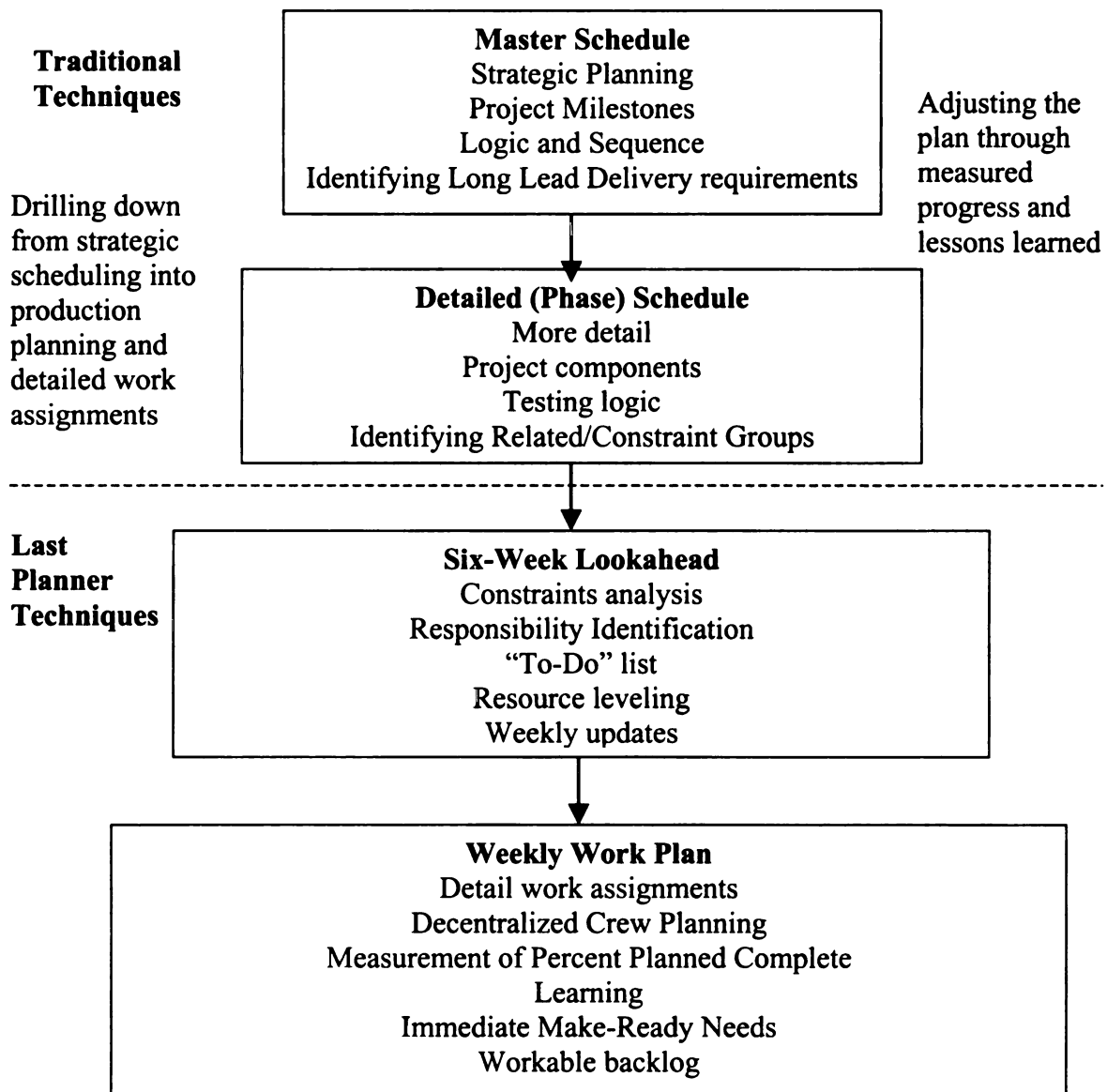
executed or not, is the Last Planner. The last planner could be a foreman, floor manager or a group of people. Before understanding the whole process of last planner and how it works, it would be necessary to understand the decision-making process in the current construction industry.

Planning of the production process in site-built construction is typically performed using the method of Work Breakdown Structure (WBS). In this method, the project is broken down into activities and sub activities, which in turn are scheduled ahead of execution. Each activity would also be assigned necessary resources for executing as scheduled. Not every activity is completed as scheduled and with the assigned resources (budget). Some activities may need additional resources and some might just need more time. These situations result from the uncertain and unpredictable nature of construction projects.

Thus, the need for reliable planning is essential in order to produce better, both in terms of quality and cost. The Last Planner system helps in better planning and controlling the production process. The focus of Last Planner system is to improve the quality of assignments in weekly (or daily) work plans and to shape and control work flow.

Planning for assignments in the Last Planner system is performed through the “Lookahead” process. Usually the lookahead involves consideration of potential assignments for the next 3-12 weeks based on the project characteristics. The lookahead process takes its input from traditional project planning techniques, which result in a master schedule with project milestones and phase schedules as shown in Figure 2.6.

Master schedules involve the development of logic and sequence that helps identify the commitments through out the project. The phase schedule involves greater detail of planning where the project components are tested for logic and the work is divided into phases to identify constraints or related work. This system of division into master and phase schedules lacks a tool of detailed work structuring.



**Figure 2.6: Construction Planning vs. Last Planner
(Modified: Kaufman Consulting Group, LLC)**

In the Last planner system, the activities, before entering into the lookahead window, are exploded from master schedule or phase schedule into a level of detail, appropriate for an assignment on a weekly work plan. This typically yields multiple assignments for each activity. As each assignment appears in the lookahead window (a 3-6 week time period), it is subjected to constraint analysis to make sure it is ready to be executed (Ballard 2000).

Assignments that are made ready for execution enter into a workable backlog. The assignments entering the workable backlog are all constraint free and in the proper sequence for execution. If the last planner finds a constraint that could not be removed in time, the assignment would not be allowed to move forward. The last planner should maintain a backlog of work ready to be performed, with assurance that everything in the workable backlog is indeed workable (Ballard 2000).

Weekly work plans are formed from the workable backlog. Such assignments help improve the productivity of those who receive them and increase the reliability of workflow between the production units. The last planner system can be viewed as a needed supplement to traditional project management for better production. The analysis of reasons for plan failure reveals more information regarding how the production system actually functions and what could be done to improve it.

The planned assignments by Last Planner can be successfully controlled by keeping track of the percentage plan complete. (PPC, Percent Plan complete is the number of completed assignments and expressed as a percentage of planned assignments.) Failure to achieve a 100% PPC are investigated to find the root cause. This

method of getting to the root causes is termed constraint analysis. In essence, PPC is a measure of the reliability of the production planning system.

2.4 SUMMARY

In Chapter II, a detailed description of terms and existing research related to manufactured housing industry, the kind of production process in a MH plant are discussed. The second part of Chapter II summarizes the different production processes, lean production, lean construction, and the existing research in these areas. Finally a background of production control and last planner are described. The next chapter, Chapter III describes the detailed methodologies and tools to be used in achieving the set goal and objectives of Chapter I.

CHAPTER III

METHODS

3.1 INTRODUCTION

In chapter 1, manufactured housing was introduced and an argument was made for production planning improvement. The goals and objectives of this research were also discussed. Relevant literature on the construction and manufactured housing industries, and the production management principles applied in these areas were explained in Chapter 2. Lean construction principles and the Last Planner system were discussed in Chapter 2 to provide the reader with a basic rounding on the origin of the tools and methods that will be used to achieve the set objectives. In this chapter, the methods, tools, and procedures used will be presented.

While the manufactured housing industry may be able to meet demand, it is important for the industry to lower costs of production arising from both fixed and variable costs of production. This is possible by performing a critical assessment of the production planning processes, which would help identify better methods of streamlining production and maintaining reliable workflow.

The main aim of this research is to evaluate the production planning process through a lean production lens and suggest process improvement initiatives. Generally, a process improvement study involves various steps to arrive at process alternatives leading to better performance. These steps are as follows:

1. Collect adequate data.
2. Analyze the data for problem patterns and trends.
3. Identify root causes of the problem.

4. Develop a new or revised method.
5. Implement the new method.
6. Evaluate impact of new method and refine approach, if necessary.
7. Permanent implementation.

This research is limited to the first four items on the list. Steps 5-7 are not in the scope of this research and are, in fact, quite difficult given the required approvals and cooperation manufactured housing companies.

3.2 METHODS AND TOOLS FOR OBJECTIVES

In the following sections, the methods used to achieve the research objectives in the context of the process improvement steps outlined will be presented. The author also visited two manufactured housing plants to understand the current production planning process and also the production process. Information on the data collected from these pilot visits will also be discussed.

3.3 OBJECTIVE 1

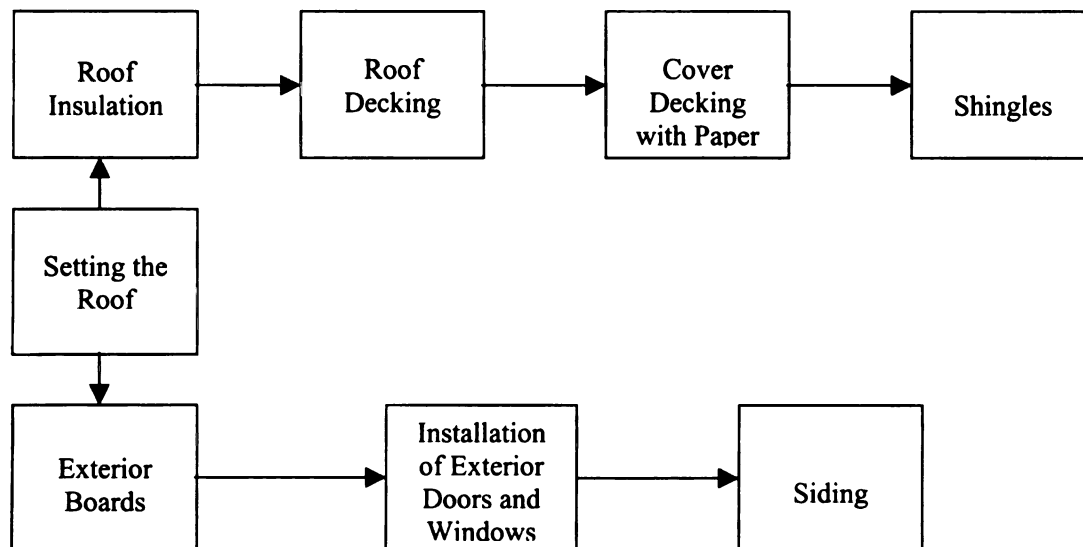
The first objective of this research is to document the current production planning process utilized in a manufactured housing plant. This will be done in two steps:

1. Study and understand the production process in a manufactured housing plant.
2. Study and document the current production planning process in a manufactured housing plant.

3.3.1 Understanding Production Process in Manufactured Housing

To study and document the current planning process in a manufactured housing plant it was important to first understand the production process of a housing unit. Existing literature was reviewed and plant visits were conducted to understand the production process.

A part of a typical plant layout is shown in Figure 3.1, found in Senghore (2001), with production stations; setting of roof, roof insulation, and exterior boards with different activity relationship among stations.



**Figure 3.1 Example of production operations in MH
(Senghore, 2001)**

As shown in Figure 3.1, there are various activities at each station and the relationships among these activities are very important. Work flows from one station to another and among the activities in each station. For example there are three different activities in the roof decking station, namely, roof decking, covering decking with paper,

and placing shingles. Work flows from placing decking to covering with paper and then placing shingles.

A different way of representing workflow and work requirements can be performed using the Activity Definition Model (ADM). As shown in Figure 3.2, the ADM represents directives, prerequisite work, and resources as inputs to the assignment. The output of the assignment is also represented in the figure and this could be a product or a release of workspace to another crew. This model of defining process activities improves the planning and sets in place a work ethic that leads to well planned assignments. It is also important to note that if an output does not meet set criteria, the work has to be redone. Needless to say, outputs that meet criteria are allowed to trigger downstream assignments.

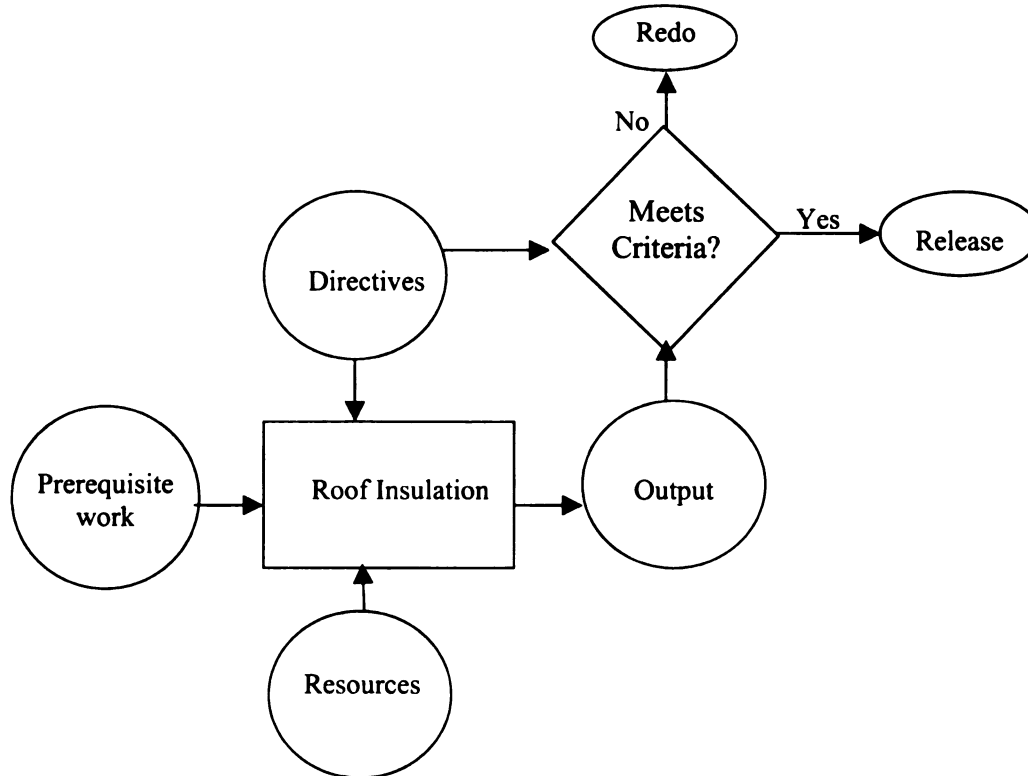


Figure 3.2 Activity Definition Model for Roof Insulation activity
(Modified: Ballard, G. 2000)

For the stations under study in this research, a representation of work similar to that of figure 3.2 was used. Representing activities in this manner would help understand the production process and the production planning process.

3.3.2 Documenting Production Planning Process

With the review of existing literature on production process of manufactured housing plant, the author collected information on the current production planning process by visiting manufactured housing production plants. Personnel involved in production planning were contacted to both understand and map the production planning process.

3.3.2.1 Data on Production Planning Process

The type of data required from a manufactured housing plant to assess the production planning process in building a manufactured housing unit was as follows:

1. How are assignments planned for crews working at a specific station?
2. How many assignments are planned for a day or an hour?

Other questions about the planning process also come from Figure 3.2. For example, a question was asked regarding the type of directives needed for a particular assignment and so on.

To answer these questions, the following two methods were be used:

1. Observing (videotaping) the process to develop actual records of the current operations.

2. Interviewing management and labor involved in the operations.

Both methods have respective advantages. On the one hand, asking the personnel involved would help detect problems or lead to suggestions for improvements. On the other, observation is an important tool for gathering information on a work process or method. Detail recordings of people's actions, flow of materials or information allows later studying and analysis. What, When, Where, How, and Who can be answered by observing the current practices, but only asking would explain the very important question 'Why.' This is because personnel involved in day-to-day operations are knowledgeable about what goes on and have excellent insight to sources of problems. It is also important to include front line workers in the interview process and not focus only on management. It is well documented that workers or foremen often have a great knowledge and better insight of situations on the line (Oglesby et al 1989). This very important source was tapped in this study.

As mentioned earlier, this phase of research followed the two mentioned approaches of observing (includes videotaping) and interviewing, and the choice is based on scope limitations. Data collection will include direct observation in the manufactured housing plant, documentary analysis, and interviewing the personnel such as production plant manager, production planner, foremen and workers.

3.4 OBJECTIVE 2

The second objective of this research was to evaluate the production planning process performance using lean construction principles. This objective will be achieved in two phases:

- a) Measuring the quality of assignments. (Is the work being completed as planned?)
- b) Assessing the performance of work crews. (How efficient are work crews in completing the work assignments?)

The two main techniques, which will be used to reach this objective, are the Last Planner system and productivity rating studies. These techniques will be explained in the following sections.

3.4.1 Last Planner

In this phase of the research, the reliability of the production planning process will be assessed using the Last Planner system with PPC as the assessment metric. Data for PPC calculation will be collected for workstations found in Senghore (2001) for a period of 2 weeks. For a typical week, the following are the steps to calculate PPC:

1. The first step in calculating PPC would involve collecting planned daily assignments at work stations of interest. The number of assignments planned will be collected from the production manager or foreman. Table 3.2 shows the form for collecting this information.

2. The number of completed assignments at the end of the day will be determined by asking the production manager.
3. The ratio of completed assignments to those planned activities will be calculated.
The resulting percentage is the PPC.

By completing the data collection for PPC as described above, it will be possible to determine the average PPC at a particular station and across stations. The next step is to analyze the failures in meeting planned assignments. This will be the topic discussed under the third objective.

Table 3.2 Sample format of PPC data collection

Station observed	Station No.	Week May4-May8					Week May11-May15				
		M	T	W	T	F	M	T	W	T	F
Roof truss-Sub activities Crew member: John Doe	6	Remarks:									
1.Build truss		Y	Y								
2.Attach ceiling			Y								
3.Insulate ceiling		N	Y								
4.Paint ceiling			N								
Completed Assignments		1	3								
PPC		50%	75%								
Finishes-Sub activities Crew member: Bill John	12	Remarks:									
1.Clean the floor											
2.Lay carpet											
3.Install lighting and electric fixtures											
4.Final cleanup											
Completed Assignments											
PPC											

It is important to note that PPC does not provide a measure of how efficient the assignments were conducted. In other words, a PPC of 100% does not indicate whether a crew was idle or working under an efficient combination. Hence, PPC measurements, at a particular station, need to be complemented with work performance or work efficiency measurements. This determination of efficiency can be made using work sampling techniques. This topic is part of the second objective and will be discussed in the next section.

3.4.2 Work Sampling

Work sampling is used as a data gathering technique for performance-improvement applications. Because operations cannot be observed over a long period of time, sampling offers an alternative. Sampling of operations on a site is rather an approximation of the reality within acceptable limits. The sampling results can form a basis for judgments about productivity problems (Oglesby et al 1989).

Work sampling can be done by various approaches, namely, field ratings, productivity ratings, and 5-minute ratings. The most comprehensive and suitable for this research is the productivity ratings method, because it explicitly accounts for work that is essential to produce a product versus work that is contributory but non-essential. The following section explores this method further.

3.4.3 Productivity Ratings

During the operations in a manufactured housing plant, the workers perform many tasks similar to the ones performed in site-built construction. As discussed, to assess how well

these tasks are planned, the PPC metric will be used. The author also observed on two site visits to manufactured housing plants that complementing PPC with productivity ratings would give a better insight of the crew performance of planning operations in a manufactured housing plant.

Productivity rating techniques are typically used to assess the amount of productive work performed by workers. Productivity ratings refer to ratings of a crew or crewmember performance, while assignments are conducted. The ratings are typically stated as percentages of productive to non-productive work. These ratings are determined by sampling the activities of crews or crewmembers. In the next section sample size determination and classification of work under the productivity ratings method will be discussed.

3.4.3.1 Sample Size

Work sampling involves making and analyzing the results of fixed observations. This helps determine what individual workers are doing at specific instants in time. Any sample size taken for observation has to satisfy a set of conditions based on the type and nature of research performed. According to Oglesby et al (1989), a 95% confidence level and limit of error of plus or minus 5% gives a good indication of the overall effectiveness of an organization or of an operation.

The Confidence level mentioned refers to the level of dependability in a result. If, say, the confidence level is 95%, then the answer can be relied on 95 percent of the time or, conversely, that the answer may be wrong 5 percent of the time. The choice of

confidence level is based on the purpose of the sample. If the subject involves humans, then the level of confidence is as set high as 99.99 percent. If the sampling is for a construction activity, then confidence level of 95 percent is acceptable. The higher the confidence level, the larger the number of observations or samples that must be made (Oglesby et al 1989).

The other important factor in determining the sample size is limit of error. Limit of error refers to the accuracy of the estimated result. With a given confidence limit, the percentage variation on either side of the expected value of the sample is the limit of error. The true values are expected to fall in this limit. For example, with an error limit of 10 percent and confidence level of 95%, it can be stipulated that the estimate of non-productive work based on sampling can fall within plus or minus 10 percent of the total work situations that were actually non-productive and this result could be depended on 95 times out of 100 (Oglesby et al 1989).

For the purpose of this research, and based on prior construction research, a minimum sample size of 384 with a confidence level of 95 percent and limit of error of 5 percent is satisfactory. This sampling can be applied to crews or projects of any size, because sample size is not related to how many number of individuals are observed. “However, it would be necessary to sample a crew of 100 men 4 times or a crew of 10 men 39 times to meet the minimum number of 384 observations” (Oglesby et. al.1989).

3.4.3.2 Classification of work

With the sample size determined, productivity ratings can be achieved by classifying work into different categories according to performance. Under the productivity ratings method, work is classified into three main categories as follows (Oglesby et al 1989):

1. *Effective work*: Work or activities that are directly involved in the actual process of making a unit or adding to the unit is considered as effective work. Work, such as, assembly of a roof truss unit or the work involving activities essential to the process of building a roof truss unit in a manufactured housing plant is effective work. Basically, effective work is work that leads to a change in shape, size, or form of material resulting in an end product to emerge.
2. *Essential Contributory work*: Work done through associated processes essential in finishing the unit, such as material handling, cleanup, checking drawings making measurements, etc.
3. *Non-useful or Idle work*: Ineffective work like being idle or doing something that is unnecessary to complete the job can be classified as non-useful work or Idle work.

This general categorization of work can be used in finding productivity ratings in any kind of construction work. Table 3.3 gives a sample of productivity ratings for a number of construction trades. As shown in Table 3.3, every trade in construction work has some amount of non-productive work. Theoretically, ideal work condition would be 100% productive work, but practically this is hard to attain. With the similarities in work

between MH plant and general construction, MH productivity ratings can be expected to be similar to those shown in Table 3.3.

Trade or craft	Percent of total time in category		
	Effective	Contributory	Not useful
Painter	45	24	31
Carpenter	36	35	29
Electrician	42	37	21
Laborer	35	29	36
Carpet layer	29	41	30
Equipment operator	47	35	18
Plumber	39	32	29
Shingle layer	42	29	29
Finishing worker	48	30	22

Table 3.3 Productivity ratings for several construction trades
(Source: Oglesby et al 1989)

Worker activities in a manufactured housing plant were identified and classified into the above-mentioned categories of work. Work identified as effective, contributory, and idle from the sample collection would help in more than one way. For example, it helps the management in identifying specific situations in which the work can be done more effectively and at a lower cost. After productivity ratings are obtained, they serve as input for calculating Labor Utilization Factor, which is detailed in the next section.

3.4.3.3 Labor-Utilization Factor

A labor-utilization factor, based on the productivity ratings method, is a percentage obtained by summing the number of observations of effective work and one-fourth the number of observations of contributory work, and the sum divided by the total number of observations. The following equation shows this calculation (Oglesby et al 1989).

$$\text{Labor-utilization factor} = \frac{\text{Effective work} + \frac{1}{4} \text{ essential contributory work}}{\text{Total observed}}$$

$$\text{Total observed} = \text{Effective} + \text{Essential contributory} + \text{Ineffective}$$

The above equation used to calculate Labor-Utilization Factor (LUF) is taken as formulated in the construction literature (Oglesby et al 1989). As described above, the work is categorized into three – Effective, Contributory, and Idle work. To calculate the amount of productive work performed, it is necessary to eliminate the work that is not adding value to the unit being built. Effective work was described as work that totally adds value to the unit, but in the case of contributory work, only a part of the work adds value to the unit. In construction industry, it has been formulated that only 1/4th of the contributory work can be considered as productive work.

Based on this literature, one-fourth of essential contributory work is used in addition to effective work to compute the Labor Utilization factor. Supporting data can be found in Oglesby et al 1989. The essential contributory work could range anywhere from 1/4 to 1/2 based on type of work in different industries.

Though the main goal of any work-improvement process is to increase the number of employees engaged in the effective-work category, some amount of contributory work is necessary in completing the work. Therefore, the LUF recognizes the essential contributory work when assessing the overall work performance.

In this research, the same workstations identified for PPC measurements will also be observed and analyzed for productivity ratings. The productivity ratings will be used to determine the LUF at each workstation. Recall also that PPC is used to assess the production planning process. The ideal scenario of the performance of the planning process that can be expected could be a high PPC with a high work performance represented by a high LUF. In other words, PPC and LUF would have a linear relation as represented in Figure 3.3. However, it is expected to find a non-linear relation between PPC and LUF, similar to that in Figure 3.3, is also possible.

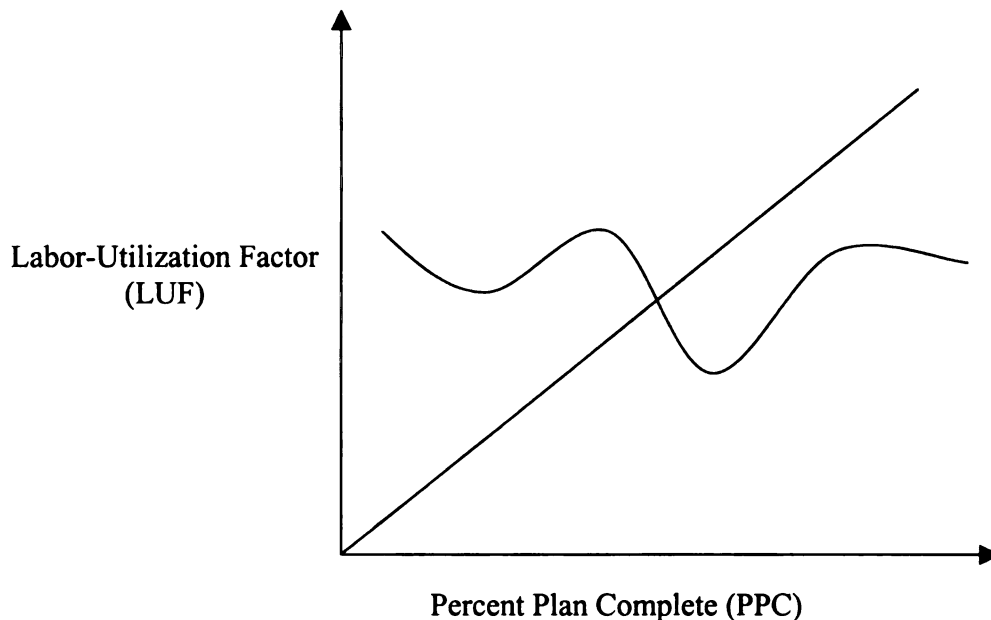


Figure: 3.3 Comparison of Percent Plan Complete vs. Labor-utilization factor (LUF)

However, it is also possible to find a non-linear relation between PPC and LUF, similar to that in Figure 3.3. Thus, LUF and PPC would be a good measure to assess the performance of the planning process. While PPC gives the measure of the quality of assignments, LUF gives the efficiency of workers that execute their assignments. The investigation of this relation is one of the unique contributions of this research.

As mentioned, PPC will be calculated based on daily operations in the manufactured housing plant. It could range anywhere from 40% to 100%. If PPC is low, the last planner techniques can be implemented to improve it. Using techniques like constraint analysis and lookahead process, PPC can be increased to 90% and above. This has been successfully proved in prior implementations in different kinds of projects.

3.5 Objective 3

The third and final objective of this research is to identify causes of off-target performance through constraint analysis techniques. In this research, Pareto analysis and Fishbone diagrams, were used to suggest opportunities for production planning process improvement.

3.5.1 Constraint Analysis

It is important for a company to be prevention oriented, rather than detection oriented, engendered by traditional methods of production management (Markland et al 1998). A prevention-oriented approach can be achieved using various techniques. One such technique is constraint analysis that identifies reasons for failure in completion of assignments and suggests improvement. The author proposes a 3-step process of

constraint analysis for process improvement of production planning process in a manufactured housing plant. The three steps in the proposed constraint analysis technique are:

1. Identifying incomplete and delayed activities from the PPC data.
2. Identifying the most trivial problems using Pareto analysis (Markland et al 1998).
3. Identifying the assignable causes of the out-of-control condition using Cause-and-Effect diagrams and suggests improvements (Markland et al 1998).

Assignments that are not completed or delayed can be identified from the Percent Plan Complete (PPC) data. Such assignments are identified at each station from observation and input from the supervisors of the station under study. These assignments are investigated to identify the reasons for non-completion.

3.5.2 Pareto Analysis

Pareto analysis is a technique that identifies the ‘vital few’ factors that are responsible for most of the problems. Most of the time, it is those few causes (20%) that create great majority of the problems (80%). Pareto analysis uses a bar chart to indicate such ‘vital few’ and ‘trivial many’ factors that effect the proper functioning of any process in general.

For example, out of many reasons for non-completion of assignments in a manufactured housing plant, assume that design failures occur frequently. The next most frequent problem is inadequate supply of material and many other reasons that occur not so frequently. Pareto charts identify these very frequently occurring problems and those

that have the greatest effect on the overall production planning system. Identifying of such vital few problems can be graphically represented as in Figure 3.4.

The next step of constraint analysis is to find the root cause of the problem as identified in Pareto analysis. This is performed using the cause-and-effect diagrams as described in the next section.

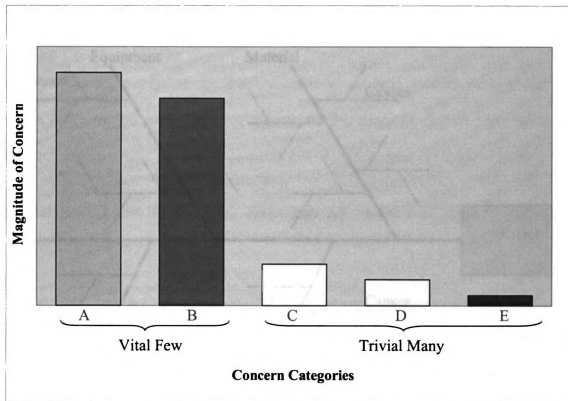


Figure 3.4 General Format for a Pareto Chart

(Modified from Markland et al 1998)

3.5.3 Cause-and-Effect Diagrams

Cause-and-Effect diagram commonly known as *Fishbone diagram* or an *Ishikawa diagram* is a tool for clarifying the causes of a problem (Markland et al 1998). Identifying

the assignable cause of a problem is done using this fishbone diagram with input from the personnel involved in the planning process and the execution of the assignments. Figure 3.5 illustrates the general structure of a cause-and-effect diagram. The problem or concern being addressed is on the right side of the diagram. This is the effect. The factors influencing the effect are generally classified as labor, material, equipment, and methods. The factors can be different based on the type of process. These four factors are the four principal branches (fish bone), from which different smaller branches are listed.

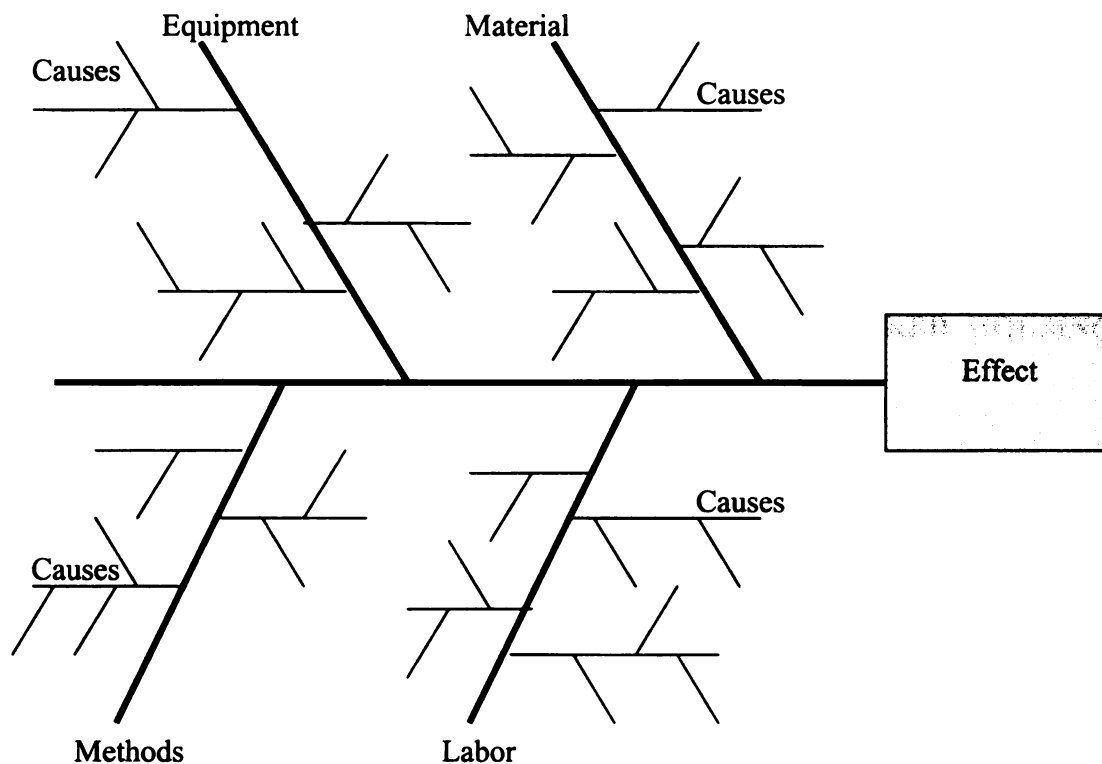


Figure 3.5 Cause-and-Effect Diagram (Fishbone Diagram)

(Source: Markland et al 1998)

For each major branch or fishbone, the method of process improvement involving management and workers would help identify a set of strategies for corrective action.

These set of strategies are developed from the information gathered from the production manager, foreman and the workers.

In this research, the information collected was categorized for root causes. For example, if a certain resource was unavailable at the time of execution, the reason for non-availability of the resource was investigated. Such information would be helpful for management to prevent future reoccurrences. Maintaining a log of such frequently occurring problems will help improve production planning.

These three steps of constraint analysis would help identify most of the root causes that send the production in a manufactured housing production plant off-target. The fault may be in the production planning process, production crew, material etc.

3.6 PRODUCTION PLANNING PROCESS IN MANUFACTURED HOUSING PRODUCTION PLANTS

To verify how realistic and achievable the proposed methods are, the author visited a MH plant to learn about the production planning process currently taking place. The following sections give an account of the visits.

3.6.1 Brief about the Production Plants

The two plants visited by the author are different in size and number of units produced. For reference the plants would be represented as Plant 'A' and Plant 'B'. Plant A is one of four production plants and the one with a higher production rate among the four. It is a medium size plant with 13 workstations along the assembly line, a few subassembly

stations and feeder stations to supply material to these workstations. The plant has a production manager, three foremen and 130 workers. Foreman 1 supervises workstations 1-3, foreman 2 supervises 4-7, and foreman 3 manages stations 8-13. On normal production days, the plant produces 5 houses (10 floors) per day (8 hour day). Due to the variations in demand and sales, production takes place only 4 days a week.

Plant B, owned by a different company, is smaller in size, has lower production compared to Plant A. Plant layout and crew make-up are very similar to Plant A. From the two plants visited the author believed plant A is better in production and capacity than plant B. In addition, plant A was studied previously in Senghore (2001) providing a basis for comparison and reference.

3.6.2 Production Process

In the following section the production process of Plant A is discussed. This section also outlines the planning and execution of production operations.

3.6.2.1 Macro level planning

Macro level planning is done at the company level for all the plants in the company, in a hierarchy as shown in Figure 3.6. Production volume is planned after the General Manager, Sales Manager, and the Operations Manager meet to discuss the company's sales and needs. After the sales manager determines the number of manufactured houses that can be sold/marketed in a month, the team decides on the number of houses to produce in that month. Operations are thus planned for the entire month. The operations

manager and the production managers meet to decide the number of days in a week the plant will function.

Every morning before the plant starts, the production managers of all the plants meet and discuss the day's operations in a pre-production meeting. The production manager then meets with the foremen in their respective plants and check on material, equipment and labor. For example, if a worker is absent from work, the production managers manage to continue work by substituting the absentees with "Swing Men" (workers who can do any kind of job in the plant, but not skilled in any particular area).

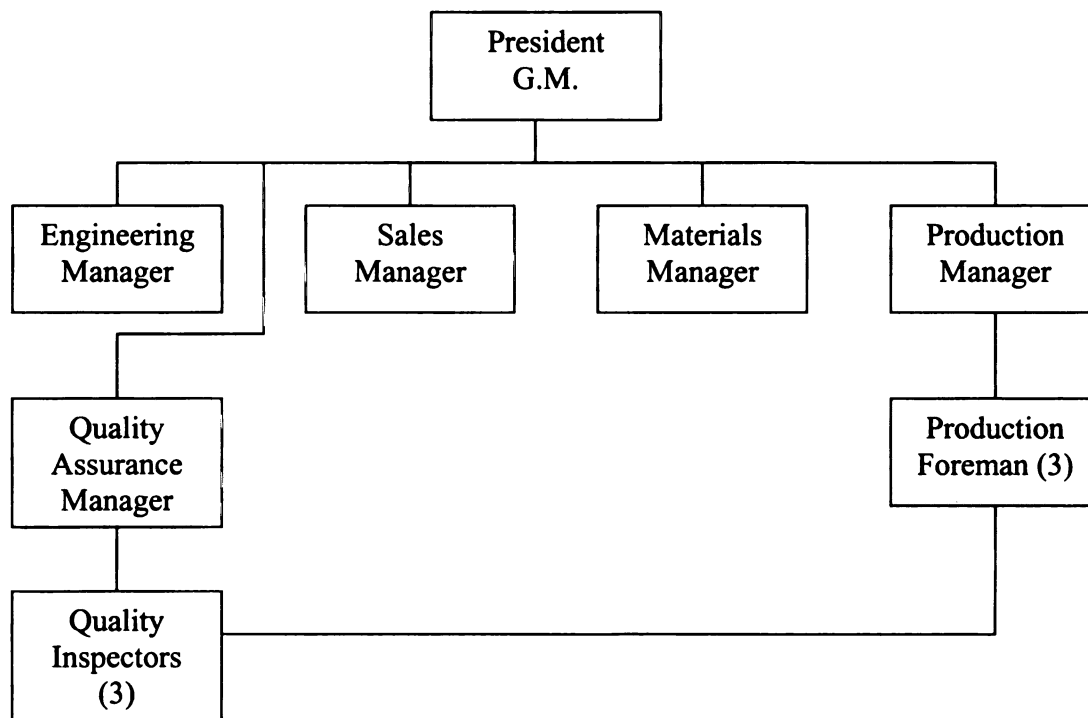


Figure: 3.6 Organization Chart for Plant A

Planning of daily work is decided based on the number of layouts that have to be produced. The work starts at 6 in the morning with a target of three floor sections to be ready by 8:30, which is also the time for the foremen and the production manager to

meet. If this target is not achieved, red flags go up in the plant and the foremen along with the Production Manager responds by putting more employees at the stations behind schedule to speed up the work.

The plant aims at producing 10 floors (2 floors = 1 house) by the end of the day. If the target units are not completed, the assembly line is stopped and the work is continued the next day. On the next day in order to get back on schedule, additional workers are assigned to the stations where problems existed.

3.6.2.2 Problems in the production process planning

The problems as seen by the production manager vary from planning to lack of coordination in the work activities. Some of the difficulties faced in the plant were:

1. Size of the units varied a lot and some of the units are huge in size and it becomes difficult to move it quickly through the line.
2. Inaccuracy in prefabricated components such as doors and windows.
3. Lack of space to move around along the assembly line and overall insufficient space (Or may be too much inventory in the plant!) to work on the house.

To avoid more problems along the assembly line, the bigger units and smaller units are run alternatively (if possible) in the production line.

The observation and study of this manufactured housing production plant's planning process gives a clear picture that

1. Though there is monthly, weekly and daily planning to some extent, there is no detailed planning of day-to-day operations.
2. The activities are planned at a macro level only considering the number of units to be produced in a week and number of floors to be produced in a day.
3. Discussion with the PM clearly shows that corrective measures are taken only when there is a problem and there are no serious initiatives taken to prevent such problems from reoccurring.

The aforementioned results of the pilot result supports the need outlined in this research. Plant A will be further studied using the methods described which plant personnel considered feasible.

3.7 SUMMARY

In Chapters 1 and 2, the manufactured housing industry was introduced, the problem statement was stated, goal and objectives of this research were discussed, and literature on both manufactured housing industry and lean construction was explained. In this chapter, methods and tools to achieve each of the three objectives set in Chapter 2 were explained. This chapter also explained in detail each step of the PPC, productivity ratings, and constraint analysis tools used in this research. Next, Chapter 4 will present the results of explain the entire data collection, calculations, and data analysis.

Chapter 4

Data Collection and Analysis

4.1 Introduction

In Chapter 3, the methods and tools to achieve the goal and objectives of this research were presented. This chapter reports on the process of data collection, production planning in the manufactured housing production plants, PPC and LUF data collection, Pareto analysis and finally a detailed discussion of the data collected. As part of the data collection for this research, the author visited two manufactured housing production plants in northern part of Indiana.

4.2 Data Collection

The first step in the data collection process involved understanding and mapping the production planning process. This was followed by the process of collecting data from a few stations along the assembly line in a manufactured housing production plant. This data collection process included videotaping activities at workstations, interviewing people involved in the planning and production process, and on-floor observation. Video recording of activities was performed to enable the productivity rating study, and to gain more insights to the production process.

The process of data collection included several visits to two different manufactured housing production plants in the initial stages of the project. The names of the plants visited are not mentioned here to maintain participant confidentiality. First step of data collection was to understand the planning process in a manufactured housing production plant. Second step of the data collection process focused on one production plant consistent with the scope of this project.

4.3 Production Planning Process

As described in Chapter 3, to understand and document the production planning process in a manufactured housing plant, it was important to be familiar with the production process of a typical housing unit in a manufactured housing production plant. The author collected data from existing literature and plant visits. The following sections describe a typical production plant, with its stages of production.

4.3.1 Manufactured Housing Production Plant

When a company steps into the business of producing manufactured houses, a production plant is the first major investment. The plant has to be equipped with the machinery to be used, material storage space, assembly line, and administrative offices. Various factors have to be considered, typically with the help of an industrial designer and plant layout designer, such as investment in building infrastructure, constructing the production plant, hiring the production staff, and so forth. Figure 4.1 represents the steps to be followed in the setup of a manufactured housing production plant. A recent masters thesis by Mehrotra (2002) at Michigan State University is a good reference for guidelines in layout designs for setting up a manufactured housing production plant.

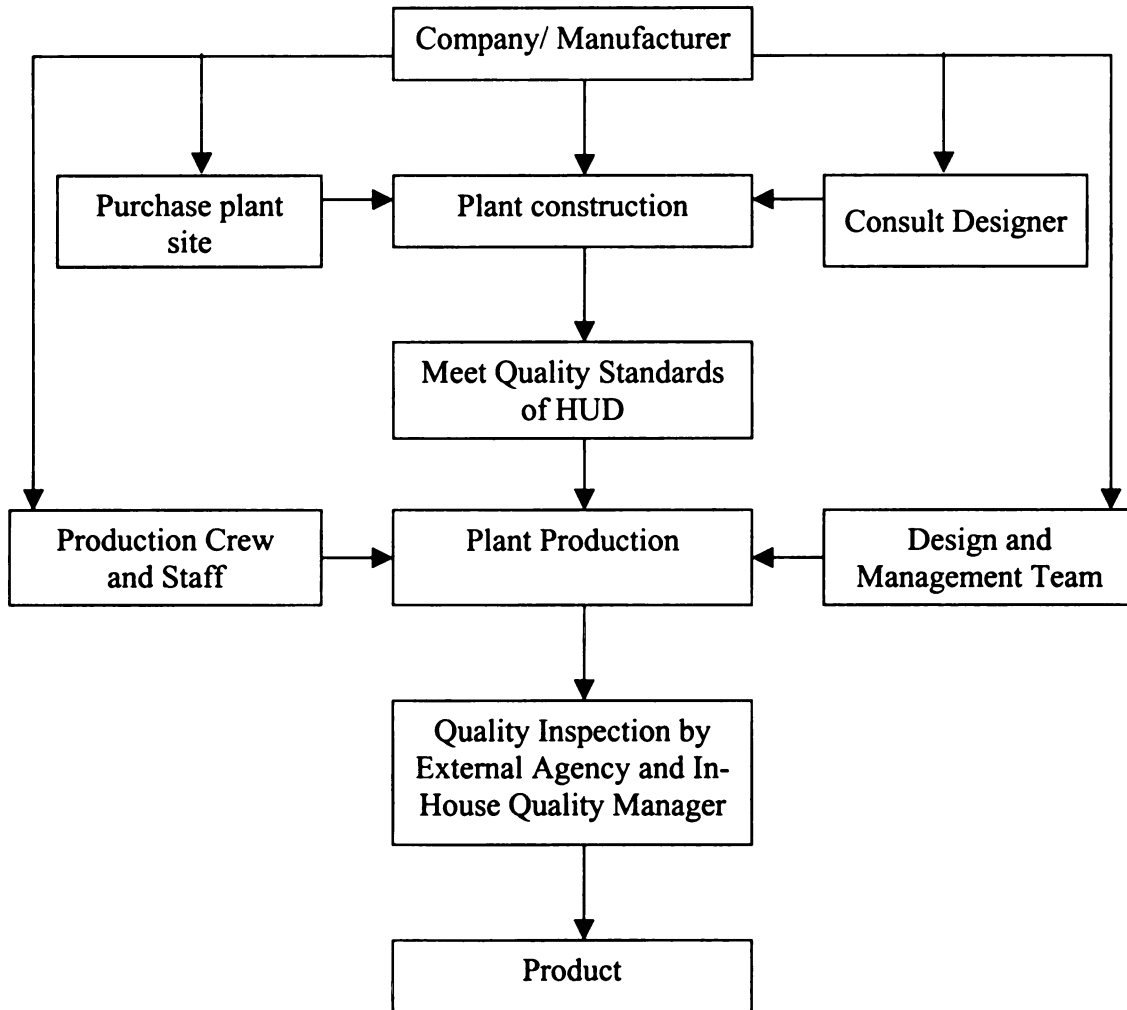


Figure 4.1 Manufactured Housing Production Plant Setup

4.3.1.1 Manufacturing Codes and Standards

To build and ship a manufactured house, the manufacturer has to comply with the National Manufactured Housing Construction and Safety Standards regulated by the U.S. Department of Housing and Urban Development. The production plant has to be certified of quality production to meet the HUD standard (Hullibarger 2001). Every unit that is

produced by the manufacturer must be engineered to meet both structural and quality standards of HUD code.

Every unit model that the manufacturer produces with the standard and optional features based on customer requirements has to be approved by a HUD-approved entity known as Design Approval Primary Inspection Agency (DAPIA) (Hullibarger 2001). Most of the models built by a manufacturer are standardized with some optional features depending on customer needs. If the manufacturer changes the standard approved design, a new approval of the design and engineering of the house has to be obtained from DAPIA.

The manufacturers usually maintain a set of design and models for the customers to choose. These standard designs are approved once and they make small modifications based on customer needs and choice. Such units with little modifications do not need approval each time. Usually manufacturers change the design of models once in a year and they get them approved from DAPIA. Once approved the manufacturer starts the production of houses. It is important to note also that DAPIA approves the manufacturer's quality assurance plan, known as Quality Manual.

Houses built in the plant are monitored by an external agency for compliance with Manufacturer's Quality Manual as governed by the HUD Code. Manufacturers usually contract with a HUD-approved Inplant Primary Inspection Agency (IPIA), which is the equivalent of building inspectors for site-built housing (Hullibarger 2001). Again, each manufacturer has their own quality assurance program by which they build the units in the plant.

The plant visited by the author was inspected daily by Inspection agency personnel who monitor the regular production and check the quality of the plant production. The inspectors go around the plant checking each house on the assembly line to check if they are being manufactured according to the codes and standards. If a house does not comply with the standards, the Foremen and Production Manager are informed to correct non-conforming items according to the HUD code.

4.3.1.2 Size and Capacity

Manufactured housing plants are of different sizes and shapes based on the production capacity of the manufacturer. Plants usually vary from a size of 30,000 square feet, with a production capacity of two to three floors per day, up to 250,000 square feet, capable of producing 20 floors per day (Hullibarger 2001). An average plant size would be around 100,000 square feet with a production capacity of about 8-10 floors per day.

The plant studied for this project is just over 150,000 square feet, employs about 130 people, and is capable of producing about 10-12 floors a day. The measure or capacity of a manufactured housing plant is the number of 'floors' it produces. Each floor can be an individual single section, or half module of a double section or a part of a multi section house. The plant is designed to accommodate future needs of building larger spans, taller buildings, and more floors. The plant, which is a recent addition to the company's existing plant, has the entire infrastructure necessary to build HUD-complaint housing.

The plant has equipment not traditionally used and some hi-tech equipment used only in newly built plants. One such equipment is the air bladder system used to move the houses down the production line. The air bladder, which raises the house only a quarter of an inch off the floor, allows the house to be moved by two people, and the movement is very easy to control with air valves. Shutting the valve lowers the house to floor level. This system also facilitates fixing tires to the unit at the end of the production line. This results in easier transportation of the house through the plant because of decreased weight.

4.3.1.3 Manufactured Housing Plant Assembly Line and Stations

Manufactured housing production plant assembly layouts are designed in different shapes. The assembly line is straight, U- or L-shaped with storage and sub-assembly areas alongside the main line. Mehrotra (2002) suggests a good approach for the layout design using the plant layout software, FactoryPLAN. The other shapes of assembly line layouts suggested are S- and Z-shaped. In general, house sections move along the assembly line either end-to-end or side-by-side (Nutt-Powell 1982).

The assembly line is organized into work stations, with sub-assembly and feeder stations along the main assembly line. The number of main stations ranges from about 10 to sometimes more than 25 (Hullibarger 2001). Different activities take place at different stations. Some stations carry out just one activity like floor decking, and other stations perform 2 to 3 activities, like roof truss insulation, roof decking, and at the same time, external board fixing, and doors and windows installation.

The work force is usually divided into departments, which cover the major work divided by clusters of stations. Most often the different stations are divided in clusters and grouped based on the kind of work. The major clusters in a typical manufactured housing plant are:

1. Frame / Floors
2. Cabinets / Interior and Exterior Walls
3. Roof
4. External and Internal finishes
5. Final finish and repairs

Some of the manufactured housing plants may be broken down into even more individual tasks. Each activity has a crew of workers to keep the assembly line production running continually. More details on the planning operations at these clusters will be discussed as observed at the production plant in later sections (Section 4.4).

4.3.2 Organizational Chart in a Manufactured Housing Plant Production

As mentioned, a manufactured housing production plant will be divided into different clusters each managed by a supervisor who reports to the production manager or the plant manager as shown in Figure 4.2. A production manager, quality manager, and purchasing manager oversee the plant. These managers in turn report to the corporate office and work in coordination with the sales department.

The corporate office and sales department work in coordination with the plant management giving input about existing orders or forecast orders. The sales department

requests plant management to produce the required number of houses. With the given target, the plant management meets and prepares a schedule to achieve the target.

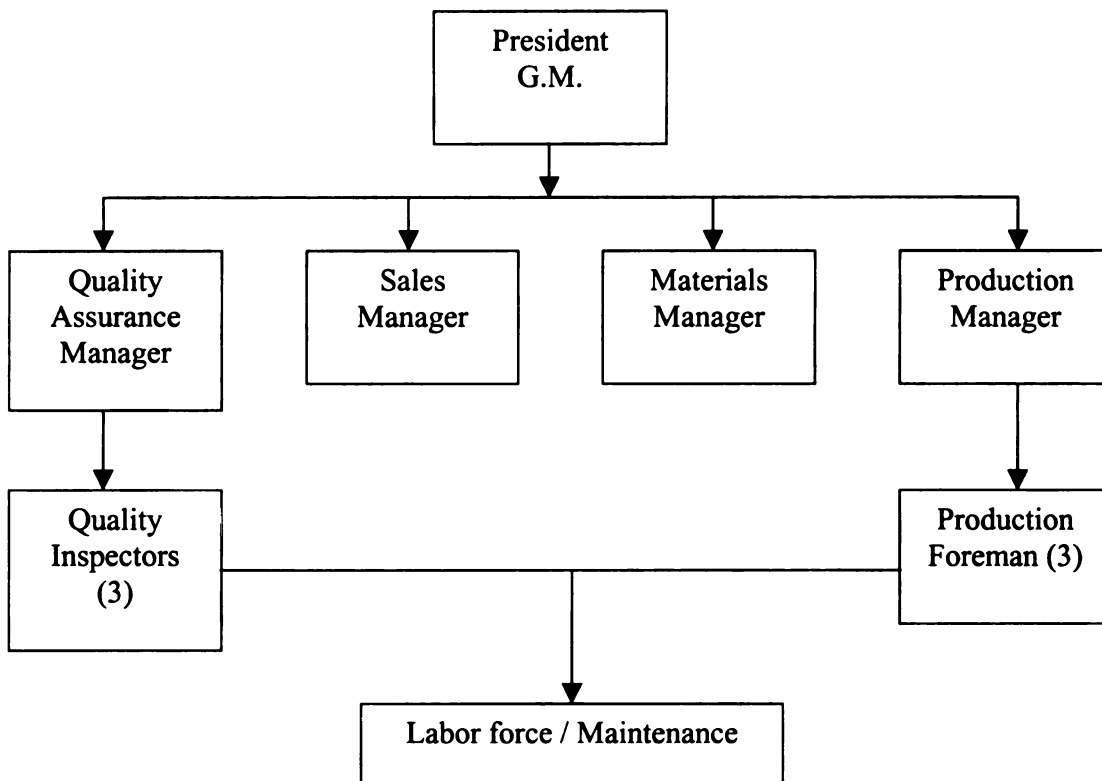


Figure 4.2 Organization Hierarchies in a Manufactured Housing Production Plant

The sales manager and his/her staff are responsible for maintaining relationship with the retailers and developers. The sales department does the job of both forecasting expected sale orders and obtaining orders from retailers, developers and individual customers. A lot of these orders depend on the market condition. The economy plays a big role in sales of houses, similar to site-built houses. Currently, manufactured housing industry is seeing a fluctuation in demand and companies are facing a tough challenge in the unstable market.

4.3.2.1 Hierarchical Planning

In any manufacturing organization, there are three levels of planning operations, namely, long-range, intermediate-range, and short range planning (Chase et al 1998).

1. **Long-range planning:** This is generally performed annually, focusing on a longer period of time, usually a year or more. Very few big manufactured housing companies do such long-range planning.
2. **Intermediate-range planning:** This usually covers a period of 6 months to one year. The planning ranges from quarterly, half-yearly to annually. Based on forecasted sales, manufactured housing companies plan their operations either half-yearly or annually.
3. **Short-range planning:** This covers the day-to-day up to six months of operations. Manufactured housing plants usually perform daily, weekly, and monthly planning of their operations.

Figure 4.3 shows the various decision-making processes at different levels based on the forecasts of a firm's production management team. The hierarchical procedure of planning divides the decision-making, with top management allocating work among different production plants based on the forecasts. At the same time the lower level of management (production plant management) determines the production at the plant. Involvement of top management in lower management's detail decisions and lower management's involvement in top level planning is not advisable.

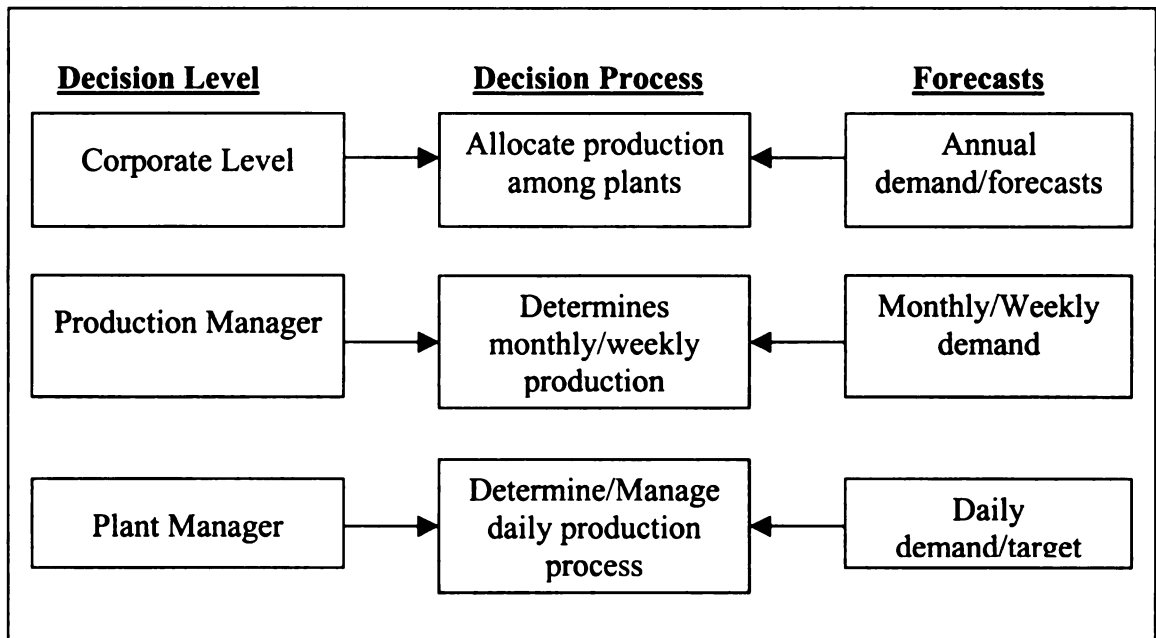


Figure 4.3 Hierarchical Planning Process
(Modified from Chase et al 1998)

4.3.2.2 Production Planning System and Strategy

Any manufacturing system's production planning includes determining the optimal combination of production rate, the workforce level, and inventory on hand (Chase et al 1998). *Production rate* is the number of units completed per unit time, usually a day or week. *Workforce level* is the number of workers needed for production. *Inventory on hand* is the balance of unused inventory carried over from the previous period (Chase et al 1998).

The form of production planning varies from company to company. In some firms, the approach to plan production operations is derived from a long-term annual or half-yearly plan. Based on the annual plan, the planning group determines how to meet

these requirements with the available resources. Available labor, material, and equipment are compared to anticipated demands. If capacity is inadequate, additional requirements for workers, equipment, and so forth are planned.

There are various internal and external factors that affect production planning in the manufacturing industry. Figure 4.4 illustrates these factors that constitute the production-planning environment (Chase et al 1998).

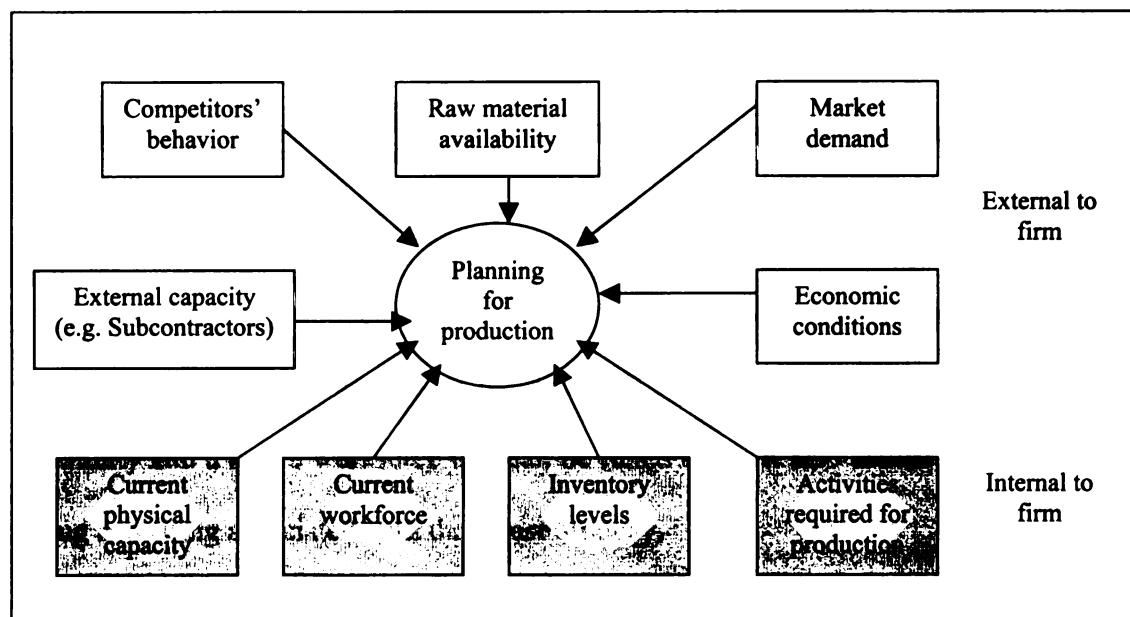


Figure 4.4 Required inputs to the Production Planning System
(Source: Chase et al 1998)

Though most of the external factors are not directly in control of the planning group, the internal factors can be managed and controlled but with varying degrees. For example, current physical capacity of a plant is usually fixed and cannot be easily increased; work force size can be more flexible but with constraints; and inventory levels tend to fluctuate. Chase et al (1998) suggest three production-planning strategies to manage the internal factors in a production planning system. The three strategies

essentially involve a process of trade-offs among workforce size, working hours, inventory, and backlog. The strategies are explained as follows:

1. *Chase Strategy*: ‘Hire and fire’ according to demand. Hiring workers when orders are high and laying them off when orders are low is a strategy that depends on the availability of a pool of easily trained applicants. It also depends on the extent of work that can be performed by unskilled labor. Manufactured housing is one such industry that uses unskilled labor and can implement this strategy. But, a drawback of this kind of strategy is its motivational impact. The approach of workers would change based on existing orders, due to the fear of being laid off as soon as work orders are completed.

2. *Stable workforce-variable work hours*: Vary the output by varying the number of work hours to match production quantities with demand. Management can plan for work through flexible work schedules or overtime. This kind of strategy provides workforce continuity and a stable workforce that can be relied upon. It also avoids various costs of hiring and firing associated with the Chase strategy.

The author found that the current manufactured housing industry appears to be following this approach. Despite the low market demand, the plant visited by the author had a stable workforce, working at flexible schedules to achieve the targeted output. From observations at the production plant, it was typical for few workers to leave after spending 5-6 hours as long as their production targets were met. Other workers stayed beyond normal working hours of the factory in order to complete the work.

3. Level strategy: This strategy refers to producing a constant output rate with a stable workforce. This may result in shortages and surpluses of inventory levels, causing order backlogs and lost sales. Workers benefit through this strategy at the expense of poor customer service levels and increased inventory costs (Chase et al 1998). This strategy may also be a threat to the excess inventory levels, which may become obsolete over a period of time. But it is known that Japanese companies have applied this successfully.

The reviewed literature, site visits, and anecdotal evidence indicate that the manufactured housing industry uses one or a mix of these strategies. With only two plants studied in this project, it is hard to make an assessment of the most used planning strategy in the manufactured housing industry. However to understand the type of planning involved in the operations at a manufactured housing production plant, it is necessary to study the methods and processes involved in the daily operations. The next sections provide a brief description of the planning operations of a production plant as observed and studied by the author.

4.4 Production Planning Operations at a Manufactured Housing Production Plant

The manufactured housing production process consists of a set of interrelated tasks that must be planned carefully to complete the product. As mentioned earlier, the manufactured housing production plant consists of three different parts and three different basic operations. The three different parts of a plant are:

1. Assembly line with main stations.
2. Subassembly stations.

3. Material storage spaces.

The assembly line runs throughout the production plant and also defines the shape of the plant. Subassembly stations are those workstations that perform work and add to the actual product on the main assembly line. Various material storage locations provide raw material to production activities at the main assembly line and subassembly stations. In addition, administrative offices are found inside the plant where most of the planning for operations takes place.

At these three different parts in the manufactured housing plant, many activities are performed to complete a manufactured house. Among the many different activities performed in a manufactured housing plant there are three main activities that manufacture the product. These three basic activities involved in a manufactured housing production system are:

1. Main assembly activities or actual construction of the product.
2. Material handling and storage.
3. Workforce management.

According to Bernhardt (1980), the assembly activities are determined by and arranged according to the nature of the product to be built. Assembly activities include main assembly and subassembly activities. Handling and storage of materials is also an important part of the production planning operations, as it is required to ensure production runs are not interrupted. Last but not least, workforce management plays a

vital role in the plant production operations. If managed properly, a dedicated workforce adds a value to the manufactured product.

Manufactured housing production plant operations will run incessantly when these three basic activities are planned and organized properly. The in-house planning team consisting of a production manager, quality manager, materials manager, and foremen, plan and manage these three basic activities as described.

The foremen play an important role in the day-to-day operations on the floor of the production plant. In the plant visited, there were five foremen responsible for plant production. They manage the operations based on pre-divided work clusters in the plant. The following section explains the operations at these clusters and the foremen planning and management role.

4.4.1 Cluster Operations

As discussed in the previous sections, the production operations are categorized into different clusters along the assembly line where a foreman supervises each cluster. The clusters closely studied in the production plant are frame/floors, cabinets/interior and exterior walls; roof external and internal finishes; and final finish and repairs. Frame and floors sections are managed by foreman 1, interior and exterior walls sections are supervised by foreman 2, roof stations, which include all the stations working on building and finishing the roof of a unit by foreman 3, internal and external finishes by foreman 4, and the final stations of finishes and repairs are supervised by foreman 5.

These foremen supervise all the operations at these stations with instructions from the production manager. Workers at each station have to complete the assignments in their normal duration according to the design and instructions from the foremen and production manager. Production managers at each plant head the in-house production operations and planning team. They are responsible for daily output of the plant and are helped on this by input from the foremen about the status of the plant.

In plant A, the assembly line was organized and the operations are planned in such a way that the unit has to move from one station to another every 20 minutes. Plant B did not have this time target to achieve, hence the operations were more relaxed. At plant B, each station had a fixed number of units to produce everyday and the target is achieved by working at their own pace. During site observations, it was noticed that some workers waited for long periods of time because the work was not released to them from upstream stations on the assembly line.

4.4.2 Daily and Weekly Operations

Information regarding the daily and weekly operations along the assembly line at different stations was obtained by interviewing the plant personnel. As described in Chapter 3, workflow and work requirements were performed using the Activity definition Model (ADM). The ADM was used to ask questions during interviews with the plant personnel. As shown in Figure 4.5, each station observed for data collection was represented using ADM diagram.

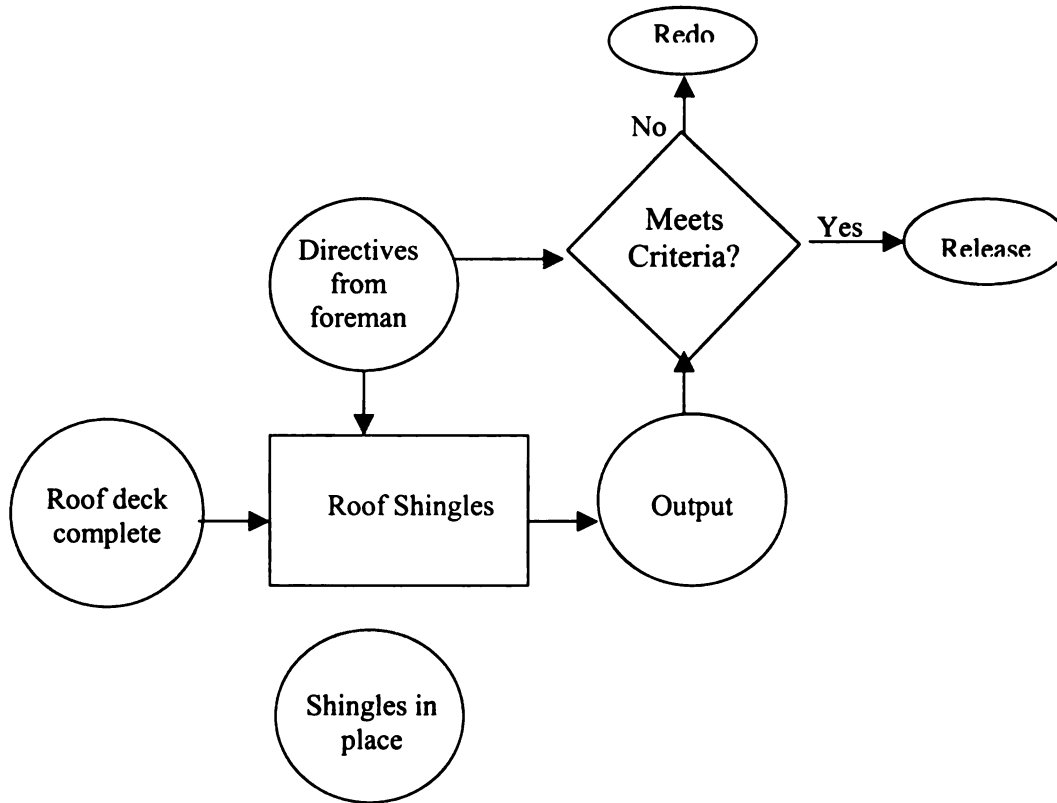


Figure 4.5 ADM diagram representation for Roof Shingles Station

Each plant has a team of production management that plans daily and weekly operations of the plant. In the plants visited by the author, both plant A and plant B had a similar operational planning but differed on execution. In both, management at the corporate level decides on the target sales for the company and distributes the number of units to be produced by each plant based on plant capacity. This is revised every month or up to six months based on the size of the company. The target sales information is communicated to a sales department in the production plant, which in turn meets with the in-house production team to determine plant operations on a weekly basis.

After deciding the number of units to be built in a week the production manager meets with the foremen and other managers in the plant every morning to plan the operations for the day. The team meets again during the day to discuss progress and status of the assembly line. All the foremen report any troubles in the assembly line. In case of serious problems an emergency meeting is held to find solutions.

At the individual station levels, foremen play a critical role in managing production operations. Release of work from station to station depends mostly on the planning and supervision of the foremen at their stations. The target output is usually achieved by the end of the day, but at the same time there are various drawbacks in production planning, which result in delays and non-completion of assignments. The observed plant had many such issues that delayed the production and incomplete units. Many of these aspects of planning failures will be discussed in later sections of this chapter.

4.5 Summary

The previous sections provided an overview of the production planning involved in a manufactured housing production plant and a step-by-step documented process of planning involved in the initial setup of the production plant and then the daily operational planning involved. The sections also document the detailed production planning as based on observations and information gathered from the production plant visited by the author. The process involved interaction with workers, foremen, and the production manager.

4.6 Percent Plan Complete

The second objective of this research was to evaluate the production planning process performance using lean construction principles. This objective was achieved in two phases: measuring the quality of assignments by percent plan complete (PPC) and assessing the performance of work crews using productivity ratings. As described earlier in Chapter 3, percent plan complete is the percentage of number of assignments completed to the total number of planned assignments during a given duration. The following sections will describe the planning of station-level assignments for PPC, PPC calculation, and finally PPC data and analysis.

4.6.1 Production Planning

Earlier sections in this chapter discussed production planning in a manufactured housing plant. The following sections will discuss planning of daily production operations and production assignments for each station, and how planned assignments are completed. In addition, documentation of the current production planning undertaken by the manufactured housing production plants to meet the uncertain future demands of the customer is presented.

In general, *production planning* includes decision making on production and inventory quantities. Any planning problem starts with a specific customer demand that is to be met by the production plan. Most of the time future demand is either only partially known or not known at all. This leaves any production planning team to rely on forecasts

of future demand. Any forecast is inevitably inaccurate and thus the production planning team needs to decide on how to account or react to demand fluctuations (Graves 1999).

Generic production planning in a manufacturing industry setting was discussed earlier in this chapter. Three strategies of production planning were described in Section 4.3.2.2. The manufactured housing industry production planning follows one of these strategies or a combination thereof. It is very difficult to generalize the kind of planning strategy the manufactured housing industry follows, but this research makes an effort to investigate the planning strategy of two manufactured housing production plants.

4.6.2 Production Planning at Two Plants

Investigating the method of production planning undertaken in the manufactured housing industry was achieved by studying related literature, actual observation of production operations, and interviewing plant production personnel. Both plant A and plant B had similar planning strategies of production as represented in Figure 4.6, but the implementation varied due to various reasons.

Plant A, was one of the four production plants the company operated and the planning was performed in three levels. The first level of planning takes place at the corporate level of the company. Input from the plant sales department and demand forecasts targeted by the company set the target output of each plant every month. Second level of planning is done at the individual production plant. Production operations are planned every week and daily target of the assembly line is outlined. Production personnel who include the plant production manager, quality manager, material manager

and foremen meet every week to decide on how many units to produce each day of the week. The third level is daily planning including the process of material and labor handling, supervising assembly operations and individual stations. Plant B had a very similar production planning strategy as described here for plant A.

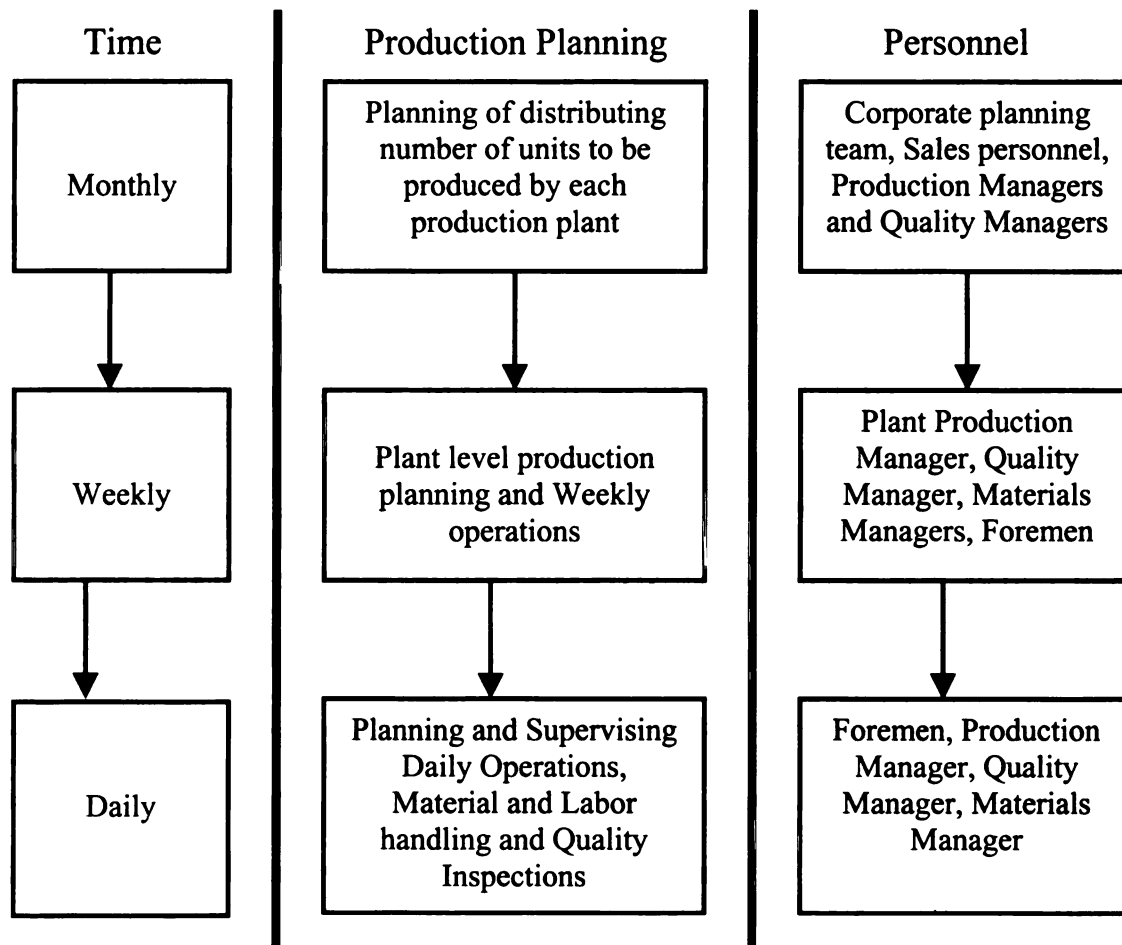


Figure 4.6 Production Planning Strategies at Plant A and B

From the observations and interviews with plant production personnel in plant B, it was understood that the production planning is not really performed inside the plant. Many reasons were given for this kind of unstructured production planning. Uncertain market demand was often cited. Manufacturers are reacting to such imbalance in market demand by exercising tight control on production and inventory levels. Inputs from

production personnel and author's observations at the plant, were again confirming the need that inspired this research, which was to increase the performance of the production planning.

As described earlier, to measure the production planning performance of a manufactured housing plant the first step was to calculate PPC and the next step was to assess the worker crew performance. To measure PPC, the production operations were observed by videotaping and also input from the production plant manager and foremen were used.

4.6.3 Percent Plan Complete Calculations

To calculate the percent plan complete (PPC), it was required to collect data on the number of assignments the production team plans for a period of time. Results from interviews revealed that the plant does not have a fixed number of assignments per day or per hour. The only assignment for the production crew of the plant was to achieve the target output for the day. To calculate PPC the inputs required are the total number of assignments planned and number of assignments completed. As explained in Chapter 3,

$$\text{PPC} = (\text{Number of assignments completed} / \text{Number of assignments planned}) \times 100$$

The first input for PPC was the total number of assignments planned for a day based on the assignment made by the weekly planning team. Work by the author at the plant included getting information on the daily production activity from the production manager and the foremen. The observation started everyday from the time assembly line starts production to the end of production. At the end of the day's shift, data was

collected from the foremen on the number of assignments completed, which was basically the number of units completed.

To have valid data, the criterion for deciding completed and incomplete assignments was based on information from the foremen and author's observations. The criteria of non-completion of assignments was the following:

1. If the unit was not complete in scheduled duration at its station, it is considered incomplete.
2. Incomplete work at the end of the day. Only completely finished units were considered as completed assignments.
3. Repair works or final finishes performed on units outside the assembly line were also treated as incomplete assignments.

For example, assignments at the Exterior boards station were to fix the exterior boards to the walls and cut out openings for the doors and windows. If the work was not complete at the station before the section moved to the next station, it was considered as incomplete. Also, if the workers at the next station are waiting for the work to be done at the exterior boards station or help in completing the work rather than waiting for the work, it was considered incomplete. Finally, if there was any repair work or reinstalling the boards after it moved from the station, it was taken as incomplete assignment.

The data of incomplete assignments was obtained from the daylong observations and interviews with foremen and workers at each station. Due to the scope of work, a subset of stations in the manufactured housing production plant were considered for

calculating PPC. Stations considered for PPC were randomly chosen based on the convenience of observation and nature of work.

Some stations like carpeting and interior works of the house were not considered, as it became too difficult to observe the activity inside an enclosed housing unit without distracting the crew working at the time. Thus, most of the stations observed were stations like roof truss, roof activity, wall stations, doors and windows, and external finishes. The following section describes the stations considered followed by the data collected from those stations and the PPC calculations performed.

4.6.4 PPC Data and Calculations

While considering all the stations in the plant would have been ideal, the research scope allowed only for a few stations to be observed. Various activities in these stations were observed for calculating PPC. The major activities observed and their corresponding stations are listed in Table 4.1. PPC was calculated for the observed activities and the PPC for the entire station was calculated by taking the average PPC of all activities belonging to the station.

Table 4.1 Manufactured housing stations and activities at each station

Station	Activity
1. Chassis	Floor joist attached to the chassis, and initial rigid insulation is done
2. Floor decking	Floor joist is covered with decking and vinyl flooring is completed. At this station the unit is fixed with an air bladder system for moving along the assembly line

3. Plumbing and HVAC	Rough plumbing, HVAC installation and sanitary appliances are fixed
4. Internal walls	Fabricated internal walls are placed on the main station
5. Cabinets / Fixtures	Cabinets and fixtures are fabricated at a subassembly station and then installed at the internal walls station
6. External walls	External walls are placed and rigid insulation placed. Rough electrical and plumbing work is also done at this station
7. Exterior boards	External wall boards are fixed to the walls, openings for doors and windows are cut out in the walls
8. Roof truss building	A subassembly station outside the main assembly line where the roof truss is built in two halves
9. Exterior doors and windows	Doors and windows are placed at this station. At the same time roof truss is placed on the house and roof insulation is done
10. External siding / Roof sheathing	External siding, external electric fixtures like lamps are installed. Simultaneously roof sheathing is fixed over the truss
11. External finishes	Other external finishes are also carried out simultaneously at this station
12. Roof shingles	Roof is completed with insulation paper and shingles placement
13. Interior finish	Interior finishes like painting and wall finishes are done at this station
14. Final finishes	Carpeting, appliances and final electric fixtures are installed
15. Attaching wheels	The unit is removed from the air bladder system and wheels are fixed for transportation
16. Final inspection and repairs	This station is used for final inspections and essential repair works

Different activities that have been considered for calculating PPC are:

1. Internal walls – Station 4
2. Exterior walls – Station 6
3. Exterior boards – Station 7
4. Doors and windows – Station 9
5. External siding – Station 10
6. Roof truss building – Station 8
7. Paint ceiling – Station 8
8. Roof board – Station 10
9. Roof shingles – Station 12
10. External finish – Station 11

Data collection was done for each activity/assignment for 5 days over a period of two weeks. Then PPC of different activities/assignments were calculated. Table 4.2 shows an example of data collection and PPC results for the roof truss station. The roof truss activity, built at a subassembly station, was one of the most critical activities in the entire production process. Usually built by two workers, the activity crew is sometimes assisted by workers from other stations when needed. Usually workers helping the roof truss crew are from the next station downstream of the production line, which is paint ceiling. If the assignment is not completed in the scheduled duration the workers at the next station wait for the work to be released.

Table 4.2: PPC of roof truss building assignment/station crew

Activity: Roof Truss building Days Observed: 5 Crew size: 2					
Days		Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crewmember I	3	1.5	50%	Big truss/No proper directives
	Crewmember II	3	1.5		
Day 2	Crewmember I	3	2	66.60%	Completion of previous days work
	Crewmember II	3	2		
Day 3	Crewmember I	3	2.5	83.30%	Material shortage
	Crewmember II	3	2.5		
Day 4	Crewmember I	3	3	100%	
	Crewmember II	3	3		
Day 5	Crewmember I	3	2	66.60%	Directives
	Crewmember II	3	2		

Figure 4.7 shows the bar graph of PPC for roof truss building station collected for a period of 5 days. This shows different variations in PPC, which indicates that the production planning is not very reliable. Only on day 4, it was 100% i.e., all assignments were completed as planned.

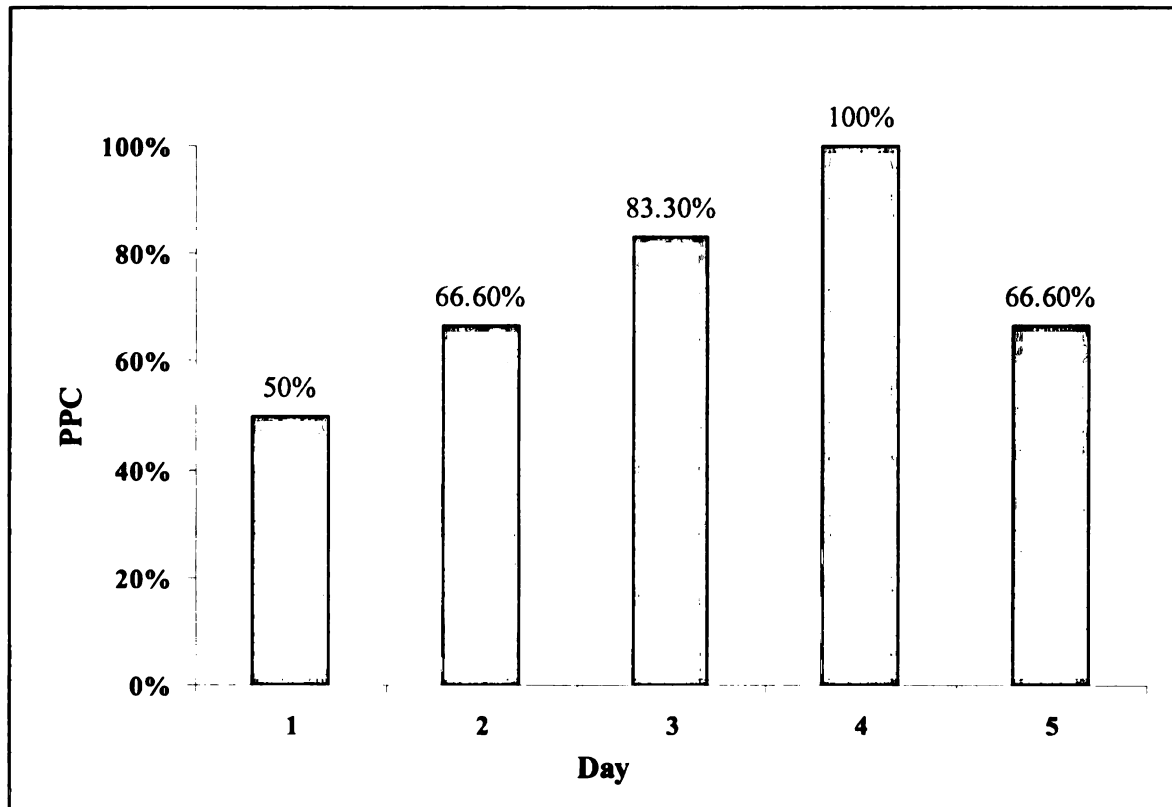


Figure 4.7 Percent plan complete for roof truss station crew

Internal walls is a subassembly station with a crew of two. Again, the activity could not achieve 100% PPC everyday due to various reasons. Most of the reasons were due to material shortage or inefficiency of the crew. Table 4.3 presents the PPC results for this activity. Followed by the PPC data, Figure 4.8 shows the line graph of PPC for the internal walls station. The graph format was changed from Figure 4.7 to avoid possible confusion to the reader.

Table 4.3: PPC of Internal walls assignment/station crew

Activity: Interior walls Days Observed: 5 Crew size: 2					
Days		Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crew I	3	2	66.60%	Inefficiency of crew members
	Crew II	3	2		
Day 2	Crew I	3	2	66.60%	Delays due to material and mistakes
	Crew II	3	2		
Day 3	Crew I	3	3	100%	
	Crew II	3	3		
Day 4	Crew I	4	3	75%	Material shortage
	Crew II	4	3		
Day 5	Crew I	3	2.5	83.3%	Rework (Mistake by crew)
	Crew II	3	2.5		

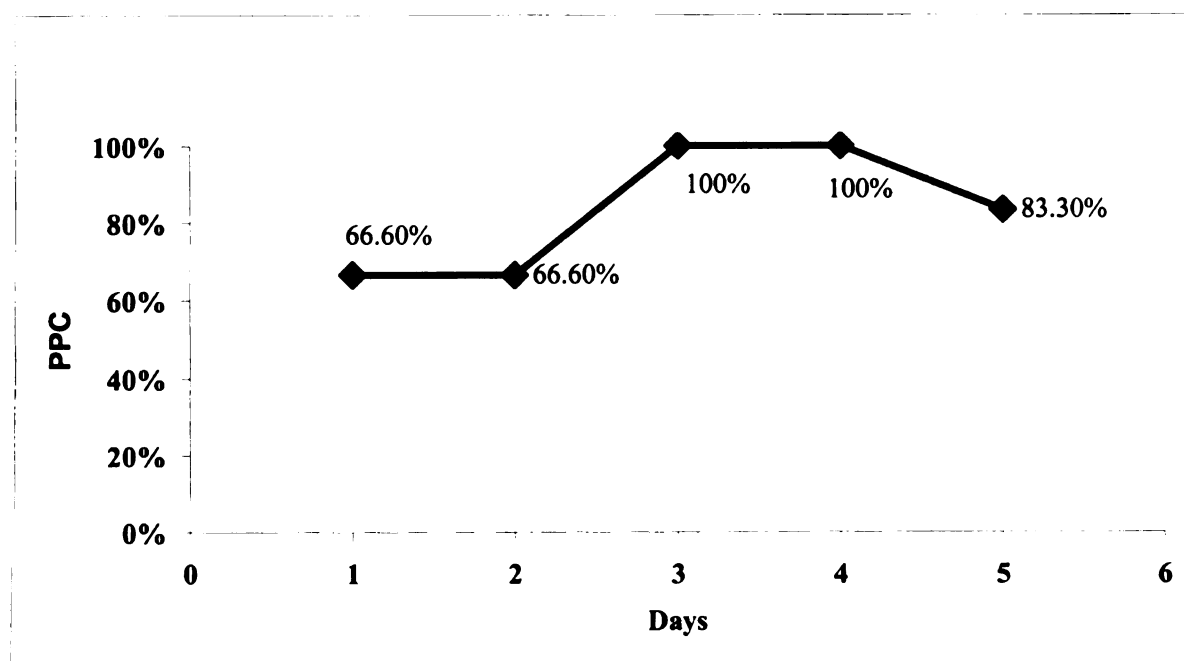


Figure 4.8 PPC for Internal walls station

Another activity observed was exterior walls station with a crew of 3. This activity was spread over two stations, a subassembly station and the other on the main assembly line. The walls are manufactured at the subassembly station and then lifted to the unit on the main assembly line and fixed in place. The main problem in this work was difficulty in fixing the prefabricated wall on the edges of the unit. A lot of rework was done due to improper fixing and nailing of the wall.

Table 4.4 PPC for External Walls assignment/station crew

Activity: External walls Days Observed: 5 Crew size: 3					
Days		Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crewmember I	3	3	100%	
	Crewmember II	3	3		
	Crewmember III	3	3		
Day 2	Crewmember I	3	2	66.60%	Material shortage
	Crewmember II	3	2		
	Crewmember III	3	2		
Day 3	Crewmember I	3	2.5	83.3%	Waiting for the unit (Directives)
	Crewmember II	3	2.5		
	Crewmember III	3	2.5		
Day 4	Crewmember I	3	2	66.6%	Delays due to mistakes
	Crewmember II	3	2		
	Crewmember III	3	2		
Day 5	Crewmember I	3	2	66.6%	Directives
	Crewmember II	3	2		
	Crewmember III	3	2		

The other activities considered for PPC are provided in Appendices. The following Figures 4.9 - 4.12 represent the PPC graph charts of all activities for which data was collected.

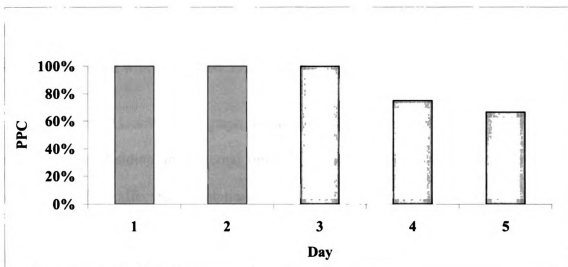


Figure 4.9 Percent plan complete of exterior boards assignment/station crew

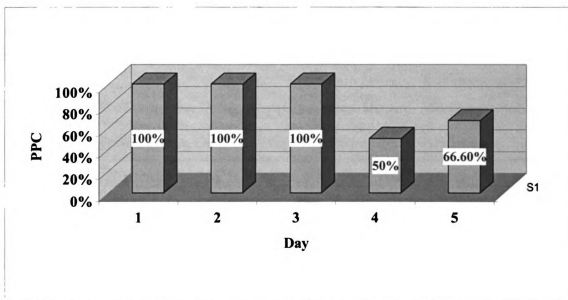


Figure 4.10 Percent plan complete of doors and windows installation station crew

Both assignments shown in Figure 4.9 & 4.10 are continuous in the assembly line and had only one crewmember assigned. Work did not start at doors and windows station until the exterior boards assignment was complete.

The effect of unreliable workflow can be clearly observed in this case in Figure 4.9. On day 4, the work was not released from exterior boards station and as a result the PPC for doors and windows is just 50% on day 4.

Figure 4.11 is the line graph showing the PPC values of two of the activities, namely, external siding and external finishes. These two jobs again had one crew each and the workflow affected both stations.

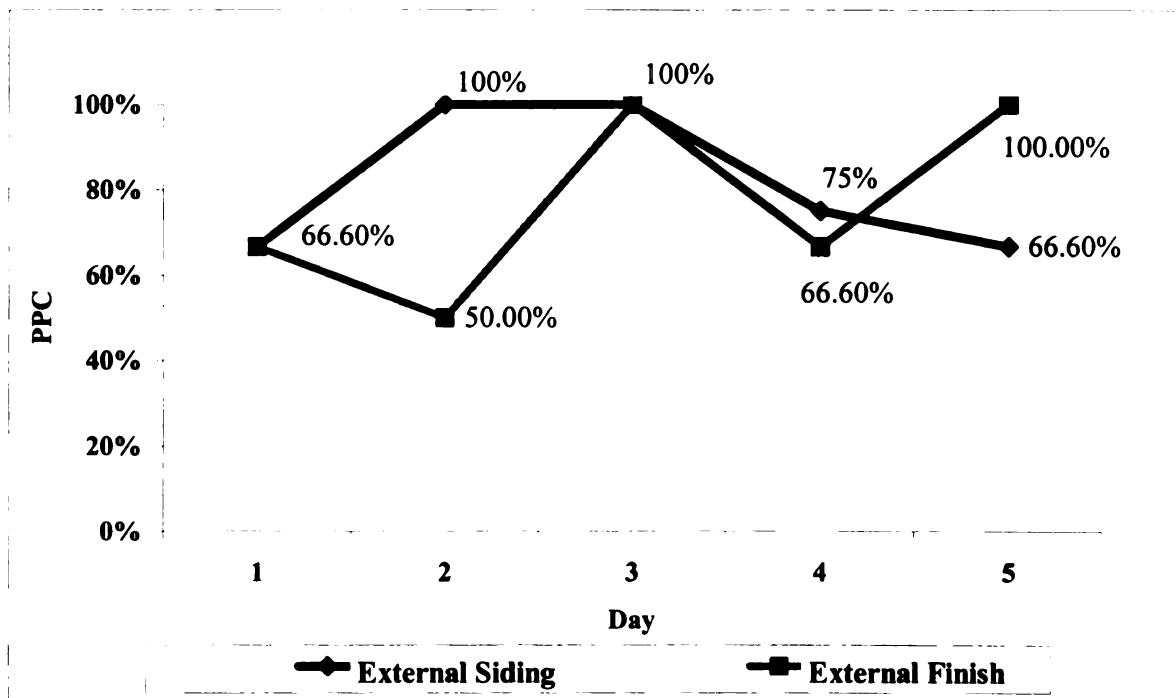


Figure 4.11 PPC for exterior siding and external finish assignment/station crews

The remaining three activities observed were paint ceiling, roof board, and roof shingles. Figure 4.12 shows the PPC for these three stations in the assembly line. Paint

ceiling is a subassembly station while roof board and roof shingles are carried on main stations along the assembly line.

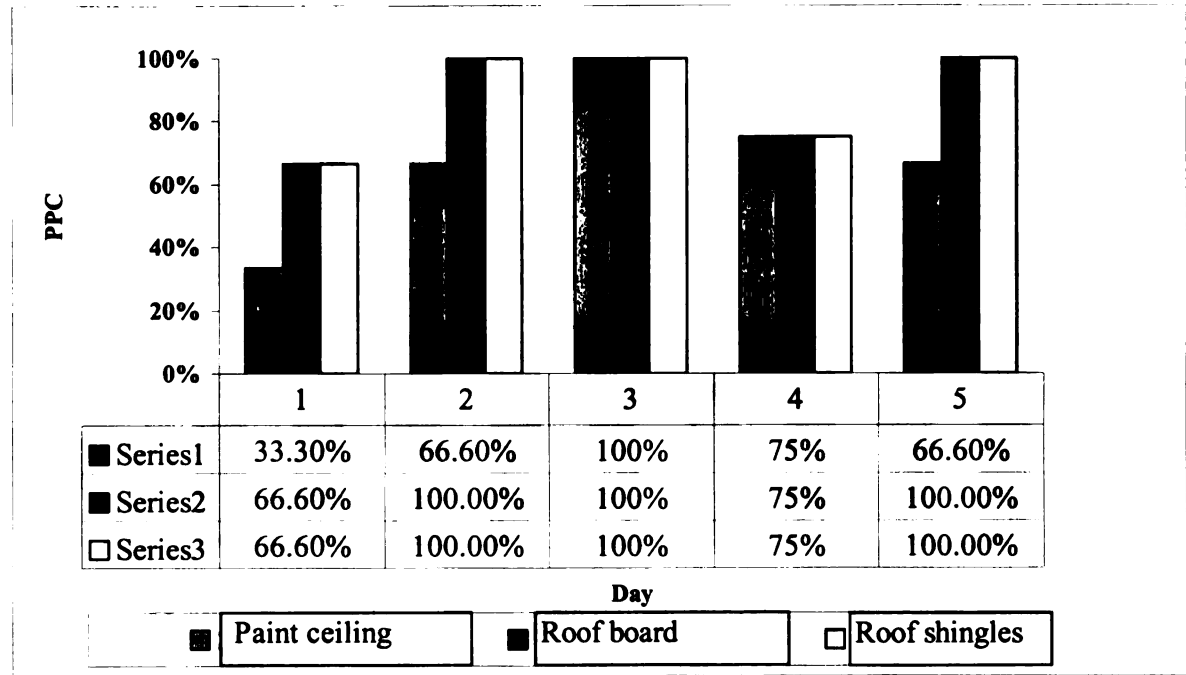


Figure 4.12 PPC for paint ceiling, roof board, and shingles assignment/station crews

4.7 Summary of PPC

The above sections presented the detail data collected for PPC and its calculations. The PPC data was collected from the foremen in charge of the above assignments for each of the crews. PPC presented above is the average crew PPC. Figure 4.13 summarizes PPC at all the observed stations in the plant. Data collected for PPC is not a very large sample and this research just makes an effort to provide a template for further investigation in production planning.

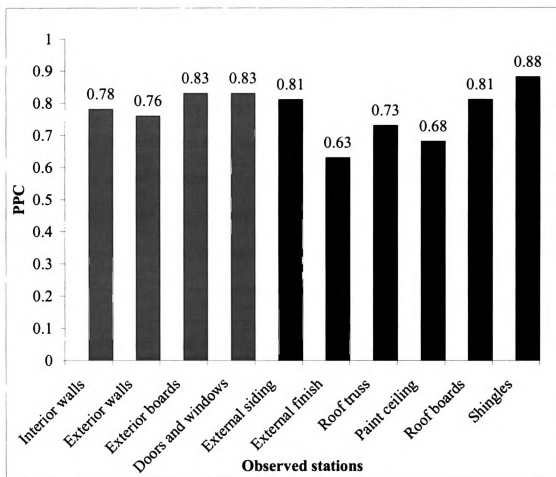


Figure 4.13 Average crew PPC of all observed stations

The PPC data will be related to the labor utilization factor (LUF) data collected to study the productivity ratings of the crewmembers performing each of the above assignments at their respective stations. The following sections present the productivity ratings sample and labor utilization factor data for the above observed activities by the different crews.

4.8 Labor Utilization Factor

Labor utilization factor calculation was described in Chapter 3. To restate, LUF is calculated from the productivity ratings that complement PPC data so that both provide a better insight to the production planning operations in a manufactured housing plant. By definition, labor-utilization factor is the percentage obtained by summing the number of observations of effective work and one-fourth the number of observations of contributory work, and the sum divided by the total number of observations. In equation format, LUF is given by

$$\text{Labor-utilization factor} = \frac{\text{Effective work} + \frac{1}{4} \text{ essential contributory work}}{\text{Total observed}}$$

$$\text{Total observed} = \text{Effective} + \text{Essential contributory} + \text{Ineffective}$$

Based on the criterion explained in the previous chapter, the productivity ratings of the work performed were calculated similar to the following example. For better understanding, the same example of Exterior board station explained for PPC is taken. The example of productivity ratings for the crewmember at this station is:

Effective work: Lifting the board, nailing of the board to the external wall studs, cutting openings for doors and windows.

Essential contributory work: Walking a distance to get the board.

Ineffective work: Waiting for the external walls station to complete the work, waiting for the exterior boards to be delivered to the feeding station.

As described in the earlier sections, each station has a different crew size based on the kind of activity taking place at that station. Some activities, which cannot take place at the main station, are undertaken at a subassembly station like the roof truss building. The observations were performed by video recording the activity of crewmembers at each station. Each crewmember's activity during the duration of the work assignment was categorized into efficient, essential contributory and non-productive work, which facilitated the calculation of LUF. For a crew of more than one, the average LUF was calculated for the entire crew. Finally, the LUF data was compared to the PPC result collected.

The next section gives a brief overview about the working environment and the work method used by the working of the labor force in the visited manufactured housing production plant. The productivity study sampling and LUF results calculated will follow this section.

4.8.1 Labor Force

A typical manufactured housing plant employs workers from areas local to the plant. These workers are usually educated at high school level and some are high school dropouts. Located in an Amish populated region in the northern part of Indiana, most of Plant A workers were Amish. Plant B, which was located in a bigger town hired mostly high school dropouts and, hence, the work practices were very different from plant A.

The manufactured housing industry has not attracted many construction workers due to its nature of work and low pay rate. Most of the work carried out in building a

manufactured house does not require high skills. And being an affordable option for housing, the costs of production are kept low and, hence, the pay rates were also not very high. From the author's observations at both production plants and interviews with production managers, the work culture was clearly different and distinguishable. Videotaping was not permitted at Plant A because of worker preference there. Production operations at plant B were video taped and then reviewed to categorize each crewmember's work activity using productivity ratings.

4.8.2 Productivity rating study

In a productivity rating study, performance of a crew or crewmember is rated to assess the amount of productive work done while the assignments are carried out. The results are usually stated as a percentage of productive to non-productive work. For construction type work, a minimum sample size of 384 observations with a combination of confidence level of 95 percent and limit of error of 5 percent is satisfactory. Choices of a detailed sampling size, confidence level and limit of error were explained in Chapter 3.

In this research, the observations were made for each crewmember while performing an activity. Eleven different assignments at different stations were observed and video taped. The total observation period of each crewmember varied from 35 minutes to one hour based on the continuity of the activity. An individual observation of the productivity status of a worker can be made every 1-5 seconds. In this research, 5 seconds was chosen as the observation interval. Hence, to get 384 observations for each crewmember, a minimum time period of 1920 (5 X 384) seconds or 32 minutes was needed.

Video recording was selected as the method of observation of the work performance of a crew, because it was easy to review the videotape later and observe the continuous performance of the worker. It also helped in video recording two or more workers in a crew at the same time and hence saved the time of actual observation in the production plant.

The plant studied, functioned from 6AM to 2PM, 5 days a week. Observing a sample of 384 only one time a day would not give a representative sample. So, productivity ratings were performed once in the morning and once again in the afternoon for each crewmember. Thus each crewmember of a particular assignment was observed a minimum of 384 times in the morning and again a minimum of 384 times of 5 seconds duration in the afternoon. The average observations from both periods were used to determine the LUF for each crew. Most of the activities observed for productivity ratings are the same as those made for PPC, and were as follows:

1. Plumbing and HVAC – Station 3
2. Interior walls – Station 4
3. Exterior walls – Station 6
4. Roof truss building – Station 8
5. Paint ceiling – Station 8
6. Roof setting – Station 9
7. Exterior boards – Station 7
8. Doors and windows – Station 9
9. External siding – Station 10

10. External finish – Station 11

11. Roof boards – Station 10

12. Shingles – Station 12

LUF data for the above activities was calculated by taking the productivity ratings observations in the AM and PM on a day when PPC was collected for the same assignment. It should be noted that PPC for a few assignments was not available and just LUF was calculated. The following section presents detail data collected for calculations of the LUF.

4.8.3 Labor Utilization Factor Data

This part of the data collection involved 5 days of video recording and more than 72 hours of watching the tapes to observe the performance of the crewmembers. There were approximately $19 \times 384 \times 2 = 14592$ observations at 5 seconds intervals, i.e., nearly 21 hours of continuous observation and data analysis. Twelve assignments with different crew sizes were observed for collecting the data. The results of each crewmember's LUF is calculated and shown in Table 4.5.

Station Crewmember	LUF	Station Crewmember	LUF
External Siding I	0.61	Exterior Boards I	0.61
External Siding II	0.54	Exterior Boards II	0.4
External Finish I	0.49	Roof Setting (Crew 1) I	0.57
External Finish II	0.49	Roof Setting (Crew 1) II	0.57

Paint Ceiling I	0.57	Roof Truss (Crew 1) I	0.43
Paint Ceiling II	0.47	Roof Truss (Crew 2) I	0.4
Plumbing (Crew 1) I	0.61	Roof Truss (Crew 1) II	0.32
Plumbing (Crew 2) I	0.62	Roof Truss (Crew 2) II	0.44
Plumbing (Crew 1) II	0.51	Doors and Windows I	0.43
Plumbing (Crew 2) II	0.41	Doors and Windows II	0.45
Interior Walls (Crew 1) I	0.6	Shingles (Crew I)	0.68
Interior Walls (Crew 2) I	0.54	Shingles (Crew 2)	0.65
Interior Walls (Crew 1) II	0.44	Shingles (Crew I) II	0.55
Interior Walls (Crew 2) II	0.45	Shingles (Crew 2) II	0.49
Exterior Walls (Crew 1) I	0.78	Roof boards (Crew 1) I	0.68
Exterior Walls (Crew 2) I	0.52	Roof boards (Crew 2) I	0.59
Exterior Walls (Crew 1) II	0.24	Roof boards (Crew 1) II	0.70
Exterior Walls (Crew 2) II	0.49	Roof boards (Crew 2) II	0.58

Table 4.5 AM and PM LUF of individual crewmembers at the observed stations

Data in the above Table 4.5 shows the AM LUF and PM LUF of each crewmember at 12 different stations. AM LUF is the morning observation and PM LUF is the afternoon observation. The observations were done in the morning and afternoon to get more representative data. This would also help observe the work pattern and productivity based on time. It can be noticed from the above figures in Table 4.5 that, the AM LUF is higher most of the times than PM LUF. It clearly shows that the productivity is low towards the end of working hours in a shift. The average of AM LUF and PM

LUF, and average of the entire crew are calculated for at each station and are represented in the bar graph of Figure 4.14.

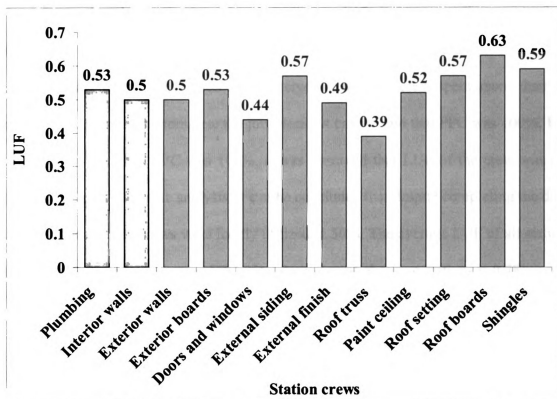


Figure 4.14 Average LUF of all observed station crews

4.9 Relation between LUF and PPC

A part of this research was to investigate the relation between LUF and PPC. An argument for the need to find out the relation between LUF and PPC was made in Chapter 3. From the data collected, it can be observed that percent plan complete of the planned assignments was high, around 70%. This figure was based on the method of calculating PPC, but actual completion was 100% most of the time, because though the assignments were not completed at the assigned station and during the time observed, all

the work was completed by the end of the day. But, according to the criteria we defined earlier this is still not complete.

From the observations as shown in Figure 4.15, it was seen that most of the assignments planned were completed by the end of the day either at a different station or outside the assembly line. It was also observed that some crew spent more than the normal working hours to complete the job. Hence it can be said that PPC was 100%. But, at the same time when PPC was 100%, it was observed that LUF of the crew was just about 50%. From this basic analysis, it can be concluded that despite completing the daily target production, the crews were hardly utilized at 50%. The average LUF of all stations observed is **0.52** and the average PPC of total number of observed stations is **0.78**.

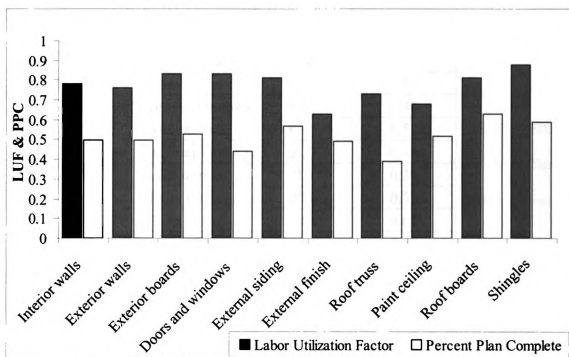


Figure 4.15 LUF vs. PPC for all the observed stations

4.10 Coefficient of Determination

In order to observe the correlation between Labor Utilization Factor (LUF) and Percent Plan Complete (PPC), data observed on a single day for LUF and PPC are plotted in Figure 4.16 as a scatter plot. The data points taken to plot Figure 4.16 are listed in Table 4.6. Regression analysis is performed using this graph with PPC on X-axis and LUF on the Y-axis of the graph. The intention of using regression here is primarily for description and not forecasting of one variable from another. Performing Regression analysis resulted in a Correlation Coefficient (r) of 25%. Also, below 80% PPC it appears there is no difference in LUF. In the region above 80% PPC, the LUF figures slightly increase with increasing PPC.

Stations	PPC	LUF
Interior Walls	0.83	0.5
Exterior Walls	0.66	0.5
Exterior Boards	1	0.53
Doors & Windows	1	0.44
External Siding	0.75	0.57
External Finish	0.33	0.49
Roof truss	0.5	0.39
Paint Ceiling	0.66	0.52
Roof Boards	0.66	0.63
Shingles	1	0.59

Table 4.6 PPC & LUF data of a single day for observing Correlation between LUF & PPC

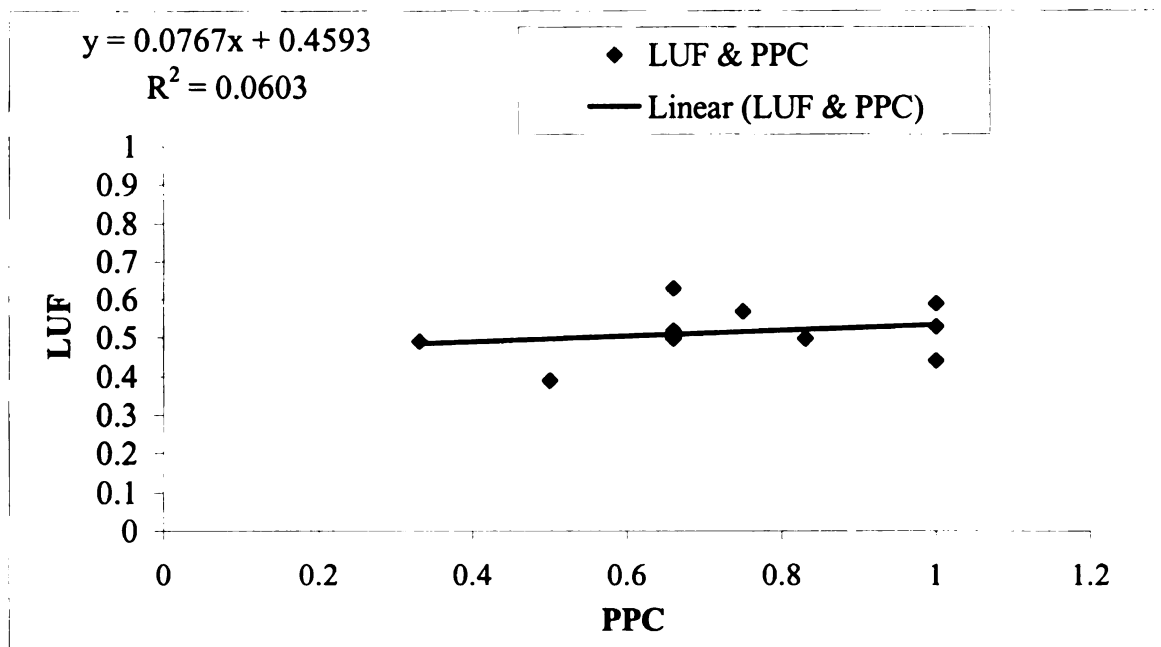


Figure 4.16 Scattered plot of LUF vs. PPC for all the observed stations

The interpretation of r^2 as the proportion of the total variation of Y explained by X is frequently taken literally. However, a regression model does not imply that Y necessarily depends on X in a “casual” or “explanatory” sense. Moreover, a value of r^2 close to 1 is not an indication of perfect inference of Y from X using the estimated regression model. The usefulness of a regression model in predicting Y from X depends upon the width of the confidence or prediction intervals. Neter et al. (1990) emphasized that:

“Regression models do not contain any parameter to be estimated by r and r^2 . These coefficients simply are descriptive measures of the degree of linear association between X and Y in the sample observations which may, or may not, be useful in any one instance.”

P-value: In order to check the statistical significance of the test to investigate the relation between LUF and PPC, **p-value** is calculated. P-value or attained significance level associated with the test is a statistical quantity that represents the smallest value of α for which the null hypothesis is rejected. Often α -values of 0.05 or 0.01 are used to attain the significance level. If p-value is less than or equal to the considered α -value, then the null hypothesis is rejected. Otherwise, if the p-value is greater than the α -value, then the null hypothesis cannot be rejected.

This test is done considering a null hypothesis that LUF and PPC are related. Denoting PPC values by x and LUF values by y , we calculate r .

$$\text{Using the formula, } r = \frac{n \sum_{i=1}^n X_i Y_i - \sum_{i=1}^n X_i \sum_{i=1}^n Y_i}{\sqrt{\left[n \sum_{i=1}^n X_i^2 - \left(\sum_{i=1}^n X_i \right)^2 \right] \left[n \sum_{i=1}^n Y_i^2 - \left(\sum_{i=1}^n Y_i \right)^2 \right]}}$$

$$r = 0.2456$$

As mentioned above, null hypothesis is that PPC and LUF are related, or assuming (PPC, LUF) has a bivariate normal distribution, $H_0: \rho = 0$ versus $H_a: \rho \neq 0$ is tested. The value of the test statistic is,

$$\text{Using formula, } z = \frac{\left(\frac{1}{2} \right) \ln \left(\frac{1+r}{1-r} \right) - \left(\frac{1}{2} \right) \ln \left(\frac{1+\rho_0}{1-\rho_0} \right)}{1/\sqrt{n-3}}$$

$$z = 0.64$$

Because this is a two-tailed test, the $\alpha = 0.025$ is the probability that Z_{calc} will fall in the rejection region of H_0 . The rejection region for H_0 is when $Z_{\text{calc}} > Z_{(\alpha/2)}$.

$$Z_{(\alpha/2)} = Z_{(0.025)} = 1.96$$

$$Z_{\text{calc}} = 0.64$$

$Z_{\text{calc}} < Z_{(\alpha/2)}$, Hence H_0 cannot be rejected.

$$\text{P-value} = 2 * P(Z > 0.64) = 2 * 0.2611 = 0.52 > \alpha.$$

Hence, for any value of alpha less than 0.5, the null hypothesis cannot be rejected. *This strongly suggests that there is no correlation between LUF and PPC.*

In this study, data was not sufficient to judge the true nature of the correlation between PPC and LUF. In addition, the limited sample size prevented an outlier analysis so that relevant data points are used. Also, the PPC and LUF measurements at each station could have contributed to the nature of data collected. Criteria for PPC for different assignments changed from station to station depending on the type of work performed and assigned. Additionally, between the two variables, LUF and PPC, requirements for collecting data for PPC were more relaxed than the requirements for LUF. Data collected for LUF was more accurate and extensive than the data collected for PPC.

With more data, and stricter requirements for PPC, it is possible that a higher correlation will be manifested. However, the results of this study do indicate that the correlation between PPC and LUF is not strong. On the one hand, a high PPC does not necessarily mean a high LUF, i.e., that the crew is efficiently utilized. On the other hand,

it appears that a low PPC is associated with a Low LUF. This indicates that it is important to consider both PPC and LUF when performance of production planning is considered. LUF adds an important dimension to the analysis as this study indicates.

4.11 Summary

This chapter has detailed out the data collection and research results. It was an arduous effort to visit the production plants and stay at the plant to observe the data from the start to close of the production. The objectives stated in Chapter 1 were achieved using the methods and techniques in Chapter 3. The last phase of this research, Chapter 5 will discuss and analyze the results. It also discusses Pareto analysis and feedback from the industry on the results obtained and uses the fish bone technique to find the constraints. The chapter finally concludes the research with future areas of research.

Chapter 5

Discussion and Conclusion

5.1 INTRODUCTION

Chapter 1 introduced the topic of this research, its goal, and objectives. In Chapter 2, literature related and necessary for this research was reviewed. Tools and methods to achieve the set objectives were explained in Chapter 3, and finally Chapter 4 reported on the data collection and data analysis. This Chapter will conclude the research with the results, conclusion, contributions, and future areas of research.

5.2 CONSTRAINT ANALYSIS

In the previous chapter, the planning process was documented, and results of PPC and LUF calculations were presented. As explained before the results were not 100% at all times for both PPC and LUF. This shows that the production planning can be improved. There could be many reasons for under performance by the production planning systems, and to explore this, constraint analysis was performed simultaneously during the data collection process. The constraint analysis technique used in this research was explained in Chapter 3, but to repeat, it is a technique to identify all the reasons for non-completion and delay of the planned assignments.

Constraint analysis, as used here, includes three steps. First, the non-completed assignments are identified from the PPC data. Second, the most frequently occurring problems are identified. Third, the reasons for such problems are determined. Finally, improvement opportunities are suggested. From the data collected for PPC and the analysis of results in Chapter 4, all the non-completed and delayed assignments were identified and are illustrated in Table 5.1. This data indicates that, on average, 22% of

planned operations were not completed. For every activity, the reason for non-completion or delay in completion was noted by asking the concerned personnel of that assignment, mostly the workers and foremen.

Table 5.1 Percent of non-completed assignments

Station	Percent NOT complete (%)
Interior walls	22
Exterior walls	24
Exterior boards	17
Doors and windows	17
External siding	19
External finish	27
Roof truss	27
Paint ceiling	32
Roof boards	19
Shingles	12

The reasons indicated by workers and foremen for completing assignments as planned were slow release of work, directives from production personnel, material shortage, planning failures, and repairs. These problems are further explained as follows:

1. *Release of work:* In an assembly line production, release of work from the upstream is extremely critical for maintaining work flow. Release of work in proper fashion as planned keeps the production line running and production smooth. Any delay in release of work causes downstream work to stop and wait.

This is one of the major problems in an assembly line production and was observed in the manufactured housing production plant under study.

2. *Planning failure:* The planning of operations at each level and at each station on the assembly line becomes very important and helps the production run efficiently.
3. *Directives:* Execution of planned operations is as important as planning the operations. Production operations directives and decisions taken at critical stages of production are quite important in proper production of the product. The planning personnel like foremen and production manager play a key role in directing the operations and giving directives.
4. *Material shortage:* Material shortage seems like an easy problem to handle, but the line progress is held hostage until the problem is resolved. According to the plant production manager, less inventory and Just-in-time are lean production ideals but have to be carefully used and managed.
5. *Rework:* This problem results due to various failures. It could be a crewmember's mistake, production planning defect, or any other unknown reason. The particular production plant studied had a separate station for repairs at the end of the assembly line. All reworks and repairs were performed at this station. If there are too many units that need rework or repairs, they are kept out of the plant, and then brought back in to the plant to complete the work. This is a sign of mass production.
6. *Other problems:* There are few other problems, which are not very frequent and unexpected, like changes in design, inspection agency changes, and so on.

Table 5.2 list all these problems and their frequency of occurrence (Number of assignments they occurred on)

Table 5.2: Problems in production operations of a MH production plant

Problem	Number of assignments
Work from upstream not released	14
Directives for operations	7
Planning failure	7
Material Failure	7
Rework/Repairs	4
Others	2

5.2.1 PARETO ANALYSIS

Pareto analysis is a technique that identifies the ‘vital few’ factors that are responsible for the majority of problems. The data in Table 5.2 was used to create a bar chart to indicate such ‘vital few’ and ‘trivial many’ factors that affect the proper functioning of the production process in a manufactured housing production plant. Figure 5.1 depicts the Pareto analysis for the plant under study.

Based on the Pareto analysis bar chart in Figure 5.1, it can be clearly observed that there are a vital few factors that cause the majority of the problems in the production process of the manufactured housing plant under study. The next step was to find out the actual assignable causes of these problems using cause-and-effect diagrams as explained in Chapter 3, section 3.5.3. The next section in this chapter explains the different causes

and traces the roots of various problems that occurred during the time of data observations and collection.

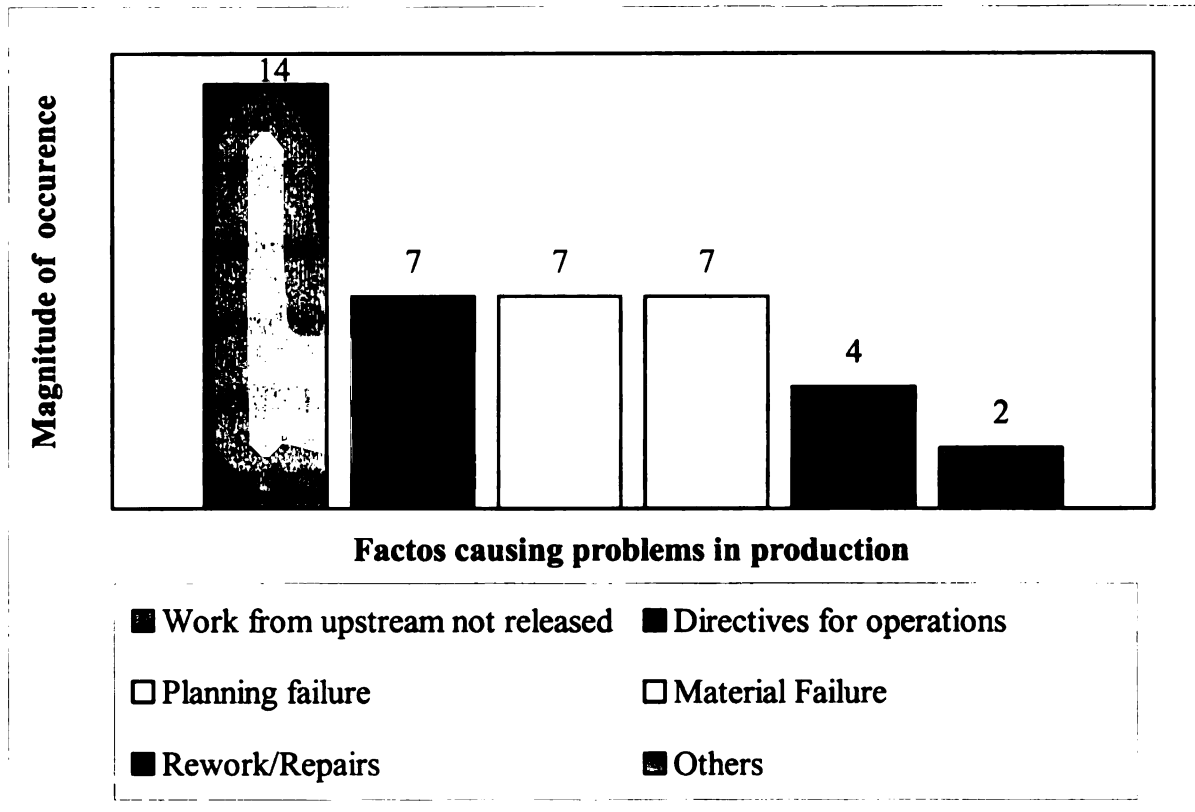


Figure 5.1 Pareto analysis chart depicting the factors responsible for problems

5.2.2 FISH BONE TECHNIQUE

Cause-and-effect diagrams commonly known as Fishbone diagram or an Ishikawa diagram is a tool used to clarify the causes of a problem (Markland et al 1998). The various problems observed and gathered during the data collection were listed in the above sections and the fishbone diagrams were constructed with the production personnel at the plant to assign the root causes for such problems. Based on this process, the following root causes were assigned for the problems observed:

1. Labor Issues: One of the plant's major problems is the worker issue. In Chapter 4, a section described the kind of labor force that usually works in manufactured housing industries. The various root causes of the labor problems were:

- a. Slow work: Most of the workers working in the plant are slow when compared to the other plant observed for this research project. The plant manager and foremen also corroborated this.
- b. Skill: Basically the workers employed in the manufactured housing industry are not very skilled, but some trades require a little skill in performing the work. This was lacking in some of the trades and caused many problems in the production.
- c. Work ethics: The production plant manager felt that work ethics have changed over the years. The workers move around slowly and are not motivated to complete the tasks. Worker abstinence was also observed and thus caused problems for the management in planning the work.
- d. Uneducated work force: The manufactured housing industry employs a large number of uneducated labor forces to cut down costs on production. But, this causes various problems in the production such as workers inability to read the drawings, inaccurately taking measurements, and other similar problems.

2. Material: Material supply is a big issue in any production environment and so is the case in manufactured housing plants. According to workers, foremen, and management, material supply to the plants is an issue, which causes problems in the production. The management also cited the lack of a systematic way to track material usage.

From the observations, it was seen that much of the plant space was being occupied by material not used for days. The author feels that imbalance in production and improper production planning was one of the reasons for material shortages. If planning is done well and the material is handled properly, using less inventory and JIT techniques would be a good option in a manufactured housing industry.

3. Methods and directives: Methods of production and directives of the production process play a vital role in a smooth and structured production flow. Most of the problems, the ‘vital few’ were caused due to the lack of directives, and uneven workflow from one station to the next.

Design issues of a manufactured house create many problems. For example it was observed that a big roof truss was to be built, and the design of the truss was not detailed and thus the workers faced a lot of problem building it. Because of delay in making the unit at that station, the work was delayed on the entire assembly line.

One of the main principles of lean production is to have a structured workflow such that the work is released from upstream to downstream at proper intervals to avoid stoppages in production flow. During the observations, it was noticed that large delays in work at one particular station were affecting the work at the remaining stations along the assembly line.

4. Equipment: Most of the equipment used in the manufactured housing industry is sophisticated and work is made much easier with such equipment. During the observations, equipment was not really a big problem in completing the assignments. A few concerns

of the workers regarding the equipment in the plant did not really affect the production process.

One of the concerns, which needed to be addressed, was the airlift system, used to transport units from one station to the next. This system did not allow smooth movement of the unit and it also did not allow work underneath the house. In another instance, a failure in a crane, dedicated to lift trusses, delayed the subsequent operations considerably.

5. Other issues: The other issues, which caused the problems in production and completions of work as, planned were: Sales problem, market demand, and government regulations. Due to the low market demand and other external problems, it was a tough job for the sales department to make sales. In order to achieve make sales, the sales department would sell the houses with special designs and other changes according to the customer choice and also to attract the customers. This created problems for the production planning team and the production crew to manufacture such units and hence slowed down the production. Government regulations, which constantly changed and clearance of quality inspection by the external inspection agency, were some of the other trivial few problems affecting production.

Overall, the production planning should be revisited and planned carefully without repeating the mistakes that were observed and identified during this research project. The data in this research project can be used to identify opportunities for improvements and making changes in the production planning to improve the operations performance.

5.3 RESULTS AND CONTRIBUTIONS

The main goal of this research was to evaluate plant production planning process in the manufacturing housing industry and to identify opportunities for improvement. The objectives were:

1. Documenting the currently utilized production planning process in a Manufactured Housing plant.
2. Assessing and quantifying the production planning process performance using lean construction principles.
3. Identifying causes of off-target performance through constraint analysis techniques and suggesting opportunities for production planning process improvement.

These objectives were achieved by using the discussed methods and tools of Chapter II and Chapter III, which were, literature review, interviews, last planner system, productivity ratings, and constraint analysis. The results of this research project were discussed in Chapter IV and Chapter V. The results of this research were:

1. Identifying the production planning process requirements.
2. Calculating Percent Plan Complete and Labor Utilization Factor for 12 stations of a manufactured housing plant.
3. Determining reasons for not completing assignments using constraint analysis.
4. Identifying opportunities for production planning process improvement.

This research makes the following contributions to the research on manufactured housing:

1. A documented production planning workflow, production planning strategies, and production planning work requirements in manufactured housing production process.
2. A method to evaluate performance of production planning process in a manufactured housing plant and identify process improvement opportunities. The method demonstrated in this research was using Last planner's PPC tool and Productivity ratings through work sampling.
3. Investigated relation between Percent Plan Complete and Labor Utilization Factor. For the present data set available it was found that a linear relationship existed between PPC and LUF. The author at the same time feels that more data points are required to access this relationship in further detail. For the available data the relationship attained was a contribution of the author.
4. Demonstrated the use of Pareto analysis and Fish bone diagrams as constraint analysis techniques to identify process improvement opportunities.

5.4 RECOMMENDATIONS AND GUIDELINES FOR THE INDUSTRY

After studying and understanding the whole production planning aspect of manufactured housing production plants, the author has come up with the following recommendations and guidelines.

1. Manufactured housing industry is a combination of site-built construction and manufacturing industry (E.g.: Automobile industry). The industry can take advantage of both the industry's practice to improve its production planning.
2. The tools used like LUF, PPC, Pareto analysis and Fishbone technique can be used to fit the manufactured housing industry needs. This research used these tools to assess the production planning. PPC, out of Last planner can be used as a production planning technique by the MH plant. The foremen to assess the performance of each individual station can also use PPC at individual stations. Similarly, the crew performance can also be measured using LUF results and finally Pareto analysis can be performed to improve the performance at each the station level, improving the performance of the whole plant.
3. Each individual plant of a company could also use these tools and the CEO or owner of the company can get a clear picture of performance of each plant. For instance, the CEO of a company would get a clear picture of the production capacity and the current productivity. If provided with a chart for one month of observations of PPC and LUF, with constraint analysis, he could determine the problem areas and take appropriate measures to streamline the production process and reduce the waste in the production.

The next section describes future areas of research and other aspects of this research project, which were not looked into due to the limits and scope of this work.

5.5 LIMITATIONS & FUTURE AREAS OF RESEARCH

This research project assessed the production planning of a manufactured housing plant using lean production principles. Like any other project, this research had certain limitations. The following were the limitations of this research project:

1. This project had a very small sample and it does not reflect the entire manufactured housing industry's production planning. Only two plants were considered to achieve the set objectives.
2. Due to the time and scope of the work, this research project observed only a few stations in the plant. Also, the selection of stations for this project was based on facilitated access to the production plant.

As a part of this research the author studied two factories in the regions of northern Indiana. Only few of the stations along the assembly line and other subassembly stations were studied. The production planning process was analyzed and assessed. Different problems and opportunities for production planning process were identified. One of the major areas of future research could be the application of this production planning process assessment technique to the complete factory.

Also, this method of production planning assessment can be applied to different production plants and a set of problems can be identified based on the location of the factory. The sample for this research project was very small and it does not give an overall picture of the entire manufactured housing industry. Applying this technique to a larger sample would give an overall picture of the manufactured housing industry.

Research can be carried out in order to map the exact material consumption involved at every activity and sub activity station. A research on this line would help find more accurate solutions to the problems presented in this research. Just-in-time concept can be applied to see the material handling in a manufactured housing industry.

5.6 SUMMARY

This thesis report has been divided into five chapters. In Chapter 1, an overview of the evolution of manufactured houses was introduced. Various aspects of the manufactured housing industry, like cost analysis, demand issues were discussed and a problem statement was formulated. The research goal and objectives were also presented.

In Chapter II, a detailed description of terms and existing research related to the manufactured housing industry were discussed. Chapter II also summarized the different production processes, lean production, lean construction, and the existing research in these areas. Finally a background of production control and last planner were described.

In Chapter III, methods and tools to achieve each of the three objectives set in Chapter 2 were explained. This chapter also explained in detail each step of the PPC, productivity ratings, and constraint analysis tools used in this research. Chapter IV reported on data collection and results.

Finally, Chapter V discussed Pareto analysis and input from the industry was used to construct a fishbone diagram and find the main constraints. The chapter finished with the research with conclusion, results and contributions, limitations, and future areas of research.

APPENDICES

Activity: Exterior boards					
Days Observed: 5					
Crew size: 1					
Days	Crew	Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crew I	3	3	100%	
Day 2	Crew I	3	3	100%	
Day 3	Crew I	3	3	100%	
Day 4	Crew I	4	3	75%	Work from upstream not released
Day 5	Crew I	3	2	66.6%	Work not released

Activity: Doors and windows installation					
Days Observed: 5					
Crew size: 1					
Days	Crew	Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crew I	3	3	100%	
Day 2	Crew I	3	3	100%	
Day 3	Crew I	3	3	100%	
Day 4	Crew I	4	2	50%	Work from upstream not released
Day 5	Crew I	3	2	66.6%	Work not released (Directives)

Activity: External siding Days Observed: 5 Crew size: 1					
Days	Crew	Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crew I	3	2	66.6%	Assisting a different crew at another station
Day 2	Crew I	3	3	100%	
Day 3	Crew I	3	3	100%	
Day 4	Crew I	4	3	75%	Work from upstream not released
Day 5	Crew I	3	2	66.6%	Work not released (Directives)

Activity: Paint ceiling Days Observed: 5 Crew size: 1					
Days	Crew	Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crew I	3	1	33.3%	Work not released from roof truss building
Day 2	Crew I	3	2	66.6%	Worker absent / Roof truss worker completes 2 out of 3
Day 3	Crew I	3	3	100%	
Day 4	Crew I	4	3	75%	Work from upstream not released
Day 5	Crew I	3	2	66.6%	Material shortage

Activity: Roof board Days Observed: 5 Crew size: 2					
Days	Crew	Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crew I	3	2	66.60%	Work not released
	Crew II	3	2		
Day 2	Crew I	3	2	66.60%	Crew not present/Shingles workers do the work
	Crew II	3	2		
Day 3	Crew I	3	3	100%	
	Crew II	3	3		
Day 4	Crew I	4	3	75%	Material shortage
	Crew II	4	3		
Day 5	Crew I	3	3	100%	
	Crew II	3	3		

Activity: Roof shingles Days Observed: 5 Crew size: 2					
Days	Crew	Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crew I	3	2	66.60%	Work not released
	Crew II	3	2		
Day 2	Crew I	3	3	100%	
	Crew II	3	3		
Day 3	Crew I	3	3	100%	
	Crew II	3	3		
Day 4	Crew I	4	3	75%	Work not complete at roof board station
	Crew II	4	3		
Day 5	Crew I	3	3	100%	Rework (Mistake by crew)
	Crew II	3	3		

Activity: External finish Days Observed: 5 Crew size: 1					
Days	Crew	Planned	Completed	Average Crew PPC	Reasons/Delays
Day 1	Crew I	3	2	66.6%	Material shortage
Day 2	Crew I	3	1.5	50%	Work not released and slow crew member
Day 3	Crew I	3	3	100%	
Day 4	Crew I	3	2	66.6%	Slow work and work released late
Day 5	Crew I	3	1	33.3%	Work not released and slow crew member

Crew LUF of Plumbing and HVAC				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	409	227	103	0.61
Crew 2	411	221	144	0.62
AM LUF				0.615
Crew 1	400	175	120	0.51
Crew 2	404	141	99	0.41
PM LUF				0.46
Average crew LUF				0.5375

Crew LUF of internal walls				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	407	215	117	0.6
Crew 2	409	204	68	0.54
AM LUF				0.57
Crew 1	425	165	102	0.44
Crew 2	425	158	134	0.45
PM LUF				0.445
Average crew LUF				0.5075

Crew LUF of external walls station				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	406	305	49	0.78
Crew 2	406	201	43	0.52
AM LUF				0.65
Crew 1	424	77	105	0.24
Crew 2	424	175	141	0.49
PM LUF				0.46
Average crew LUF				0.365

Crew LUF of Exterior boards				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	384	230	102	0.66
AM LUF				0.66
Crew 1	394	131	111	0.4
PM LUF				0.4
Average crew LUF				0.53

Crew LUF of External Siding				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	410	222	115	0.61
AM LUF				0.61
Crew 1	432	201	142	0.54
PM LUF				0.54
Average crew LUF				0.575

Crew LUF of External Finish				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	397	167	117	0.49
AM LUF				0.49
Crew 1	432	181	136	0.49
PM LUF				0.49
Average crew LUF				0.49

Crew LUF of Roof truss building				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	400	152	88	0.43
Crew 2	404	140	95	0.4
AM LUF				0.415
Crew 1	432	115	98	0.32
Crew 2	432	148	173	0.44
PM LUF				0.38
Average crew LUF				0.39

Crew LUF of Shingles Station Crew				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	418	270	58	0.68
Crew 2	418	262	51	0.65
AM LUF				0.665
Crew 1	398	212	35	0.55
Crew 2	398	187	47	0.49
PM LUF				0.52
Average crew LUF				0.59

Crew LUF of Paint ceiling				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	432	233	61	0.57
AM LUF				0.57
Crew 1	401	168	94	0.47
PM LUF				0.47
Average crew LUF				0.52

Crew LUF of Roof setting in place				
Crew	Total Observations	Efficient	Contributory	LUF
Crew 1	407	210	101	0.57
AM LUF				0.57
Crew 1	408	206	113	0.57
PM LUF				0.57
Average crew LUF				0.57

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