# ASSESSMENT OF PRODUCTION PLANNING PROCESS IN RESIDENTIAL CONSTRUCTION USING LEAN CONSTRUCTION AND SIX SIGMA

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## ABSTRACT

ASSESSMENT OF PRODUCTION PLANNING PROCESS IN RESIDENTIAL CONSTRUCTION USING LEAN CONSTRUCTION AND SIX SIGMA

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The homebuilding industry in the United States is at its peak with the increase in demand for homes. With the projected demand for homes in sight, many companies are preparing themselves to be able to build more and more homes. Hence, it is vital for companies to adopt the best practices of production planning and control. The research aims at providing a production planning process performance assessment tool for the homebuilding industry while exploring the possibilities of using a combination of Six Sigma and Lean Construction principles to achieve the goal of zero-defect in a process. Interviews with professionals from the homebuilding industry were conducted to study the prevalent practices. Data was collected from a homebuilding site and a set of analysis tools was used to analyze the data and find areas of improvement. An assessment tool and a metric for performance assessment of production planning process were developed. A production planning process model was developed based on this study. The model is a combination of the Six Sigma DMAIC methodology and the Last Planner System. The study shows that homebuilding companies generally perceive a higher production yield than actual. Data analysis revealed that task pre-requisites, coordination with suppliers, and overestimating productivity were major causes for unreliable production planning.

*I wouldn't have been producing this thesis if not for the support and encouragement I got from my father. I dedicate this thesis to him.*
*I also dedicate this thesis to my mother who compromised her own happiness by letting me away from her, so that I could achieve this.*
*I extend my dedication to my lovely sister and my brothers. And to my two little nieces who always kept me in high spirits.*

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# Chapter 1

# Introduction

## Introduction

### 1.1 Motivation

Construction is as old as any civilization. Every civilization in this world considers construction of structures as a symbol of their prosperity. Construction of structures has been executed for shelter, transportation, defense, storage as well as for public entertainment and meetings. In the past few centuries the world has seen amazing structures like the Pyramids of Egypt, Taj Mahal in India, and Great Wall of China. It is remarkable that these were built in an age when technology was way behind what we have now.

These constructions projects had so many challenges to tackle; one can imagine the logistics involved, the different materials requirements, specifications of the owners (generally a king or a ruler), labor productivity, etc. How did they manage to achieve such a task? Most of such projects didn't have a time restriction and labor force was large and money also was abundant. Yet, history of the construction of such structures does show some sort of formal planning (Patrick, 2004). One can imagine the complexity of the production planning process involved.

As civilizations grew, the variety and quality of construction improved (Allen and Thallon, 2002). In the last century, technology had an exponential growth and this also had an influence on construction. The construction systems became more and more sophisticated, the construction materials improved, the labor force started to receive formal training, and formal management techniques began to be recognized (Allen, 1999). The industry has recognized management has an important and distinctive requirement of a successful project (Patrick, 2004). Today, the construction industry follows traditional management techniques. The main functions of project management are planning, organizing, staffing, coordinating, directing and controlling (Patrick, 2004).

The first of the many steps involved is Planning. This task basically means establishing the course of project execution. Project planning involves outlining a course of action, deciding on what is to be done, who will do it, how it will be done, when will it be done, and how much it will cost (Syal 2003). A good and reliable plan will exude confidence in the project team. Highly complex projects have been executed successfully with the aid of systematic and skilled planning. Planning being the first step of the project management functions, it decides the success of all the following functions. If planning is not done meticulously, execution and control becomes difficult. The success of a project is determined on how well it is executed in comparison with the plan. When plans change due to unexpected events and uncertainties, the project team develops recovery plans to stay within the broad objectives of the project as previously captured in initial plans.

The planning process differs across the different categories of construction. For example in residential construction companies building few homes a year have less needs for detailed planning compared to larger homebuilding companies. It is the author's opinion that a systematic planning process as well as a system that will measure the effectiveness of the planning process is necessary to increase its production.

The typical construction process for small size homebuilding companies, is a very ad-hoc approach where one builder finds a good site, decides to build a home, hires local subcontractors and starts the process of construction. All the planning process is done mentally and informally with many details left to chance. When this builder is building about 3 to 5 homes simultaneously, everything is in chaos. This typically leads to confusion, less productivity, monetary losses and delay. Medium companies have a more systematic approach, wherein they have proper written agreements, qualified subcontractors, planned production goals and deadlines to meet. Most of the larger companies follow a system with bids, contracts, planned production, well-maintained cash flows, performance analysis, quality considerations, safety and environmental considerations, and requirements for customer satisfaction.

To successfully compete long term, a company must satisfy its customers by providing superior quality which is rapidly becoming the criterion which differentiate companies from their competitors (NAHB, 1993). With increasing demand for homes, it is evident that more and more construction companies will participate in the competition. Thus, it is clear that companies have to plan their operations to reach and maintain the highest level of customer satisfaction.

Planning being the first step towards the successful execution of a project, it needs to be as representative as possible (Hinze, 1998). Equally important is site production planning done by homebuilding companies. Site production planning is the planning done for day-to-day site activities. It is planning at a smaller level that includes all tasks performed on site for completing the project. Present site production planning methods used in the construction industry have evolved out of experience and knowledge. Site production planning is necessary to breakdown the whole construction process into smaller tasks done on a daily basis and achieve the production goals. Thus, site production planning is critical for successful execution of tasks. Construction companies need to assess the current practices and improvise on its techniques if needed. This could be done by accepting and implementing some changes, even small ones. In order for companies to identify areas needing improvement, a system of performance assessment is the key.

Performance assessment is a very vital tool to improvise on any process (Evans and Lindsay, 2001). Assessment means to evaluate how effective a process is. For this, a framework has to be developed such that the process can be studied, its outcomes can be measured and areas needing improvements can be identified. Such a framework will have to be developed for all processes that considerably affect the execution of site eoperations. Therefore this research developed an assessment framework for residential construction site production planning process. This framework will allow homebuilders, and possibly contractors from other sectors, to find improvement opportunities in the production planning process.

### 1.2 Need Statement

In residential construction, a homebuilder needs a system of planning, to manage and control the entire construction process. It is the author's opinion that a good system of planning will be one that can establish the future course of actions correctly as to when what work will be completed, how can the construction process finish on time, provisions to tackle crisis, and at the same time produce a high quality product, in the most efficient and profitable way. With the projected growth in demand for housing (Bureau of Census 2000), as shown in Table 1.1, the homebuilding industry needs a system, which will address both the short term and long term goals and thus keep the entire process under control and it should help in the process of continuous improvement.

Most homebuilders follow a system of planning where the whole process is broken down to the activity level such that it can be monitored and controlled and each activity is sequenced following technical, structural and regulatory considerations. Sometimes, the duration and timing is decided such that they save on time without even considering whether it is practically possible. Later, during the construction process when things do not go as planned, crashing and other crisis management techniques are followed.

| *YEAR* | *TOTAL NUMBER OF HOUSEHOLDS* |
|---|---|
| 2000 | 105,480,101 |
| 2001 | 106,478,583 |
| 2002 | 107,690,202 |
| 2003 | 108,800,265 |
| 2004 | 109,937,037 |
| 2005 | 111,052,797 |
| 2006 | 112,216,108 |
| 2007 | 113,396,397 |
| 2008 | 114,596,986 |
| 2009 | 115,802,105 |
| 2010 | 117,059,577 |

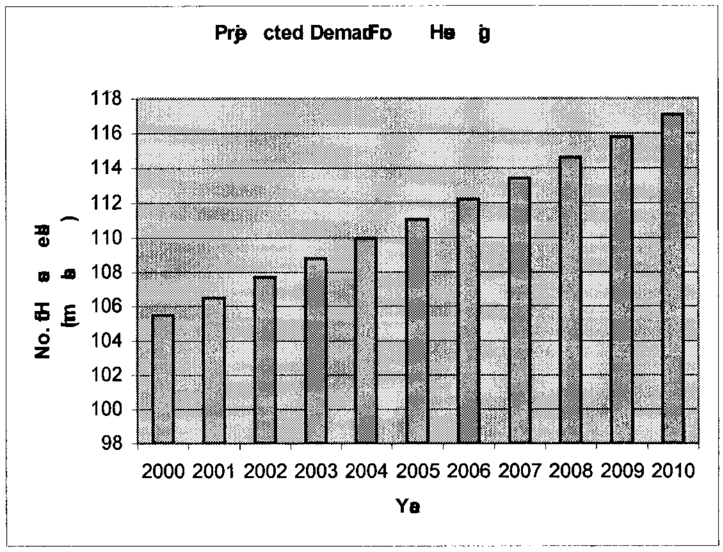


**Table 1.1 Projected demand for housing**

**(Source: Bureau of the census 1996 projections updated with 2000 census results)**

According to Lauri Koskela (1999), a production planning and control system should follow three principles. "The first principle is that the assignments should be sound regarding the prerequisites... The second principle is that the realization of assignments is measured and monitored... The third principle dictates that causes for non-realization is investigated and those causes are removed. Thus, in fact, continuous, in-process improvement is realized."

The Last Planner System proposed by Ballard (2000) is a system of production planning in which any assignment has to be well defined, sequenced in such a way that it is constructible, should be sound, and should be "sized to the productive capability of the crew".

A careful consideration of the planning procedures suggested in prior and state-of-the-art research raises the question of whether homebuilders plan their production process accordingly? Few questions that arise are:

- Do the homebuilders have a systematic production planning method? If yes, then do they measure and monitor the process effectively?
- Do homebuilders investigate the causes behind production plan failures?
- Are these causes eliminated and better methods applied in future projects?

These questions underscore the need for a detailed study on the production planning system commonly used and its effectiveness in the residential construction industry. Improvising on the production planning system promises a process that is in control and more reliable. The residential construction industry will benefit from an effective production planning system with a proper monitoring and analyzing tool.

### 1.3 Research Goal and Objectives

The goal of this research is to assess the effectiveness of production planning process in the residential construction industry. To attain this goal the following objectives were achieved:

- Documenting the production planning process prevalent in the industry

  This objective involved the following steps:

- Interviewing of homebuilders to understand the production planning method currently in use.
- Field observations on project sites to record how the production planning process is conducted.

- Developing a framework for production planning performance assessment and identification of process improvement opportunities.

  This objective involved the following steps:

  - Conducting a literature review and evaluation of tools and techniques used for measuring and analyzing production performance to find a suitable tool for measuring production planning performance and for identifying process improvement opportunities.
  - Measuring, through field visits, the production planning performance using the selected tools and techniques.
  - Analyzing results to identify process improvement opportunities.

**1.4 Research Scope**

The scope of this research is limited to the assessment of the current production planning system used in the industry. This research will measure the performance of a production planning process and analyze it to find opportunities for improvement. The goal of this research is not to generalize any of its findings; rather, it develops a framework for assessing the production planning system and for identifying opportunities for improvements. The framework is evaluated on two example buildings and the production planning process of one homebuilder is studied in detail. The homebuilder falls into the category of a 'medium' size homebuilding company. The company operates in the

Lansing area (Michigan). This is due to accessibility, time and budget constraint. The tool that was used to measure and analyze the performance is selected after the study of tools commonly used for performance measurement.

### 1.5 Report Overview

This proposal is divided into five chapters. Chapter 1 discusses the importance of a planning process in construction. A need statement was formulated and research goals and objectives were presented along with the scope of the research.

In Chapter 2, a background of residential construction is discussed including previous research in the area. This chapter also discusses the various performance measurement and analysis techniques commonly used, of which one technique or system is selected for use in this research.

Chapter 3 outlines the methodology that is adopted to attain the research goal. Detailed discussion on action items that are undertaken to achieve the various objectives is presented. A hypothetical case study demonstrates the research methodology and the expected results.

Chapter 4 presents the data collection and analysis procedures. This chapter also presents, in detail, the Production planning Model developed in this study.

Chapter 5 concludes this report with a summary, research contributions and conclusions. This chapter also includes a discussion on research outcomes and opportunities for future research.

# Chapter 2

## Literature Review

## Literature Review

### 2.1 Residential Construction

Growth in the housing industry is an indicator of a strong national economy (Willenbrock et al., 1998). The housing industry in the US is a fast growing industry and is expected to grow astronomically in the coming years (Bureau of Census, 2000) as explained in the 'Introduction' chapter. Large homebuilders currently anticipate construction of up to 30,000 houses a year across the nation to meet the huge demand for houses. And the rate of production is going to increase proportional to the demand for houses. To accommodate this, the housing industry has adopted production building as a process for constructing homes. Houses are built in mass numbers and customization of houses is also made possible with various options for the customers to choose from. The planning involved in a production process is a meticulous task and it is a key to successful production.

This section describes the production planning process and gives an understanding of production planning process in residential construction industry. Prior research in this area is presented and its limitations are stated.

#### 2.1.1 Production Planning Process

The meaning of the term '*Production*' at its most generic sense is synonymous with "making" (Ballard, 2000). In the US, the residential construction sector generally repeats a small number of models several times in a relatively confined area using specialized trade contractors to complete each phase of each home (Bashford et al, 2003). The homebuilders make a large number of homes in a specified time while allowing numerous customization options to the customers. This essentially is production of homes, similar to the production concepts used in the manufacturing industry. A *production process* can be defined as the method or the steps involved in making a product. In residential construction, production processes includes site preparation, construction of homes, and finishing and delivering the end product.

The project planning process in residential construction includes defining and organizing the work to be accomplished; the most common way of doing this is by developing a list of activities and determining relationships between each activity and sequencing them. A Work Breakdown Structure (WBS) is generally used to develop a list of activities and a Gantt chart (Bar chart) and a network drawing is used for sequencing and showing the interrelationships. Next, a quantity takeoff is performed for each activity and the productivity of the crew is determined, from which activity duration is calculated. All this information is integrated into a 'plan' with inputs of additional information for responsibility, cost, constructability and availability of resources. For the purpose of this research, the planning of construction activities in the field for a period of time is referred to as 'production planning process' and is different from project planning. *Production planning* is the process of organizing and developing a plan of daily actions to be executed to complete a production process. This process depends on a number of factors and variables as well as a number of key people who have been or will be associated with the project (Peterson 1993).

Residential construction could be viewed in two different ways: a single project view or a multiple project view. According to Bashford et al (2003), in a single project view it is assumed that start of an activity depends on completion of its predecessor whereas, in a multiple project view factors such as availability of subcontractors, their response time and communication between numerous parties has to be also considered while planning. Thus, production homebuilders view their project as a factory type setting and not as small individual projects (Bashford et al 2003). Planning for such a setting has to be systematic, accurate and reliable.

In addition to the process of planning explained above for residential construction, planning for a production type setting would include coordination of trade contractors, planning of material supply chain, continuous availability of work and contingencies for possible uncertainties involved in completing a task. Production planning should provide superior organization, control throughout the project, and workflow reliability such that work starts and finishes according to the plan.

### 2.1.2 Prior Research

This section reviews studies performed in the area of planning in residential construction that are relevant to the research. Previous research efforts in this area have focused on scheduling for repeating activities, comparison of production building and manufacturing, and evaluation of production planning systems in construction.

In his book "*Scheduling Residential Construction,*" Love (1995) mentions that "...many builders might be able to guess with a fair degree of accuracy. But can you afford to guess when there are ways to predict accurately?" The book has an entire chapter on the process of construction planning process to complete a residential project successfully. Love (1995) has explained in detail the planning and scheduling of a residential project, where planning is explained as the process where the project is organized into different phases, developing a work breakdown structure, sequencing activities and assigning responsibilities to perform activities to various trade contractors or crews. Planning for a production style residential construction project with many homes has not been explained in detail in scheduling books reviewed by the author (NAHB 1993, Love 1995, Hinze 1998, and Patrick 2004).

The National Association of Home Builders (NAHB) research center published a report in June 1993, titled, "*Cycle-time reduction in the residential construction process,*" which described an investigation conducted to find the time various builders take to produce an average single home. The report compared the various methods used by homebuilders for planning and scheduling to enhance their competitive position. The report identified few approaches that defined best practices: reducing activity durations, reducing or eliminating non-value added activities from the work schedule, performing activities concurrently which are traditionally sequential, and creating an even job flow (NAHB 1993). These suggested best practices require detailed planning taking into consideration all resource limitations, constructability issues, and productivity or capacity of resources to be used.

Harris et al. (1998), argues that existing planning systems are 'activity-oriented' and are of limited use for projects with repeating activity. The authors propose Repetitive Scheduling Method (RSM) as a planning and scheduling method which provides an uninterrupted use of resources from one repeating unit to another. This method is 'resource-oriented' and it recognizes the need to have continuous use of resource through many similar units. This method, which incorporates continuous resource usage, is suitable for homebuilding companies with many similar units to be built. However, adoption of such techniques is not yet widespread.

Any planning system, currently practiced by a company, should also be evaluated for its accuracy and efficiency. Bernardes et al. (2002) identified fourteen practices to improve efficiency during development and implementation of a project control system. The practices suggested includes:

- "Planning in hierarchical levels" which means that the degree of planning details should be more when the date of performing the activity approaches (Bernardes et al. 2002).
- Short term planning
- Explicitly documenting assigned tasks
- Creating detailed specifications for tasks
- Using measurement techniques to indicate performance

Seidel (1999) presented a production planning methodology for large homebuilding firms. This methodology focuses on production planning as a core process of business planning. The production planning is viewed as a process which utilizes both internal and external resources such as management, cash, labor, and material to build homes (Seidel 1999). According to Seidel (1999), production planning for large homebuilding companies involves organizational planning, development schedule, and financial planning. It is a core sub process of business planning for the firm (Seidel, 1999). In contrast, this research views production planning as a process by which the daily construction activities are planned in the field. This view of production planning is similar to the production scheduling as used in the manufacturing industry.

Research performed on manufactured housing with focus on production planning is discussed later in appropriate sections. Prior research, concentrating on the planning aspect of production building, which fall under the Lean Construction domain will be discussed in the next section.

## 2.2 Lean Production System

The second part of this literature review introduces the lean production concept, lean construction, principles of lean construction, and finally the Last Planner System of production control as conceived under lean construction.

### 2.2.1 Lean Production?

Lean production is a design and production management system developed in the '50s by Engineer Ohno at Toyota. The aim of Lean Production is to shorten the cycle time to get products to market by minimizing waste. According to Engineer Ohno, this new production philosophy should provide (Howell et al., 1998):

- A uniquely custom product
- Instant delivery with minimum inventory
- Production with zero waste

Unlike *Craft production*[1] *or Mass-production* system[2], *Lean production* has the qualities of both wherein custom-made goods are produced at lower costs. The concepts of lean production include multi-skilled workers, stopping the production process by any worker when faults are found, no rework area, pull system (Hopp and Spearman, 1996), flexible and automated machines, and transparency of the production systems.

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[1] *Craft production* system which uses highly skilled workers and simple but flexible tools to make exactly what the customer ask for—one item at a time, and of course very expensive

[2] *Mass-production* system which uses narrowly skilled professionals to design products, using expensive single-purpose machines and thus higher volumes are produced at lower costs but at the expense of variety

Lean principles have been applied successfully worldwide in the automobile industry. Manufacturers like Toyota have strived to achieve 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 great success. The best results can be obtained when used in a repetitive or continuous production environment.

Two primary entities have advocated application of lean philosophy to construction: The International Group of Lean Construction (IGLC) and The Lean Construction Institute (LCI). 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.

### 2.2.2 Lean Construction

According to Howell et al (1998) current project management in construction views a project as a combination of activities whereas, Lean views the entire project in production system terms. Lean thinking brings into attention the concept of value generation instead of activity management. The main aim is being able to minimize waste, adopt a pull system[3], and produce a custom made product that satisfies the owner. Application of the Lean production philosophy in construction has been researched and implemented and proved to be a success. Lean construction researchers have developed techniques and tools, which enable the implementation of Lean Construction concepts in construction environment (Abdelhamid, 2003).

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[3] *Pull System in construction implies that upstream activities should not start before the downstream work is assured to be released (Howell and Ballard, 1998).*

Koskela (1992) introduced a new unified theory of production, termed as the *Transformation-Flow-Value Generation* (TFV). This theory is an integrated theory developed from the three main production paradigms namely; *Craft production, Mass Production, and Lean production*. The TFV theory can be defined as follows (Koskela 2000):

- Transformation view – Concept of transforming inputs to outputs.
- Flow view – Materials and information flow in a production process
- Value generation view – Process where the value for customer is created through fulfillment of his/her requirements.

Koskela (2000) states that "...the new TFV theory of production provides a new, theoretical foundation for construction." Koskela (2000) also mentions that this theory has the potential of inducing changes in performance in the construction industry.

Lean construction ideas have been adopted in the construction industry and companies have reaped the benefits. Homebuilding companies that have adopted the production system of construction have the most advantageous position with respect to application of the Lean Construction philosophy. However, application of lean principles in residential construction is relatively new. The following section will further discuss the even flow methodology and last planner system (both of which seem to be very suitable to the residential construction industry) with related literature in the area.

**2.2.2.1 Even Flow Methodology**

Even flow production is based upon the theory of constraints described by Goldratt (1992) and is linked closely to Lean thinking. Bashford et al (2003a) describes and presents the implications of even flow production techniques in the residential construction industry. The objective of this technique is to reduce the work flow variability and thus gain efficiency. Current production management strategies frequently do not account for variability in workflow[4] between independent contractors, which reduces the efficiency of production. The objective of even flow production strategy is to reduce the workflow variability in an effort to gain efficiency. The study by Bashford et al. (2003a) included a simulation of a hypothetical subdivision of 90 homes in which even flow methodology was implemented where two types of even flow were studied, namely; activity-based and start-based. It concluded that activity-based even flow involves a rigid schedule that is maintained for each specific activity such as foundation setting or framing across the entire tract of homes and it is a good way to reduce management effort and workflow variability. Whereas, start-based even flow is when only the initial activity for each home in the tract is scheduled to occur at a uniform rate and it increases management effort and increases workflow variability. The study also indicates that theories and practices used in the manufacturing industry can be effectively applied in the construction industry.

#### 2.2.2.2 Last Planner System

Constructing a building element requires planning to deliver materials in time and at high quality. There is a lot of decision making in the production process where the product moves from one stage to the other. Who is the right person to make these decisions? The Last Planner System™ (LPS) states that the last person who performs the work is the one responsible for making execution-related decisions. The last planner could be a superintendent, foreman, or a crew member. The Last Planner System is a lean based

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[4] *Variability in Workflow* refers to the uncertainty of time taken by one trade contractor to finish and transfer his work to succeeding trade contractor

production planning and control system. Application of the LPS to projects has shown reduction of duration and costs while improving quality and safety.

Ballard (2000) presents the LPS as a system of production planning and control which can increase workflow reliability. Work assigned to a crew is termed as 'Should-do' work, the capability of the crew to perform that 'Should-do' work is termed 'Can-do' work, and the work the crew actually commits to is termed 'Will-do' work. In traditional project planning systems, the 'Can-do' aspect is not considered and a crew is assigned to work without making sure that the work can be done. In contrast, planning for assignments in the Last Planner System is performed after work assignments are subjected to a constraint analysis that ensures no obstacles will prevent execution. Figure 2.1 shows the steps involved in the Last Planner technique.

As illustrated in Figure 2.1, master schedules involve the development of logic and sequence that helps identify the commitments throughout 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.

In the Last planner system, as shown in Figure 2.1, the 'Lookahead' process takes its input from traditional project planning techniques, which result in a master schedule with project milestones and phase schedules. Usually, the lookahead involves consideration of potential assignments for the upcoming 3-6 weeks based on the project characteristics. The activities 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).

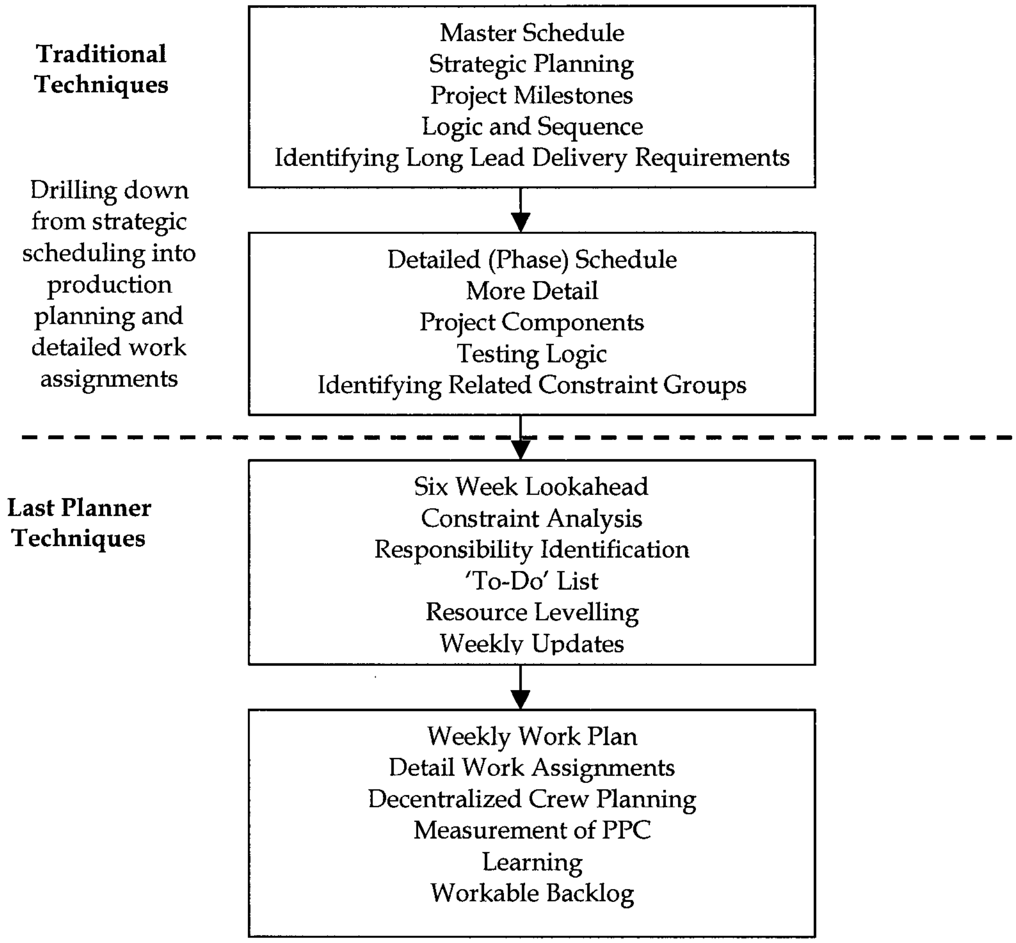


**Fig 2.1: Construction Planning vs. Last Planner**
**(Modified: Kaufman Consulting Group, LLC)**

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. Ballard (2000) suggests that assignments are quality assignments when they satisfy the following criteria: definition[5], sequencing[6], soundness[7] and size[8]. 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.

To assess the quality of the assignments made, a metric known as the Percent Plan Complete (PPC) calculated as a ratio of the number of assignments completed to the total number of assignments planned for that particular unit in a given period of time. PPC is expressed as a percentage with a range between 0%-100%. In general, the higher the PPC, the more reliable the production planning system. A PPC of 100% means all the work assigned is completed as planned and it is the best-case scenario. A PPC value less than 100% means there is a problem with the production planning system.

The reasons for the failure have to be evaluated to enable future improvement of the production planning process. Thus, in the homebuilding industry where a production

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[5] *Definition: the work should be specific enough to understand the requirement and completeness of the assignment (Ballard, 2000).*

[6] *Sequencing: the assignment should be sequenced in thecorrect constructability order (Ballard, 2000).*

[7] *Soundness: the materials design and perquisites are identified and constraints removed (Ballard, 2000).*

[8] *Size: means that the assignments should be correctly sized based on the capacity of the crew (Ballard, 2000).*

process is adopted, a planning system like the LPS will make the process very reliable and thus reduce variability, while increasing throughput and profits.

Chitla (2003) used the LPS to evaluate the production planning process in manufactured housing and to identify opportunities for improvements. The PPC metric of the Last Planner System was used to evaluate the efficiency of production planning. Analysis of the output from the evaluation utilized the Pareto Analysis and Fish Bone Diagrams. This analysis was used for finding reasons behind the failure of the plan and it can also be used as improvement opportunities (Chitla, 2003).

The next section discusses performance measurement tools by introducing Total Quality Management and Six Sigma, the quality concepts used in the manufacturing industry to increase productivity.

### 2.3 Performance Measurement in Construction

The Arizona Partnership for Advancing Technology in Housing (AzPath) is a regional partnership formed to promote research and development in the Arizona homebuilding industry. Arizona State University (ASU) has entered into a partnership with PATH (a White House initiative aimed at bringing new technologies to the homebuilding industry), five major Arizona homebuilders, and the Home Builders Association of Central Arizona (HBACA). AzPath was formed to serve as a vehicle to lead the southwest area housing industry to embrace research, learning, and the adoption of innovation to provide housing of higher value at a reduced cost.

Figure 2.2 shows the evolution of residential construction as compared to the manufacturing industry. In the manufacturing industry various new philosophies were introduced and implemented which escalated the production capability. Residential construction had evolved primarily as a Craft production system and has some improvements with the introduction of modularization, smarter materials and management systems, information technology, and new manufacturing technology. Homebuilding, which has been accepted as a production process, certainly needs to take the path of manufacturing industry and explore the various techniques and tools used to improve on production and increase efficiency and profits. The construction industry certainly needs to be at par with manufacturing industry, and this can be achieved by researching on the progress track of manufacturing industry and adopting and then tailoring the philosophies to the needs in construction.

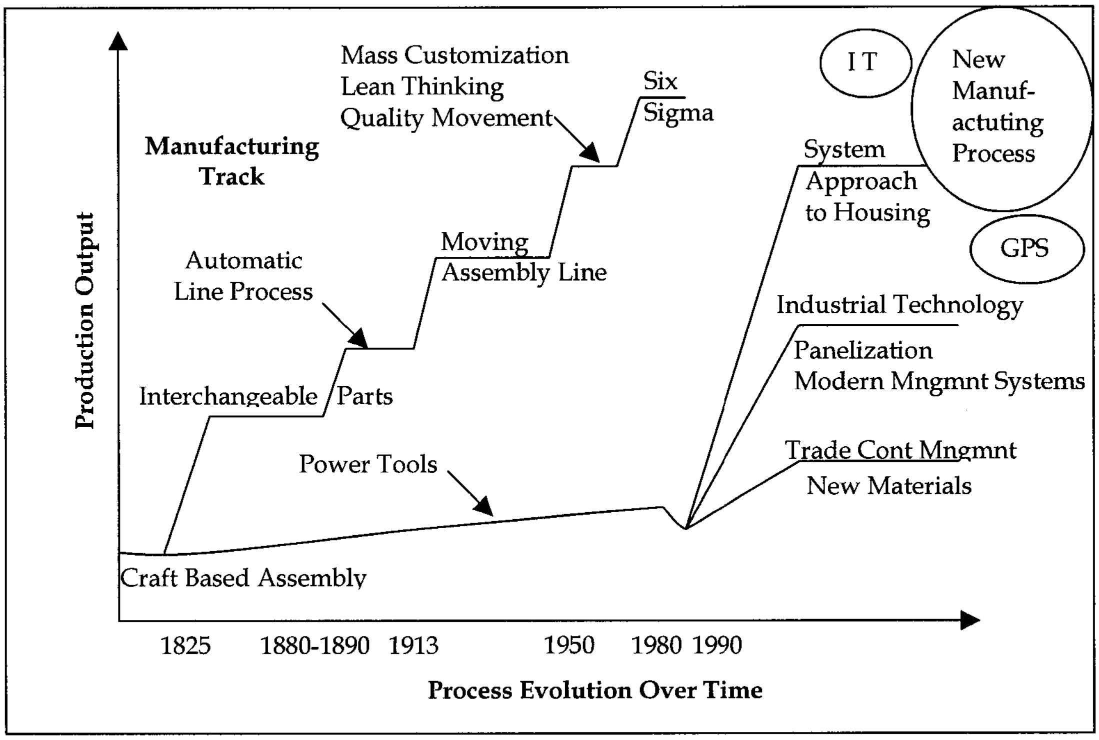


**Fig 2.2 Evolution of residential construction**

**(Modified: Azpath Website, http://construction.asu.edu/azpath/images/Poster.jpg)**

Lean production, Total Quality Management (TQM), and Six Sigma are the three most recent philosophies that had a major role in the present success level of the manufacturing industry. The following section will briefly discuss TQM and Six Sigma philosophies, which focused on quality and continuous improvement. Lean production and its application in construction have been discussed in earlier sections of this chapter.

### 2.3.1 Total Quality Management

The primary purpose of TQM is to provide excellence in customer satisfaction through continuous improvements of products and processes by the total involvement and education of each individual who is in any way a part of that product/process. It is a structured approach to improvement. If correctly applied, it will assist a construction company in improving its performance (Ahmed et al, 2001).

Ahmed et al (2001) have explored TQM as a tool to achieve continuous improvement in construction. The primary objective of this study was to develop a measurement model - with tools and methodologies for the identification and measurement of construction processes for continuous improvement and customer satisfaction (Ahmed et al, 2001). The authors have identified some causes for client satisfaction, and this was achieved by developing a model using TQM tools. The study emphasized on the necessity of measurement of construction processes. The author states that continuous improvement and customer satisfaction will in turn improve quality, productivity, and competitiveness. For a homebuilding company it is important to have a high level of customer satisfaction, indeed most of the home companies focus on this aspect because it is the 'word-of-mouth' of satisfied customers that can increase its popularity and standing in the industry. Hence a technique to assess and measure customer satisfaction and also internal process performance is the primary need for growth. Bassioni et al. (2004) addresses the need for research to develop comprehensive performance measurement frameworks for the construction industry.

Process performance can be measured on the basis of any aspect that improves the quality of the final product. Performance measurement techniques and tools are abundant in the manufacturing industry, but it's critical to first identify what has to be measured and then find out how it is to be measured such that it leads to process improvement. Cox et al. (2003) have identified performance indicators to measure construction performance. They termed these as "Key Performance Indicators" (KPI). The study identifies quantitative and qualitative performance indicators as perceieved by management in construction firms. The study identifies quality control, on-time completion, and cost as three of the six highly significant performance indicators as perceived by management (Cox et. al., 2003).

In other studies, the major focus in the process improvement has been reduction of variability in a process. According to Picard (2002) "...reducing the variation or variability in a process is considered a sign of improved quality of the construction process." Lean Construction also advocates reduction of waste and value generation. To reduce waste and non-value adding activities, the process has to be studied extensively and all non-value adding activities identified and eliminated. Thus, the objective should be to understand the process, measure the performance, and find out the causes for variability and then eliminate or reduce the causes. Six Sigma approach aims at this objective and is discussed next.

### 2.3.2 Six Sigma

Motorola developed Six Sigma in the late '80s as a system that would help them achieve near-perfect products (Breyfogle et al. 2001). This system aims to reduce variability and uses various statistical methods and tools to identify and reduce variability and thus achieve a 'closest to zero-defect' product. Linderman et al. (2003) defines Six Sigma as "…an organized and systematic method for strategic process improvement and new product development that relies on statistical methods and scientific method to make dramatic reduction in customer defined defect rates."

The aim of a company adopting Six Sigma is to bring all its defect rate to as low as 3.4 defects per million opportunities, which translates to a 6-$\sigma$ measure. Sigma ($\sigma$) is the symbol for standard deviation in statistics. Thus a six sigma level means having all the products produced within six standard deviations of the mean (average). Thus a process having a six sigma yield level will have 99.99966% of its products produced without defect. The methodology used to achieve six sigma goals is known as DMAIC (Define, Measure, Analyze, Improve, and Control).

The following example of the sigma metrics applied to a small library will illustrate the different sigma yield levels (Breyfogle, 2001). The example also shows that the sigma yield levels are not linear but they are exponential.

- Sigma level 1 corresponds to 170 misspelled words per page in a book
- Sigma level 2 corresponds to 25 misspelled words per page in a book
- Sigma level 3 corresponds to 1.5 misspelled words per page in a book
- Sigma level 4 corresponds to 1 misspelled word per 30 page in a book
- Sigma level 5 corresponds to 1 misspelled word in a set of encyclopedias

• Sigma level 6 corresponds to 1misspelled word in all the books in a small library

Abdelhamid (2003) reviews Six Sigma, its methods and metrics and suggests applying it to lean construction. The paper shows an example by extending the Six Sigma metrics to the Percent Plan Complete (PPC) of the last planner system. The Six Sigma metrics provides a more thorough understanding of the process and gives a true picture of its performance. This metric will standardize the performance measure and thus can be used to compare the performance of various processes. According to Abdelhamid (2003) the advantage of finding the sigma quality level is that it better reflects the magnitude of the disability in the production planning process to maintain a reliable workflow.

This research uses Six Sigma methods and metrics to measure the performance and assess the planning process in the residential construction industry. A detailed explanation of all methods and metrics to be used are included in the next chapter.

### 2.4 Summary

This chapter provided the relevant literature available with respect to this research. Literature in residential construction that focused on planning and its importance was covered in the first part of this chapter. The second part summarized Lean production and its application to the construction industry. The Even flow methodology and Last Planner System, which are two Lean-based techniques, were discussed as they are suitable for the homebuilding industry's production planning. Finally, TQM and Six Sigma were briefly discussed in this section. The next chapter describes the methodology used to achieve the goal of this research.

# Chapter 3

# Methodology

# Methodology

While the residential construction industry may be able to meet demand, it is important for the industry to satisfy its customers by improving its performance. Improving performance should incorporate an assessment of its current process. This research aims to do this by taking the first step. Planning as explained in earlier chapters has an impact on the entire homebuilding process. Thus, assessment of the production planning process is the main focus of this research. The DMAIC (Define, Measure, Analyze, Improve, and Control) method proposed in the Six Sigma literature and the LPS in Lean were selected as appropriate approaches for the assessment of the production planning process. The following sections will explain the methodology of this research and steps taken to fulfill the objectives and each of these steps will be discussed in detail.

## 3.1 Methods and Tools for Objectives

The goal of this research is to develop and implement an assessment framework for the production planning process (PPP) in the residential construction industry.

To attain this goal the following objectives were proposed and accomplished:

- Documenting the production planning process prevalent in the industry.
- Developing a framework for production planning performance assessment and identification of process improvement opportunities.

The following section will discuss how each of these objectives were achieved.

## 3.2 Mapping the Production Planning Process

The production planning process in the residential construction industry is different from one homebuilder to the other. However, the aim in this research was to develop a framework for assessing the PPP by considering a small group of homebuilders. The aim is to assess the PPP and not to generalize on current practice.

The first objective, as mentioned in chapter 1, involved mapping the PPP. Mapping of a process involves determining the process inputs and outputs, the value adding sub-processes, the involvement of any other process, flow of information and all cross functional activities. Once these are determined it is easier to create a process map. A process map is similar to a basic flow chart with all functions shown in boxes and flow of data shown by arrows. Mapping a process is explained by Pande et al. (2000) to be analogous to the act of putting a puzzle together. While putting pieces of a puzzle in place, firstly the puzzle box should give you a basic idea of what has to be done. Next, one will assemble the edges of the puzzle together and then assemble the internal pieces such that it adds to the clarity of the initial image. This step will involve some trial-and-error and some research too. Similarly, in this research, a broad picture of the PPP was established. Then, the details of the various process steps were determined. This data was incorporated in the form of a map, which gave a clear picture of how the PPP is undertaken. Mapping the PPP had the following advantages:

- gave a clear 'big-picture'
- defined the key inputs and outputs of the process
- facilitated the understanding of cross functional activities
- showed the interface between various contributors in the process
- showed how the process flows through the organization
- highlighted the value adding sub-processes in the overall process

The information necessary for creating a process map of the PPP for homebuilding activities were collected in two steps:

- Interviewing management and field personnel,
- Field observations.

### 3.2.1 Interviewing

The interviewing process involved the development of an interview questionnaire focusing on understanding the PPP employed by homebuilding companies. It also included questions intended to shed light on the interviewee's perceptions about the process, what was lacking in the process, and any recommendations for improvement. The interview questionnaire is included in Appendix A.

### 3.2.2 Field visits

The purpose of field visits was to develop the complete process map of the PPP. After the interviews, the author had a macro-level view of the process. Similar to completing the inner pieces of the puzzle, the field study gave a better representation of how a plan was developed directly from the inception stage. Data on how each step of the planning process was sequenced, how the information flowed between sub-processes, and what inputs were used to complete the planning processes were collected. Any other process that had an impact on the planning process was also considered for the study. The duration of each field visit was driven by the magnitude of the process in the particular company.

### 3.2.3 Creating a Process Map

A process map was used to show the flow between each step involved in the overall process. Pande et al. (2000) suggested the "SIPOC" process model which includes the following:

- Supplier: the person or group providing key information or material or other resource to the process.
- Input: the "thing" provided.
- Process: the set of steps that transforms or adds value to the input.
- Output: the final product of the process.
- Customer: the person group or process that receives the output.

Such a process map will give the overall picture of the process. All information collected in this research was documented in this format.

The process map provided insights critical to the second objective of the research. The map clarified what items had to be measured for an accurate assessment of the production planning process. The next section explains the tools used for measuring the performance of the production planning process.

## 3.3 Production Planning Process Performance

The second objective of this research was directed at measuring the production planning performance with a suitable tool to identify improvement opportunities. This objective was realized by performing the following three steps:

1. A literature review was conducted to evaluate previously developed tools and techniques for measuring and analyzing production planning. A suitable tool for

measuring and analyzing production planning performance was selected and tailored to the research needs.

2. The production planning performance was measured using the selected tools and techniques.
3. The results were analyzed to identify improvement opportunities.

Measurement of process performance is a necessary step to identify the shortcomings of any process. Measuring, analyzing, and implementing are the three basic steps to improve any process. Once the process performance is measured, it makes it easier to analyze and find out the shortcomings, if any, in the process. The identified shortcoming should be rectified or removed and the new improved process should be implemented. This new implementation should be measured and analyzed again for its performance and then control can be achieved. These are the steps, that make it possible to continuously improve a process. However, this research is limited to measuring the performance and analysis of the observations.

### 3.3.1 Performance Measurement Tool

The second chapter included a section for performance measurement, wherein two tools suitable for measuring the performance of the production planning process were identified, namely, Percent of Plan Complete (PPC) and the Six Sigma metrics. The following sections will discuss how the two metrics were used in this research.

#### 3.3.1.1 Percent of Plan Complete (PPC)

The Last Planner System (LPS), as explained in Chapter two, provides a framework to plan and control daily production assignments in a construction project (Ballard 2000). This system uses a metric termed Percent Plan Complete (PPC) to measure the reliability of production planning and that of workflow. PPC is the ratio of number of assignments completed to those planned. The PPC is generally calculated on a daily or weekly basis. It is reported for a particular trade or crew on a periodic basis to measure the effectiveness of the planning process or the capability of the crew to execute the assignments they commit to. Once PPC for a crew is obtained, an average value of the metric over a period of time will reflect the efficiency and effectiveness of production planning for that particular crew was.

#### 3.3.1.2 The Six Sigma Metrics

The Six Sigma approach to improve quality of an organization advocates the use of quantitative metrics to assess performance. A number of metrics are available depending on the problem. Rolled throughput yield ($Y_{RT}$) is a metric suitable to this research, especially when combined with the PPC metric.

Abdelhamid (2003) proposed the application of Six Sigma in Lean Construction. In this paper, the rolled throughput yield ($Y_{RT}$) metric was explained and its use as a performance measure with the Last Planner System was demonstrated. Generally the metric 'Yield' (Y) represents the percentage of units that pass final inspection relative to the number of units that were processed (Abdelhamid 2003). This metric does not take into account the rework performed in any of the sub-processes within a process, and thus, it masks the true output of the process. In contrast, the Rolled Throughput Yield ($Y_{RT}$) metric takes into account all the rework done in a process. The $Y_{RT}$ metric measures the output at every sub-process within a process to calculate the final Yield of the whole process. The $Y_{RT}$ can be mathematically shown as follows:

$$Y_{RT} = \prod_{i=1}^{m} Y_i \qquad \ldots(i)$$

where m is the number of processes involved and $Y_i$ is the throughput yield of process *i*.

The Six Sigma metrics are obtained by converting the $Y_{RT}$ to a sigma level so that comparison is possible across different operations and even across industries. This can be achieved by using standard tables or by calculations. The sigma quality level for a process using rolled throughput yield can be calculated using the set of equations (Breyfogle 2002).

**Sigma level calculations:**

- The rolled throughput yield is calculated from the yields of different sub-processes as follows:

$$Y_{RT} = \prod_{i=1}^{m} Y_i \qquad \ldots(i)$$

Where, $Y_{RT}$ = Rolled throughput yield

$Y_i$ = Yield of sub-process 'i'

- The rolled throughput yield is normalized by finding the geometric mean as follows:

$$Y_{norm} = \sqrt[m]{YRT} \qquad (ii)$$

- The normalized yield is then converted to Defects Per Unit (DPU) using the following equation:

$$DPU_{norm} = -\ln (Y_{norm}) \qquad (iii)$$

- To determine the sigma quality level, also called as $Z_{benchmark}$, for the process, the following equation is used

  Sigma quality level = $Z_{norm} + 1.5$ (iv)

  Where, $Z_{norm}$ is the standard normal value corresponding to the $DPU_{norm}$ found using the standard normal table.

**Modified calculations using PPC (Abdelhamid, 2003)**

The modified equations used for this research using PPC value are as follows:

- The rolled PPC is calculated using PPCs of different sub-processes as follows:

  $$\textit{rolled}\ PPC = \prod_{i=1}^{m} PPC_i \qquad (v)$$

- The rolled PPC is normalized by finding the geometric mean as follows:

  $$PPC_{norm} = \sqrt[m]{\text{rolled PPC}} \qquad (vi)$$

- The normalized PPC is then converted to Defects Per Unit (DPU) using the following equation:

  $$DPU_{norm} = -\ln (PPC_{norm}) \qquad (vii)$$

- To determine the sigma quality level, also called as $Z_{benchmark}$, for the process, the following equation is used

  Sigma quality level = $Z_{norm} + 1.5$ (viii)

Where, $Z_{norm}$ is the standard normal value corresponding to the $DPU_{norm}$ found using the standard normal table.

The sigma level corresponds to 'parts per million' (ppm) which essentially is the number of defects per million parts. Hence, this metric emphasizes the magnitude of the problem. It gives a more representative picture of the state of the process. A low sigma level indicates need for process assessment and problem solving.

**3.3.1.3 Percentage of Plan Complete (PPC) vs. Rolled throughput yield ($Y_{RT}$)**

Abdelhamid (2003) illustrated an example of using the $Y_{RT}$ metric instead of PPC in a manufactured homes factory setting. He suggested using *rolled* PPC similar to the rolled throughput yield as explained above. Using the *rolled* PPC metric, as suggested in the paper, exposed the hidden factory (rework performed to rectify defects during sub-processes). It also standardized the metric so that it can be compared with other production processes as well as other production processes of other companies. The *rolled* PPC metric "...gives a better sense of magnitude of the process performance failure" (Abdelhamid 2003).

This research uses the *rolled* PPC metric as a measurement tool for assessing the performance of production planning in residential construction. This metric gives a true picture of the deficiencies of the planning process for any homebuilder. In contrast to calculation of PPC, the *rolled* PPC will better reflect the magnitude of the problem, and thus it is more realistic tool for performance measurement. The *rolled* PPC can be calculated by multiplying the PPC of every single sub-process as shown in the previous section for calculation of rolled throughput yield. The PPC of every sub-process will be useful to determine the inefficiency of planning for that particular process, whereas, the *rolled* PPC will aid in finding the shortcomings of the planning process as a whole.

### 3.3.2 Measurement of Planning Performance

The second step towards attaining 'Objective II' was to measure the performance of production planning process of the homebuilding companies selected. This step involved field visits and recording of day-to-day activities. The idea was to calculate the number of assignments completed vs. the number of assignments planned to be completed. The data was collected from the supervisor on site as well as by direct observation. A sample form for data collection is shown in Figure 3.1.

| Crew Observed | Feb 4 - Feb 8 | | | | | Feb 11 – Feb 15 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | T | W | T | F | M | T | W | T | F |
| **Framing Crew** | REMARKS: | | | | | | | | | |
| 1. Measuring and cutting | | | | | | | | | | |
| 2. Framing First half | | | | | | | | | | |
| 3. Framing Second half | | | | | | | | | | |
| 4. Flooring | | | | | | | | | | |
| 5. Finishing and Cleaning | | | | | | | | | | |
| Completed assignments | | | | | | | | | | |
| PPC | | | | | | | | | | |
| **Insulation Crew** | REMARKS: | | | | | | | | | |
| 1. Outer Wall Insulation | | | | | | | | | | |
| 2. Inner wall insulation | | | | | | | | | | |
| 3. Flooring Insulation | | | | | | | | | | |
| 4. Ceiling Insulation | | | | | | | | | | |
| Completed assignments | | | | | | | | | | |
| PPC | | | | | | | | | | |

**Figure 3.1 Sample format of data collection**

The choice of entries in the form were a 'C' (Complete) or an 'I' (Incomplete), respectively indicating whether the assignment was completed successfully or not by the crew. The calculations for the rolled PPC were performed for each process as explained in the earlier section. This rolled PPC was converted to a corresponding sigma value to determine the efficiency of the production planning process.

For this research, PPC data was collected for 11 weeks. This data was sufficient for calculating the rolled PPC value and for use in analysis. The next section will explain the analysis techniques adopted in this research.

### 3.3.3 Data Analysis

Once all the measurements were available, the next step was to find the causes behind failures in the production planning process. For this research, visual tools and root cause analysis (Breyfogle, 1999, and Evans and Lindsay, 2001) were used. The following sections will discuss these methods of analysis and their use in this research.

#### 3.3.3.1 Visual Tools for Data Analysis

The best way to detect a problem is when it is visual. When the data is arranged in certain patterns, one can detect variability, catch the outliers, and follow trends that occur in the data set (Pande et al., 2000). Visual presentation of data also helps in understanding the process and thus makes it easier to identify the source of a problem. Some common techniques used are: *Pareto Charts Frequency Plots, Run Charts, and Correlation Diagram (Evans and Lindsay, 2001 and Breyfogle, 1999).* The choice of a technique depends on the type of data collected as well as anticipated problems. The Pareto chart and the Run Charts were used for analysis of the PPC data collected. The following sections provide examples of how these tools were used.

**Pareto Charts or Pareto Analysis**

The Pareto Charts are bar charts where the data is stratified into groups and displayed in a descending order according to frequency of occurance. It helps in finding out the most common cause of a problem under investigation. Pareto analysis is based on a notion that 80% of the problems are created by 20% of the causes. This suggests that for most situations, major portion (about 80%) of defects or inefficiencies are caused by factors that are about 20% of all the factors determined. Thus a Pareto chart helps in highlighting the factors that cause most of the problems. This indicates that these factors should be analyzed first and the root causes can be eliminated. A typical Pareto chart looks like Figure 3.2. In the figure, categories A & B are the main problem areas.

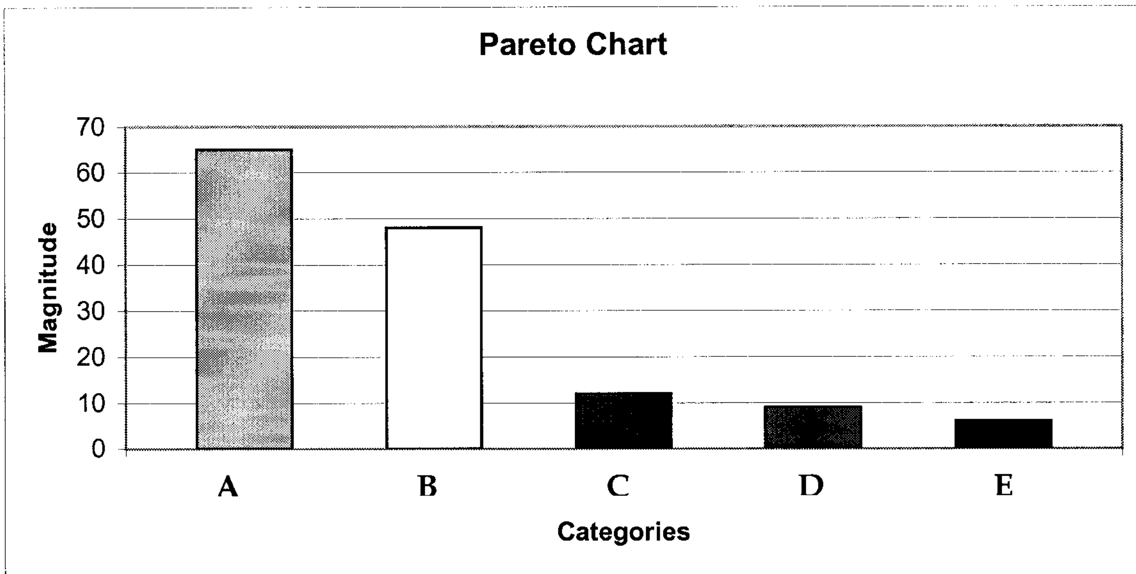


**Figure 3.2 Typical Pareto Chart**

In this research, the Pareto chart was used by first dividing the data into categories of production problems. Hence the type of work needing a better planning technique can be identified. Then each of the problem areas are separately analyzed and factors causing non-completion can be determined. This can again be shown using a Pareto chart and the major contributors can be analyzed further to find the root causes. For example, if framing and roofing are found to be the two major contributors causing most of the delays, we analyze these two activities separately to determine the root causes for each of these activities.

The Pareto chart can also be used to compare problems by days of the week to assess whether a particular day of the week has more planning problems. For example, if the planned assignments are met the least on Thursdays and Fridays, we could utilize this finding and change the planning process such that less volume of work is assigned to the crew on these days. Thus, the data available can be used in different formats and find ways to improve the process. Pareto charts can also be used to identify the root cause that creates most of the problems. This use of Pareto charts is described later during the root cause analysis discussion.

**Run Charts or Time Series Plots**

The Run Chart is useful for showing degree of variations in the process over time. It could be also used for detecting any pattern (weekly cycle or an hourly cycle) in the data-set over time. It is a very useful tool to see how a process is responding to a change. There are various types of run charts. The *p-chart* with variable sample size is the most suitable for this research. In a *p-chart*, a statistical range (upper and lower limits) is set for the data and the data is plotted. The range can be set by defining an upper control limit (UCL) and a lower control limit (LCL). These limits can either be set by the company or can be mathematically calculated as shown later. Any data that is outside the limit is an indicator of an out of control process. This may be due to a special cause and it can be detected and avoided.

For plotting a p-chart with variable sample, the data collected has to be rearranged in a spreadsheet depending on the type of the problem being investigated. Figure 3.3 is the format used for plotting the p-chart for the data collected in this research. It should be noted that the PPC metric is converted to a Percent Plan Incomplete (PPIC) calculated as 1-PPC or as a ratio of Tasks Incomplete to the Tasks Planned. This modification was necessary because of interest in causes for incomplete assignments. Plotting the PPIC made it easier to detect instances where the assignments were not successfully completed.

| Day | Tasks Incomplete | Tasks Assigned | PPIC (ratio) | Std Dev | UCL | CL | LCL |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | | | | | | | |

**Figure 3.3 Format for *p-chart* data**

The attributes for each day can be calculated using the following formulas (adapted from Breyfogle, 2003):

- $Std\_dev = \sqrt{\frac{PPICavg(1 - PPICavg)}{Tasks\_assigned}}$ ...(ix)

  where, $PPICavg = \frac{\sum Tasks\_incomplete}{\sum Tasks\_assigned}$ ...(x)

- $UCL = PPICavg + Std\_dev$ ...(xi)
- $CL = PPICavg$ ...(xii)
- $LCL = PPICavg - Std\_dev$ ...(xiii)

Completion of the spreadsheet in Figure 3.3 enables plotting the p-chart. Figure 3.4 is an illustration of a p-chart with variable number of assigned tasks for each day. Different p-charts for different crews observed can be plotted to find crew-wise variations or total for each day can be considered. This will depend on the type of analysis to be done. This research includes all possible p-charts for the data-set to determine variations of different aspects of planning.

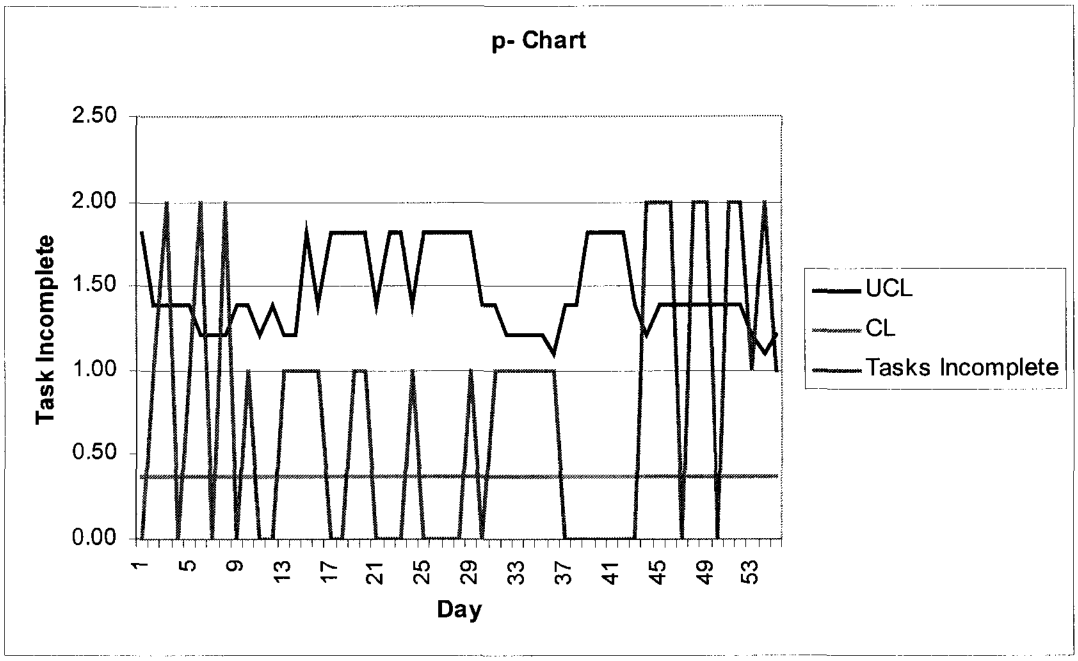


**Figure 3.4 Sample p-chart**

### 3.3.3.2 Root Cause Analysis

Typical analysis of data is comprised of two major activities: detection of a problem and finding the root cause of that problem. The Pareto chart and the P-chart as described in the previous section helps in detecting problem area and specific problems. The next step of finding the root cause for the identified problems can be performed by drawing a 'Cause and Effect' diagram. The following section explains how a cause and effect diagram was used for this research.

**Cause and Effect Diagram**

Variation in a process performance can occur due to many reasons, such as materials, methods, measures, machines, environment, and people (Evans et al., 2002 and Pande et al., 2000). Identifying causes of such problems can be achieved by using a cause and effect diagram. It is a simple graphical method for presenting causes and effects and for sorting out causes and identifying relationships between variables (Evans et al., 2002). It is also called a *Fishbone Diagram* due to its structure. The general structure is shown in Figure 3.5.

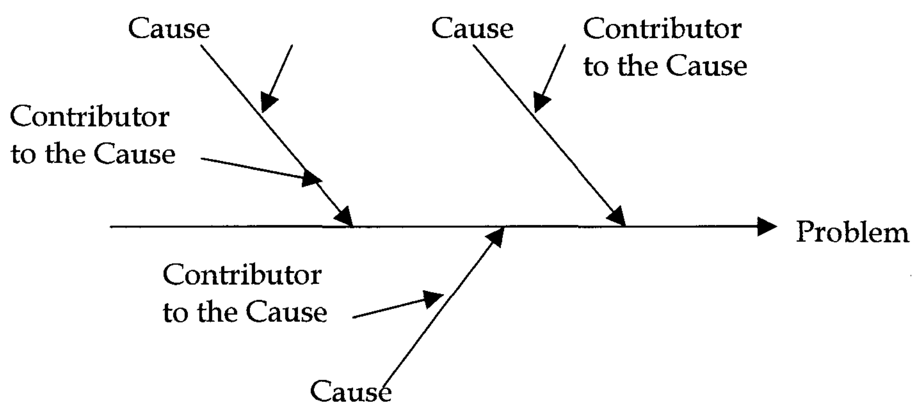


**Figure 3.5 General structure of a cause and effect diagram**
**(Source: Evans et al., 2002)**

The best way to construct a cause and effect diagram is in a brainstorming session with all the participants giving various ideas that could be a cause of the problem. In this research, a Cause and Effect diagram to find the root causes of the problems identified using the Visual tools was constructed. The root causes having the most impact were identified and selected as a prime candidate for further evaluation.

Both the visual method and root cause analysis aided in finding the problems causing poor performance of the production planning process. The identified causes will lead to many process improvement suggestions, which will be discussed in the following chapters.

### 3.4 Summary

This chapter described the methodology used to achieve the goals and objectives of this research. The production planning process was assessed using Last Planner System and Six Sigma concepts. The findings and LPS are used to demonstrate how a production planning model specific to a residential housing company may be developed.

# Chapter 4

# Data Collection and Analysis

## Data Collection and Analysis

### 4.1 Overview

In the previous chapter, the methodology adopted to achieve the goal and objectives of this research were presented. This chapter explains, in detail, the steps involved in data collection and its analysis. The analysis is performed following the steps discussed in section 3.2 and 3.3 of the previous chapter. The outcome of the data collection and its analysis are presented in this chapter. Data collection was conducted over two phases: Interviews were conducted with construction professionals from four homebuilding companies, and data of daily activities at one residential construction site were recorded. Each of the steps involved are discussed in the following sections.

### 4.2 Interviews

Interviews were conducted for this research in order to understand and map the production planning process prevalent in the homebuilding industry. For this purpose, a questionnaire was developed. The questionnaire contained 45 open-ended questions categorized under six headings, Background information, Long-term plans, Subdivision plans, Construction process, Planning process and Opinions. Refer to Appendix A for the complete questionnaire. The questionnaire was approved by the University Committee on Research Involving Human Subjects (UCRIHS).

The author interviewed eight construction professionals from four homebuilding companies. An upper management and a field management personnel were selected from each company. The companies selected were from Mid-Michigan and Southeast Michigan. The number of homes built by the companies ranged from 10 homes to 500 homes annually. The interview answers are summarized and presented in Appendix C.

The names of individuals and their companies are not disclosed for confidentiality. In the summary, ABC 11, ABC 22, etc. are used to identify the different companies, and XYZ 11, XYZ 12, XYZ 21, XYZ 22, etc. are used to identify the individuals interviewed in each company.

### 4.2.1 Interview Response

This section summarizes the responses to the interviews conducted by the author. For detailed responses from all the interviewees refer to Appendix C. Highlights of the interview responses are as follows:

- Number of subdivisions for the homebuilding companies ranged from 4 to 32 subdivisions with a goal of building 18 to 400 homes in the year 2004.
- Most companies set the goal for number of homes based on demand, market trends, sales and historical data.
- Production planning for a subdivision is generally done 3 to 4 weeks before construction.
- Almost all companies have a schedule or a representation for a subdivision or single home. The companies use MS Excel or any standard/tailored scheduling software for the same.
- Generally a time contingency ranging from 1 week to a month is built into the schedule for compensating time lost.
- If the interviewee has worked for another company previously, they are of the opinion that the current production planning practice used is better.

- The interviewees are of the opinion that regularly updating the schedule, and centralized scheduling are good practices of production planning.
- Most interviewees believe that more research is necessary and can improve production planning in homebuilding construction. Some mentioned that internet based planning, benchmarking, Just In Time (JIT) etc are areas that could be adopted to production planning in residential construction.

### 4.2.2 Production Planning Process

The main objective of the interviewing process was to understand and map the production planning process prevalent in the homebuilding industry. For the purpose of this research, homebuilding companies are classified as small size (1 to 50 homes per year), medium size (51 to 300 homes per year), and large size (301 and more homes per year). The interviews reveal that the production planning process implemented typically varies with respect to the size of the company. The information obtained from the interviews was used to construct flow charts representing the production planning process. Three different flow charts are produced, each representing the production planning process in the three categories of homebuilding companies. The following sections detail the production planning process in each category of homebuilding companies.

***Small Size Homebuilding Companies (1 to 50 homes per year)***

In homebuilding companies building less than fifty homes per year, it is typical to have a specific production plan for each home to be built. The company builds a home mostly on demand by a particular customer or developer. Once the plan is selected and the permits have been requested, the superintendent drafts a rough schedule based on past experience and a general idea about the specific home plan. Mostly basic spreadsheets are used to represent the schedule. When the subcontractors are selected, they are allotted the time they request to complete the activities they are responsible for. The rough schedule is then adjusted according to each subcontractor's time input. Once an activity is started, the superintendent keeps track of the trades to determine the exact date on which the trade will finish, and informs the following trade contractor to start their work. In case of delays due to weather, material and/or low productivity, the superintendent communicates with the subcontractors and reschedules the activities.

It appears that, in small homebuilding companies, the production planning is on an activity-by-activity basis. The schedule largely depends on the availability of subcontractors and this becomes a constraint to achieve the finishing dates planned initially. No formal recording and assessment technique is used for improving the production planning process. The typical average percentage of work completed per plan (or PPC) is about 70% (this is based on the interviews conducted). Figure 4.1 is a flow chart representing the production planning process for the small size homebuilding companies interviewed. It is safe to assume that this is representative of most small homebuilding companies.

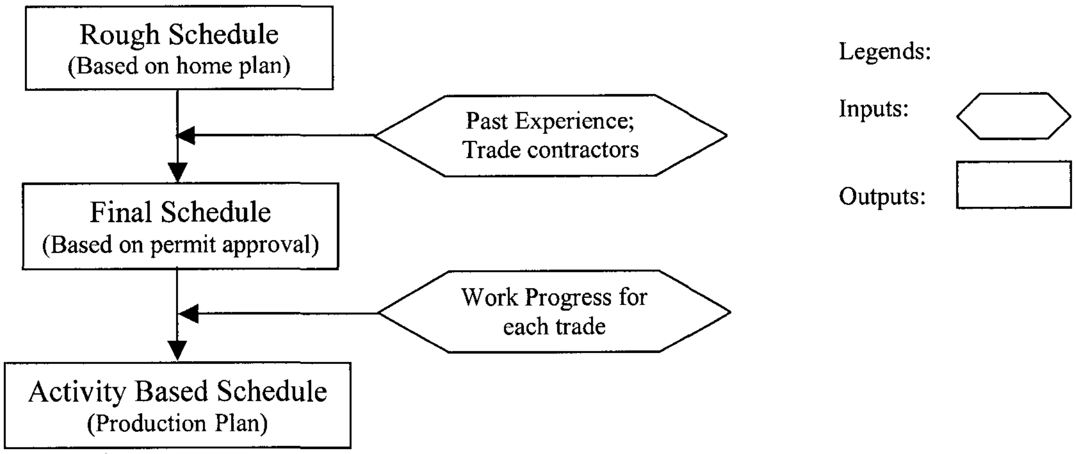


**Figure 4.1: Flow Chart Representing Production Planning for Small Homebuilding Company**

***Medium Size Homebuilding Companies (51 to 300 homes per year)***

In medium sized homebuilding companies, it is typical to have a general template of the production plan. Typically, the production plan is graphically represented on spreadsheets or using custom software outputs. The project manager for the respective subdivision will use this template to form a new template based on the specific home plans to be built. This new template will incorporate the time required for each activity based on the project manager's past experience with the selected subcontractors. This new template is used for production planning for all the homes in the subdivision. Once, a plot is selected and permits are secured, the expected start date is plugged in the template to produce a complete production plan for the home. This is repeated for each home. Some companies will have specific software tailored for the company, which will adjust the schedules for more than one home when the same resources are used.

The production plan for each home is handed to the various trade contractors and suppliers. Typically, the superintendent will update the production plan on a weekly basis. Most of the delays due to low productivity and/or weather are countered by working weekends and/or overtime. If such adjustments are not possible, a new updated production plan is communicated to the downstream subcontractors.

In general, the production planning in medium size homebuilding companies seems to follow a unit-by-unit scheme. The company may have a performance assessment system for each subcontractor or supplier to gauge their capability and to make selection decisions in the future. There appears to be no formal production planning process assessment technique. Records of daily performance are not maintained and are not used for future planning. The typical average percentage of work completed per plan (or PPC) is about 80% to 90% (this is based on the interviews conducted). Figure 4.2 is a flow chart representing the production planning process for medium size homebuilding companies.

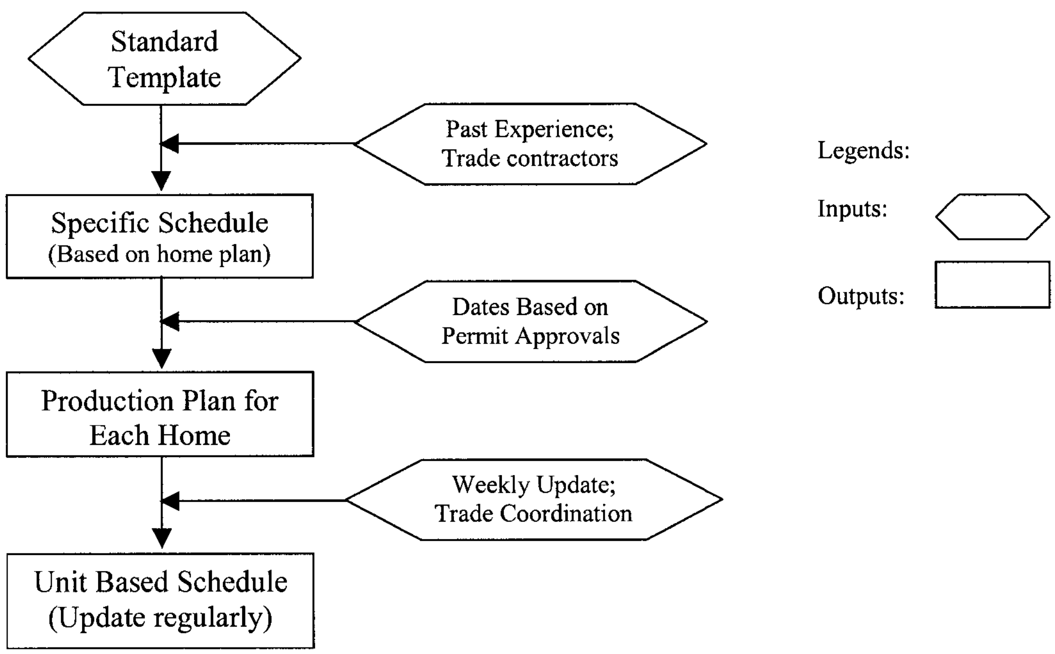


**Figure 4.2: Flow Chart Representing Production Plan for Medium Homebuilding Company**

***Large Size Homebuilding Companies (301 or more homes per year)***

Large size homebuilding companies will typically have a fixed number of starts in each of its subdivisions. This is predicted based on various factors such as number of households in the area, employment growth, census, and competitive survey. The sale of homes is generally high and this helps in keeping a steady construction rate. The company will generally have customized software for production planning. The planning is based on a standard template for each home. The software uses data regarding the number of homes to be built for each type of home, expected start date, and permit request submission dates to produce a production plan for the whole subdivision. The template can be modified specific to certain conditions in the subdivision to obtain a more realistic production plan. The specific production plan is shared with trade contractors, typically by fax. A spreadsheet with dates or a graphical representation of the production plan is produced. It is common to have a schedule for suppliers too such that the required material is delivered on site per the production plan.

Weekly updates and meetings are conducted to track the progress of the production plan. Typically, a biweekly lookahead plan is produced after each update and this is communicated to the trade contractors performing any task in the two weeks. This ensures that no last minute surprises occur during construction. The large size homebuilding companies may have a centralized scheduling system, which will track the overall production plans for all the subdivisions. This helps in coordinating trade contractors, equipments, and materials. This system is also used to assess the production planning process performance. In case of any delays, it is resolved by working overtime and weekends.

Given the volume of houses they work with, large size homebuilding companies, typically plan production on a subdivision-by-subdivision basis. The company may have a performance assessment system for each subcontractor or supplier to gauge the capability and to make selection decisions in future. Typically, a production planning process performance assessment technique is used to keep track of the progress of construction. Records of daily performance are maintained and are used for future planning. The typical average percentage of work completed as per plan (or PPC) is above 90% (this is based on the interviews conducted). Figure 4.3 is a flow chart representing the production planning process for large size homebuilding companies.

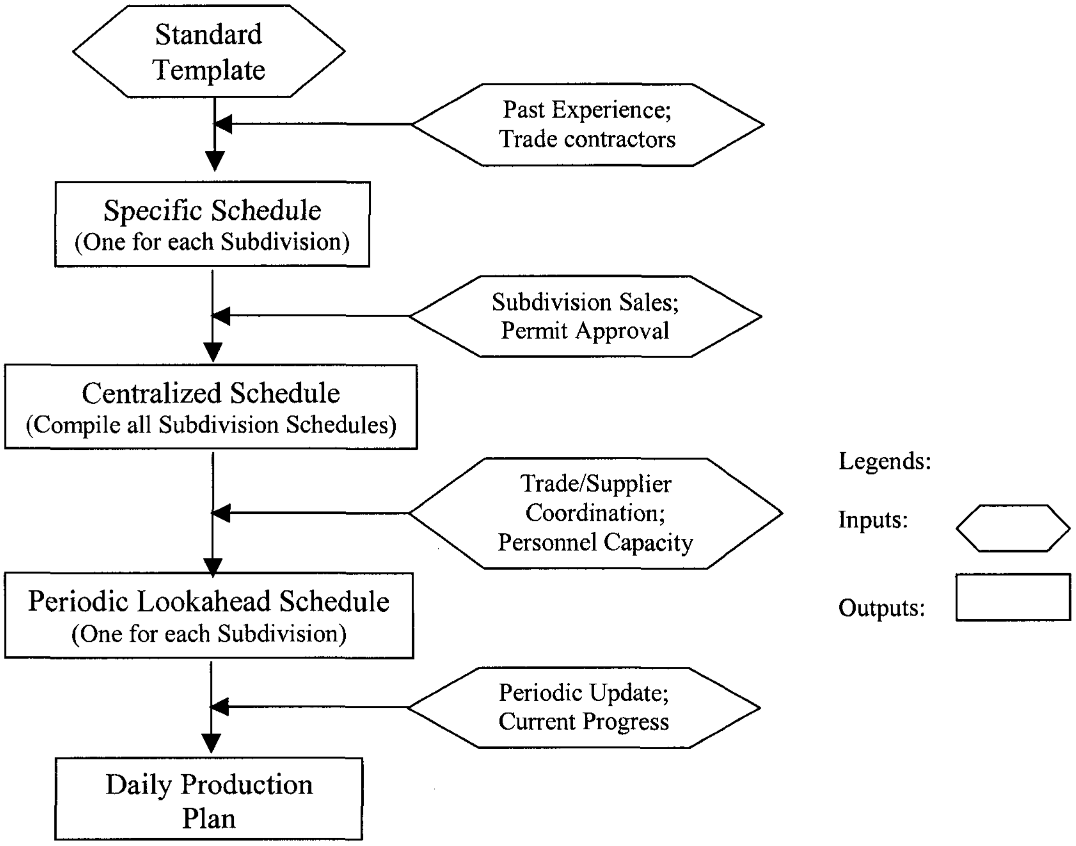


**Figure 4.3: Flow Chart Representing Production Plan for Large Homebuilding Company**

### 4.2.3 Summary

The previous section provides an overview of the production planning process prevalent in the homebuilding industry. It also documents a detailed production planning process by means of the three flowcharts representing the process of production planning observed in the three broad categories of homebuilding companies. The documentation was based on interviews and site observation performed by the author.

## 4.3 Data Collection on Site

To facilitate measuring production planning performance, an assessment tool was developed. A complete explanation of the assessment tool was presented in Section 3.3. To demonstrate the use of the assessment tool and to identify areas of improvement, data collection and analysis was conducted for one homebuilding project. The following sections will present the details of the data collection process and respective analysis.

### 4.3.1 Site Overview

One homebuilding project was selected for the purpose of data collection. This construction site was situated in Lansing, Michigan. The homebuilding company was building one community with 12 apartment complexes. Two of the 12 buildings were selected for data collection, as the work in progress in the two buildings was substantial during the period of data collection. Each of these buildings comprised of 12 apartment units. Most of the work was subcontracted. The site had one Project Superintendent, who managed most of the daily tasks on site.

### 4.3.2 Data Collection

The purpose of data collection was to demonstrate the assessment tool developed in this research and to help in developing the production planning process model. Data was collected for a period of eleven weeks for two apartment buildings. The activities for which data was collected included pre-drywall inspection, hanging drywall, plastering, painting, flooring, trim carpentry, cabinet and door installation, plumbing, and HVAC. These activities were in progress in Building I and Building II.

During the period of data collection, the site was visited daily at approximately one hour before the end of work. On each day, the site superintendent provided details of the activities planned for the next day. The author also walked around the site to check what activities were completed each day in the two buildings. Any activity that was not performed or partially completed was recorded as "Incomplete".

Data was recorded in a spreadsheet as shown in Figure 4.4. The activities planned to be completed for each day were recorded in the 'Activities Planned' row and activities which were not completed were recorded in the 'Incomplete Activities and Reasons' Column with details on why the activity could not be completed (see Figure 4.4).

The data collected on a daily basis were then used to calculate the daily Percent Plan Complete (PPC). This was done using another spreadsheet as shown in Figure 4.5. The reason for incompletion of any activity was recorded using the following reason codes: Productivity, Engineering, Non-Conformance, Owner Decision, Weather, Pre-Requisite, No-Show, Trade, Supplier, Space, and Other.

| Daily Data Collection Sheet<br>Building I | | | |
|---|---|---|---|
| | **15-Mar** | **16-Mar** | **17-Mar** |
| **Activities planned** | Drywall Stocking | Drywall Stocking | *Drywall 2 units* |
| | | *Inspection* | *Inspection* |
| **Incomplete activities and reasons** | All Completed | Inspection Incomplete | Drywalling not started |
| | | (Inspector didn't turn up) | (Pre drywalling approval |
| | | | not granted) |
| | | | |
| | | | |

**Figure 4.4: Format for Data Collection**

| | 15-Mar | 16-Mar | 17-Mar | 18-Mar | 19-Mar | PPC | |
|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 1 | 2 | 2 | 2 | 2 | rolled | Weekly |
| **Tasks Completed** | 1 | 1 | 0 | 2 | 1 | | |
| **PPC (%)** | 100 | 50 | 0 | 100 | 50 | 0.00 | 0.56 |
| | | | | | | | |
| **Productivity** | | | | | | | |
| **Engineering** | | | | | 1 | | |
| **Non Confirmance** | | | 1 | | | | |
| **Owner Decision** | | | | | | | |
| **Weather** | | | | | | | |
| **Pre requisite** | | | 1 | | | | |
| **No show** | | 1 | | | | | |
| **Trade** | | | | | | | |
| **Supplier** | | | | | | | |
| **Space** | | | | | | | |
| **Other** | | | | | | | |

**Figure 4.5: Spreadsheet Showing Daily PPC and Reasons**

The spreadsheet used for data collection and recording has been maintained for the eleven weeks of data collection and is presented in Appendix D. The spreadsheet for PPC and Reason Codes is presented in Appendix E.

### 4.4 Data Analysis

The data collected was analyzed to find opportunities for process improvement. As explained in Chapter 3, an assessment tool was developed to measure the performance of production planning process. The Last Planner System's (Ballard, 2000) PPC metric and *rolled* PPC (Abdelhamid, 2003) are used for measurement of performance. The detailed steps for data analysis and its outcomes are presented in the following sections.

#### 4.4.1 PPC Calculations

The data collected on site was used to produce a spreadsheet as shown in Figure 4.5. In this spreadsheet, the number of activities planned for each day was recorded and then based on daily site visits the number of activities that was actually completed was recorded. The daily PPC was calculated using this data. PPC can be expressed as the ratio of number of activities completed to the number of activities planned to be completed. This ratio is expressed as a percentage. The average PPCs over a week was calculated to obtain an 'Average Weekly PPC'. This data was then used to plot a graph of average weekly PPCs. The graphs for average weekly PPC for Building I and Building II are shown in Figure 4.6 and Figure 4.7 respectively.

The overall average of the weekly PPCs for Building I is 64% and for Building II is 75%. The PPCs for Building II is higher than that of Building I because all the activities in Building II were performed after completing the same in Building I. This may reflect a 'learning' experience accumulated by the management and the trade crews in the process.

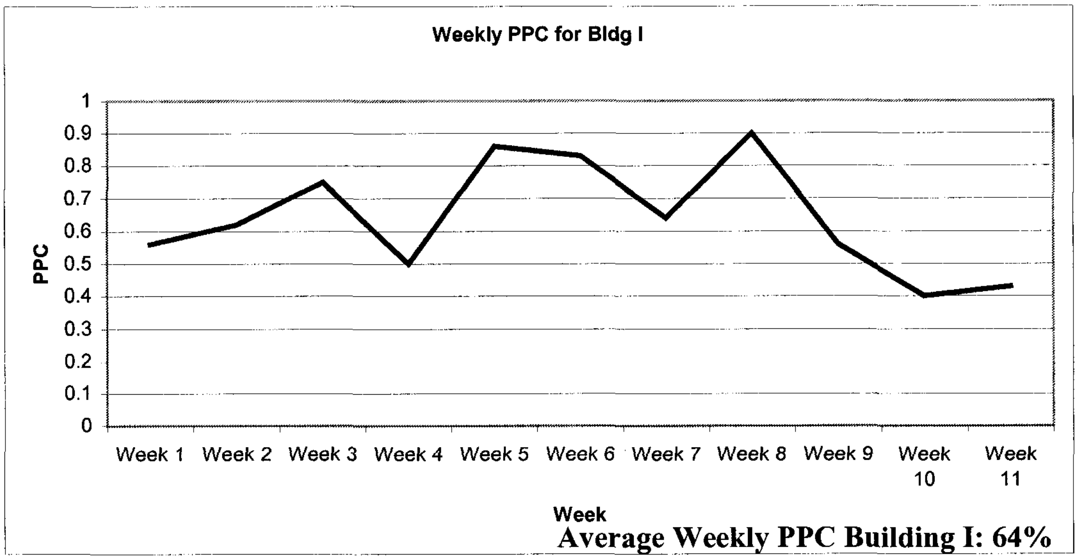


**Figure 4.6: Graph Showing Weekly PPC for Building I**

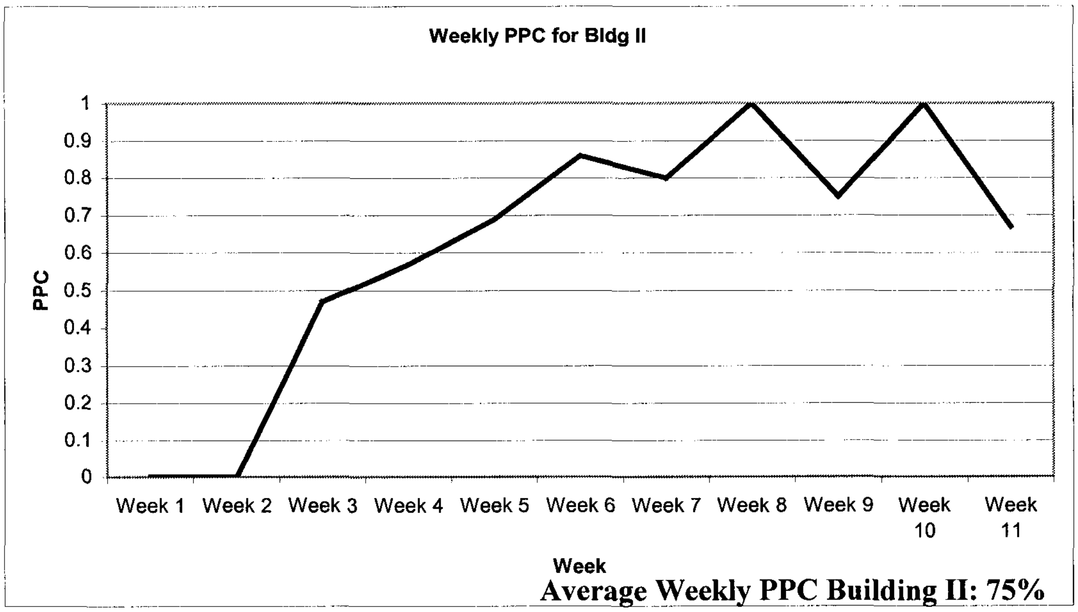


**Figure 4.7: Graph Showing Weekly PPC for Building II**

Figures 4.6 and 4.7 indicate that the work was completed according to plan, 64% and 75% for Building I and Building II respectively. Thus, it can be concluded that according to the PPC calculations, the production planning process adopted by the company was unreliable 25% to 35% of the times.

In general, incomplete assignments could be due to over expectation from the crew while planning and/or incapability of the crew to complete the assignment. The underlying cause could be lack of coordination, shortage of materials, low productivity, space constraints, etc. Regardless of the reason, the production planning process should result in assignments that are realistic, constraint free, and achievable.

The following section will explain the use of the *rolled* PPC metric versus the PPC metric as a measure of the production planning process performance.

### 4.4.2 PPC vs. Rolled PPC

In a homebuilding project, the construction process is divided into various activities using a particular Work Breakdown Structure (WBS). If an activity is not completed in one particular day, it has to be completed the next day, thus in turn, reducing the output for the particular day as planned. Thus, a PPC value lower than 100% for one day will affect the output for the next day. If this scenario is considered over a week's time, having a variable PPC on each day, at the end of the week the overall output is much less than planned. Thus at the end of the week, the performance assessment metric should be able to project the inefficiency of the process such that it can be used to improve the process.

PPC measurement on a daily basis is effective, but planning for production on a daily basis is very tedious and close to impossible considering the effort and cost that would be required. This is especially true for the homebuilding industry, where the competition is based on the final cost of the product, it seems impractical to require such a tedious process. Therefore, evaluation of the construction progress and implementation of the necessary changes on a weekly basis is considered more appropriate and this was reflected in the conducted interviews. Hence, the metric used for performance assessment should reflect the true scenario on site and should be used to improve the production plan on a weekly or bi-weekly basis. Using an average PPC value for the period will not reflect the inefficiency in the process correctly. This can be better explained with an example. Consider a sample data for a week as shown in Table 4.1.

| **Building I** | 26-Apr | 27-Apr | 28-Apr | 29-Apr | 30-Apr | Weekly PPC | *rolled* PPC |
|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 2 | 3 | 3 | 3 | 3 | | |
| **Tasks Completed** | 1 | 2 | 2 | 2 | 2 | | |
| **PPC (%)** | 50 | 66.66 | 66.66 | 66.66 | 66.66 | 64 | 10 |

**Table 4.1: Sample data for a week**

The table above shows the tasks planned and completed for a week. It also shows the PPC value for each day. The 'Weekly PPC' is an average of the daily PPCs for the week. The data for this week shows an average PPC of 64% and this is calculated by taking an average of all the daily PPC values.

Turning attention to the daily PPC values shown in Table 4.1 shows that on day 1, one out of two activities were completed giving a PPC value of 50%. On day 2, two out of three activities were completed giving a PPC value of 66.66%. The incomplete activity on day 2 was due to the extra work performed to complete the previous day's work. Thus, on day 2 only 50 % of the work expected to be passed from day 1 was actually completed and passed on. Thus, the PPC value for day 2 hides the extra work done owing to incomplete work on the previous day. Thus, in reality, on day 2, only 66.66% of the work passed on was completed. Multiplying PPC for day 1 with PPC for day 2 can accurately reflect this. So, at the end of day 2 the PPC should be 33.33% (50% * 66.66%). Similarly for day 3 the work passed on was only 33.33% completed as planned and hence the output for day 3 will reduce due to the fact that earlier work had to be completed. This can be shown by multiplying daily PPC for day3 with the previous days PPC and so on.

The multiplication procedure indicated above is the same procedure for arriving at the rolled PPC metric described in Chapter 3. The weekly '*rolled* PPC' is a value obtained by multiplying the daily PPCs for the week. The weekly *rolled* PPC for the sample data in Table 4.1 is 10% (50%*66.66%*66.66%*66.66%*66.66%). Thus, the *rolled* PPC metric gives an accurate value for measuring the performance of the process without hiding the rework because of incomplete tasks on the previous day(s).

The metric *rolled* PPC is developed from the rolled yield metric suggested in the Six Sigma methodology. This metric focuses on revealing the hidden work or rework in a production process. Hidden work or rework reduces the output of a process and thus it should be eliminated. Thus, rework or hidden work should be taken into account when assessing performance of production planning.

Figure 4.8 and 4.9 shows graphs plotted for PPC and *rolled* PPC for Building I and Building II. It can be seen from the graph that the *rolled* PPC is much lower than the PPC for each week. A value of zero for *rolled* PPC indicates that the week had at least one day with a PPC of zero, and a value of hundred for *rolled* PPC indicates that the week had 100% PPC on all days of the week. This clearly shows the effectiveness of the *rolled* PPC metric in being able to measure the performance of the production planning process in both the best and the worst cases.

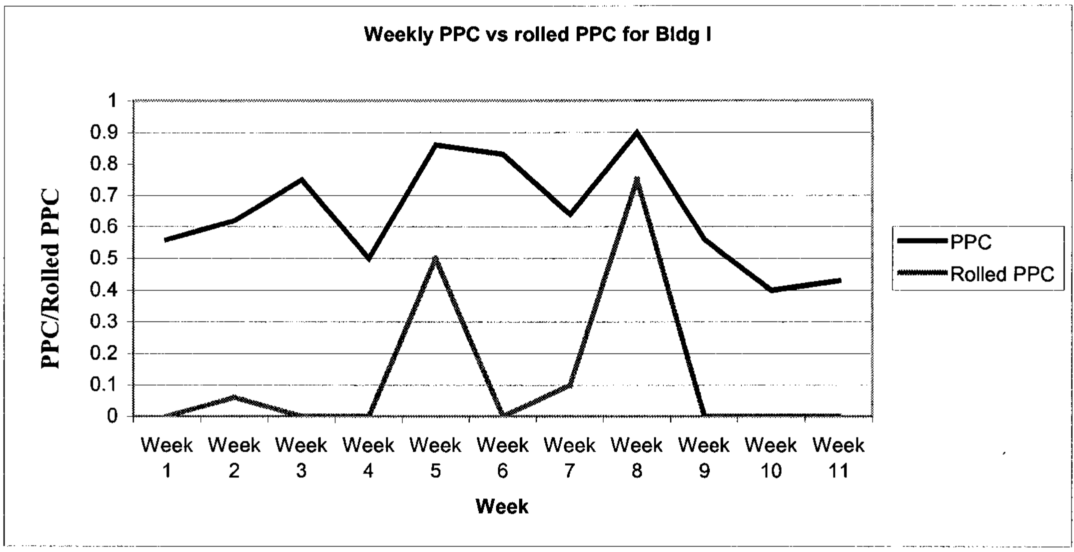


**Figure 4.8: Graph of PPC and *rolled* PPC for Building I**

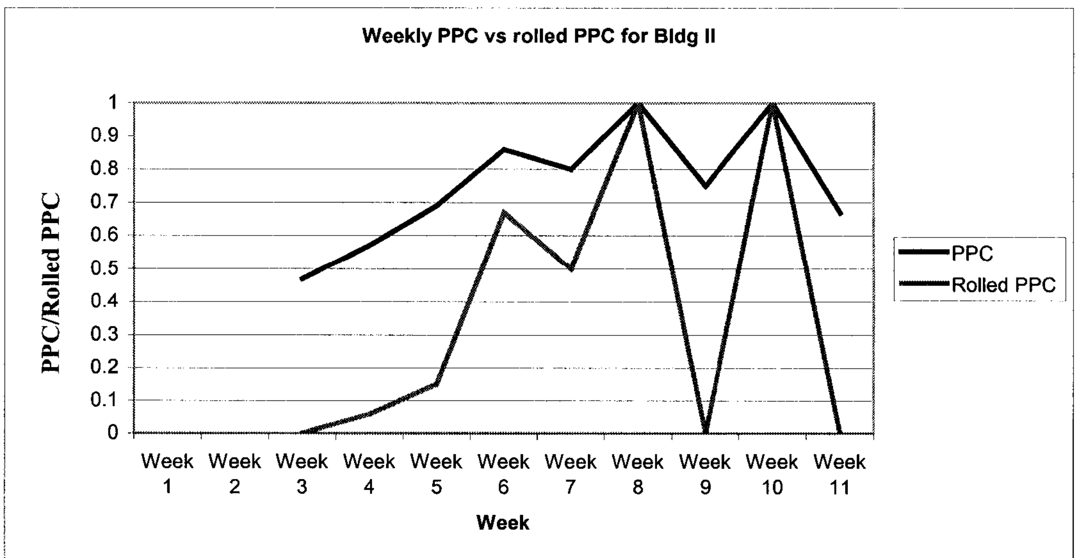


**Figure 4.9: Graph of PPC and *rolled* PPC for Building II**

### 4.4.3 Sigma Value

Once the rolled PPC is calculated, the sigma yield value for the process has to be calculated as explained in chapter 3. Equations (v) to (viii) are used to derive the sigma value for this process. The sigma yield value for the production planning process in each building was calculated on two basis. Firstly, the average PPC value was used to find the sigma yield value and then the rolled PPC value was used. The values were as follows:

- Sigma Level for Building I

  By Average PPC, Sigma Yield Value = **3.24**

  By rolled PPC, Sigma Yield Value = **2.39**

- Sigma Level for Building II

  By Average PPC, Sigma Yield Value = **3.44**

  By rolled PPC, Sigma Yield Value = **2.85**

The difference in the sigma yield value for the same building is due to the different yield metric used to calculate the sigma level. The rolled PPC, as suggested by the author shows a true picture of the efficiency of the production planning process. This is due to the fact that rolled PPC metric captures the extra work done to complete the previously incomplete activities. The difference between the sigma values in the two buildings when we use the same metric is due to the learning effect achieved in Building II because it always followed Building I. As a normalized value, this sigma value can be used for comparing different processes and can also be extended to compare between one company to another, and even one industry to another.

### 4.4.4 Statistical Analysis of Data

In general, measured or collected data can be analyzed statistically in various ways to determine areas of improvement. This is necessary so that management can identify the aspects that need immediate attention and assign priority levels to the tasks that need to be undertaken to improve the overall production planning process and thus improve crew performance and crew-to-crew handoffs (workflow). This step of prioritizing items that need action is advocated in the Six Sigma Methodology. Determination of high priority actions can be achieved by performing statistical analysis of the data. Chapter 3 explained various tools that can be used to determine the causes of incomplete assignments.

The metric 'PPC' can be modified to focus on the incomplete assignments by introducing the Percentage Planned Incomplete (PPIC) metric. The sole purpose of developing this new metric in this research is to focus on incomplete tasks and find causes for the same. PPIC is the ratio of total number of tasks incomplete to the total number of tasks planned to be completed.

***Run Chart or Time Series Plot***

Variation is inherent in any process and it leads to unreliability in the process. The aim of Lean Construction and Six Sigma is to reduce the variations to the extent possible. The variations could be attributed to either common causes or special causes (Abdelhamid 2003). Common causes are those causes that are built into the process and can be eliminated by means of reengineering. Whereas, special causes are those that create sudden variations in the process and can be eliminated without changing the overall process. Run Chart or Time Series Plot is a popular method to determine the special causes and it is used here to statistically determine such causes and find means to eliminate the cause.

In Chapter 3, run charts were discussed and a brief discussion on *p-chart* and its appropriateness for this data was presented. Thus, for the PPIC data a *p-chart* is plotted for both buildings in the study to determine special causes that lead to incomplete tasks.

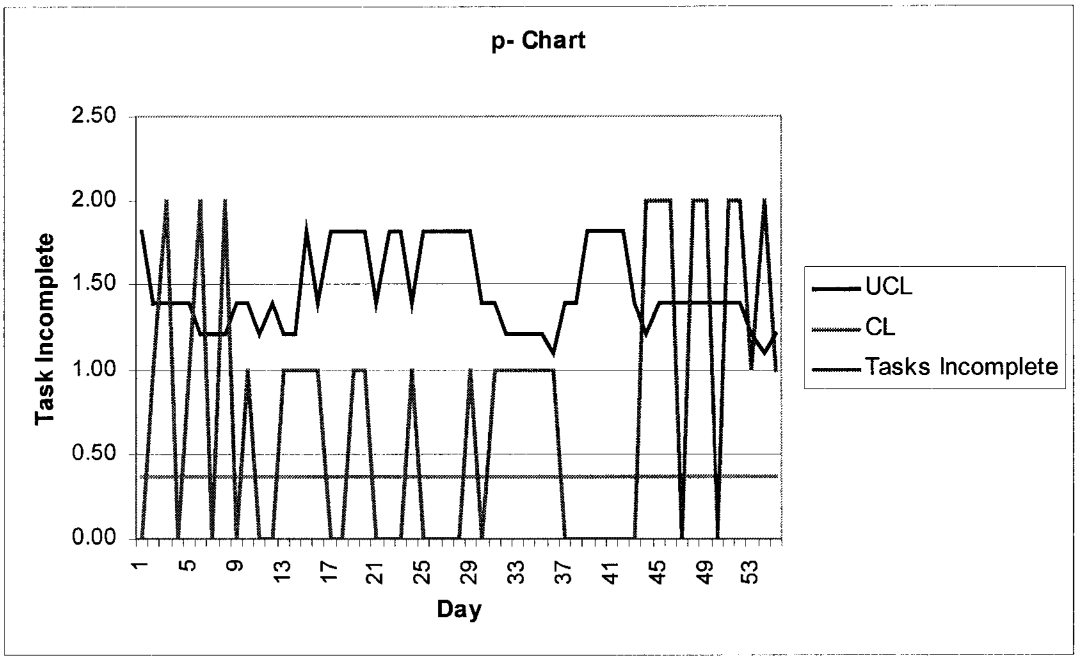


**Figure 4.10: p-Chart for Task Incomplete in Building I**

Figure 4.10 shows a *p-chart* plotted using data of incomplete tasks for Building I and the equations listed in Section 3.3.3. The plot shows an Upper Control Limit (UCL) line, a Center Line (CL), and the Tasks Incomplete plot. The LCL limit is zero in this case. The UCL value for each day is varying because the number of tasks assigned for each day is varying. On any given day, the tasks incomplete should not be more than the UCL value.

In Figure 4.10 we can clearly see that on some days, the tasks incomplete were more than the UCL. This is an indication of special cause variation. Such days can be identified and reasons for incomplete tasks can be evaluated and reduced or if possible eliminated, such that similar conditions does not reoccur. This is the main aim of monitoring and controlling using statistical analysis. If this process is repeated on a weekly basis or any fixed period of time, the past causes for high number of incomplete activities can be determined and measures can be taken to avoid such instances in the future. Table 4.2 shows the days having incomplete assignments more than the UCL and reasons that caused them.

| Day | Planned | Incomplete | Planned Work | Reasons for incompletion |
|---|---|---|---|---|
| 3 | 2 | **2** | Drywall 2 units<br>Inspection<br>Drywalling not started | (Pre drywalling approval not granted)<br>Inspector approval not obtained |
| 6 | 3 | **2** | Engineering of truss<br>Truss repair<br>Inspection | <br>Truss repair completed but not approved by inspector<br>Inspector approval not obtained |
| 8 | 3 | **2** | Insulation<br>Drywall unit 1<br>Drywall unit 2 | <br>Wanted insulation to finish for space<br>Wanted insulation to finish for space |
| 44 | 3 | **2** | Stock Doors<br>Install doors in 3 units<br>Install Countertops | <br>Stocking took most of the day<br>time enough to install in only one unit |
| 45 | 2 | **2** | Install doors in 3 units<br>Install Countertops | Less manpower<br>Installed in only one unit |
| 46 | 2 | **2** | Install doors in 3 units<br>Install Countertops | Less manpower<br>Installed in only two unit |
| 48 | 2 | **2** | Install doors in 2 units<br>Install Countertops | Supplier didn't suuply right types<br>Supplier didn't suuply right types |
| 49 | 2 | **2** | Install doors in 2 units<br>Install Countertops | Supplier didn't suuply right types<br>Supplier didn't suuply right types |
| 51 | 2 | **2** | Install doors in 3 units<br>Install Countertops | crew all around the building completing small jobs<br>crew all around the building completing small jobs |
| 52 | 2 | **2** | Install doors in 2 units<br>Install Countertops | Less manpower<br>Less manpower |
| 54 | 4 | **2** | Plumbing 3<br>HVAC 3<br>Electrical 3<br>Install doors in 2 units | <br><br>Manpower<br>Design problem |

**Table 4.2: Special Reasons Causing Variations in Building I**

Similarly a *p-chart* is plotted for Building II and a table is produced showing reasons that led to incomplete assignments. Figure 4.11 shows the *p-chart* plot for incomplete assignments in Building II and Table 4.3 shows the reasons that led to the incomplete assignments.

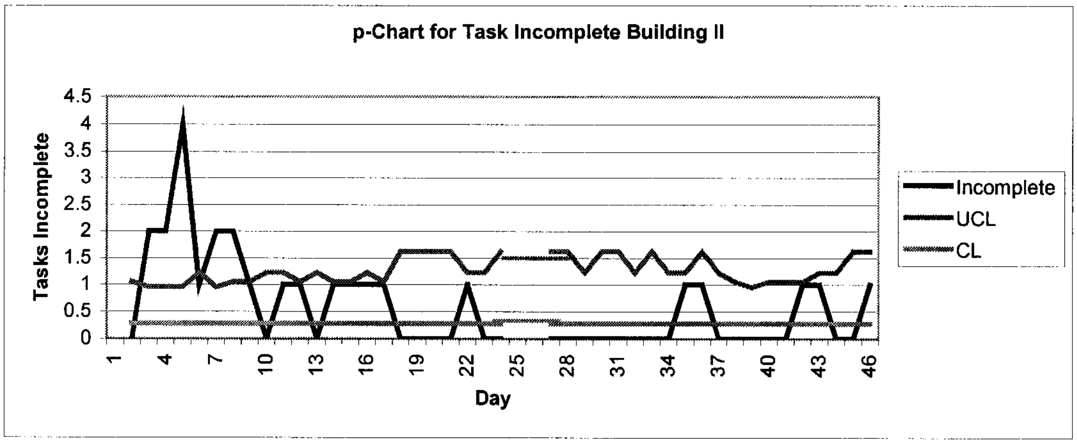


**Figure 4.11: p-Chart for Task Incomplete in Building II**

The reasons listed in Table 4.2 and Table 4.3 here can be evaluated to find and eliminate their root causes and thus improve the process. A Cause and Effect diagram approach can be used to arrive at the root causes. This was explained in Chapter 3, Section 3.3.3.2. The following sections will describe various other analyses that were performed on the data to find areas that need improvement.

| Days | Planned | Incomplete | Planned Work | Reasons for incompletion |
|---|---|---|---|---|
| 4 | 4 | 4 | Truss Repair<br>Building Inspection<br>Insulation Interior<br>Drywall Stocking | Truss repair completed with fault have to be redone<br>Inspector No Show<br>Insulation could not proceed without inspection<br>Drywall Stocking could not proceed without inspection |
| 6 | 4 | 2 | Truss Bracing<br>Building Inspection<br>Insulation Interior<br>Drywall Stocking | <br>Inspector No Show<br><br>Supplier didn't respond |
| 7 | 3 | 2 | Building Inspection | Inspector No Show |

**Table 4.3: Special Reasons Causing Variations in Building II**

### 4.4.5 Pareto Analysis

Pareto Analysis is a tool used to stratify the data into groups and Pareto Charts are used to present this data. Pareto analysis is used for this research to stratify the data into specified groups and identify areas that need improvement.

The reasons for incomplete assignments are stratified into various reason codes and are used to identify the reasons that caused most of the incomplete assignments. A Pareto chart is used to present this data graphically. Figure 4.12 shows the various reasons grouped into eight different reason codes and the number of times each reason code has caused an incomplete assignment.

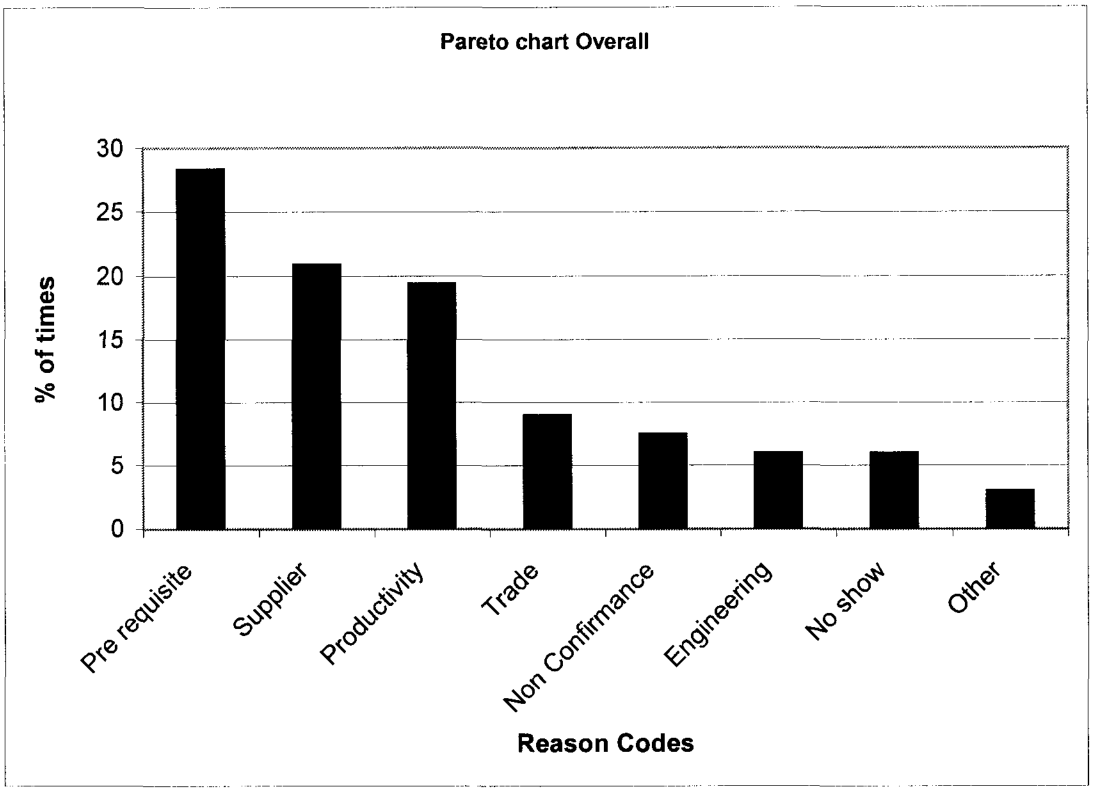


**Figure 4.12 Pareto Chart for Reason Codes**

The chart shows that 'Pre-requisite' is the reason code that caused most of the incomplete assignments in the data. 'Pre-requisite' means work that needs to be completed before the particular assignment can be undertaken. 'Supplier' is shown as the second highest reason causing delays to the project. 'Productivity' stands at the third highest reason causing incomplete assignments. The reason code 'productivity' is used when an assignment could not be completed due to overplanning for a certain crew, or when the crew couldn't complete the assignment in the given duration. The Pareto chart for this data almost conforms to the 70-30 rule, which states that 70% of the inefficiencies are caused due to 30% of the factors.

The results obtained from the Pareto analysis can be used to identify the areas that need immediate attention. In this case, the homebuilding company should focus attention on making all the prerequisites available before making assignments to crews. The second highest reason code 'Supplier' also needs immediate attention. The homebuilding company can use such data to conduct a brainstorming session with the personnel involved to develop a Fish Bone Diagram and find the root causes for the incomplete assignments as explained in Chapter 3.

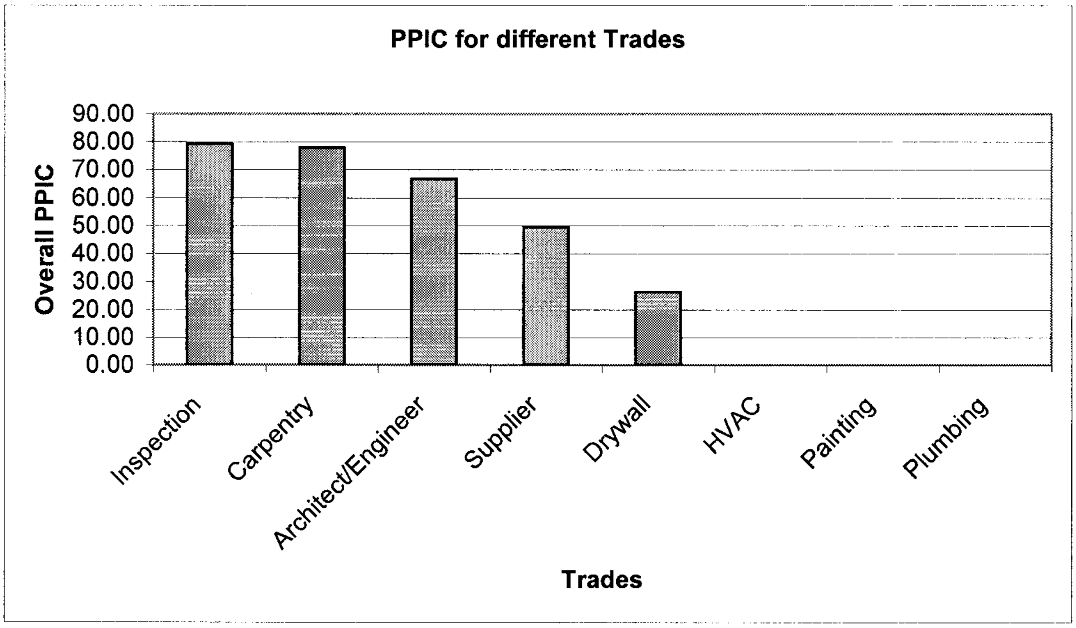


**Figure 4.13 Pareto Chart for Trades**

The Pareto Analysis was also used to stratify the data based on trade type and weekdays. Figure 4.13 shows a Pareto chart that identifies the number of incomplete assignments associated with each trade. The figure shows that 'Inspection' had the most number of incomplete assignments, which could either mean that the Inspector did not show up, or the inspection could not be passed most of the times. The company should look into the reasons for such performance and improve on the process.

Another chart was constructed to show the production performance on site based on the day of the week. Figure 4.14 shows a graph for PPC vs. Day of the week. The nature of the graph shows that Tuesday and Wednesday is the days when the production is higher compared to other days, and Friday shows the least production. This result matches with a graph cited in Oglesby et al. (1989) for production rates on different days of the week.

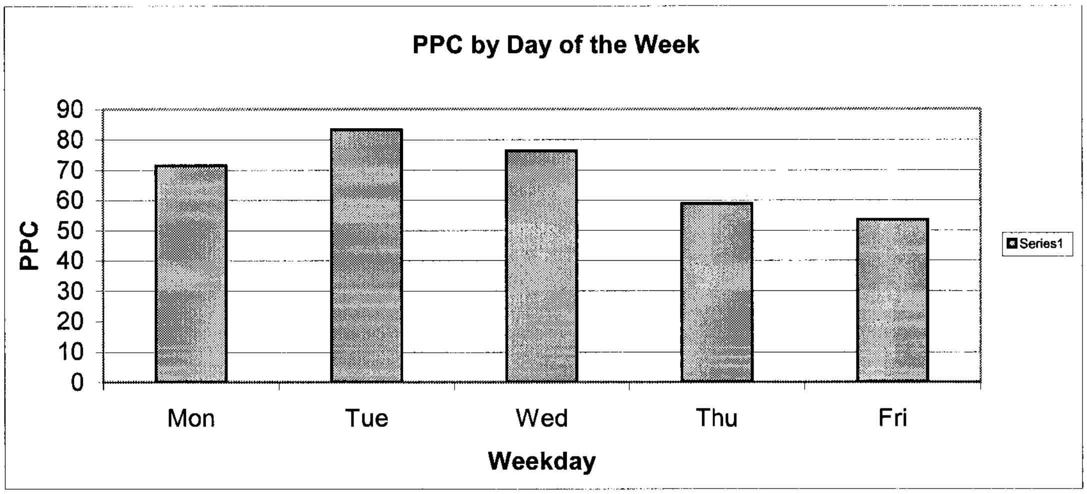


**Figure 4.14: Graph of PPC vs. Weekday**

## 4.5 Summary

The above sections detailed the steps followed for data analysis. The interviews conducted were used to understand the production planning process prevalent in the homebuilding industry. Homebuilding companies can use the interview data to improve the technique used for production planning. The section also illustrated various tools suggested for data analysis to obtain information on the performance of the production planning process. The statistical data analysis presented, would be useful for determining the shortcomings of a process and can be used to prioritize and focus on problems that need fixing.

The next sections describe a production planning process model suitable for the homebuilding industry. This model is developed on the basis of data acquired in the interviews and analysis performed on the data.

### 4.6 Production Planning Process Model (PPPM)

This section presents a production process planning model. This model was developed using inputs from the interviews and the data analysis. The planning model is based on the Last Planner System (Ballard, 2000) and Six Sigma methodology. The following sections will describe the model in detail.

#### 4.6.1 Six Sigma Methodology for Process Improvement

As explained in Chapter 2, Six Sigma methodology is a method for process improvement that relies on statistical methods to reduce defect rates. This methodology has been widely used in a variety of industries. The aim here is to bring a process to a zero-defect condition. Chapter 3 of this report explained how Six Sigma methodology is used in conjunction with Lean construction principle in this research. Data collection was conducted using interviews and site visits to explain the use of this methodology, as presented in previous sections.

Six Sigma methodology is based on a 5-step process. This process is illustrated in Breyfogle (1999), and Pande, et al (2000), and was briefly explained in Chapter 2 and Chapter 3 of this report. The 5-step process is also known as DMAIC: (Define, Measure, Analyze, Improve, and Control). The development of the PPPM follows the DMAIC methodology and LPS by superimposing both on the conventional planning processes depicted in Figures 4.1 through 4.3.

***Define***

The first step in process improvement in the Six Sigma methodology is to define the process that needs improvement. All possible processes that require improvement can be identified, and then prioritized to select the processes that need immediate attention. For this research, the production planning process was selected for study and improvement. Once, the process is selected as a candidate for improvement, the second step in the methodology, which is 'Measure', can be performed.

***Measure***

The Six Sigma methodology is based on statistical methods to improve process performance. After the process needing improvement is defined, the next logical step is to measure the performance of the current process. Performance measurement can be performed in various ways. It is important to understand the process completely and select a measurement method and metric that is most suitable for the process.

In Chapter 2, the author reviewed the existing literature in various fields for process performance measurement and identified the PPC metric suggested in the Last Planner System (Ballard, 2000) as a relevant and suitable technique to achieve the goal of this research. Also, a study presented by Abdelhamid (2003), advocating rolled throughput yield as a metric for production planning performance assessment was studied. The author adopted and implemented the new metric 'rolled PPC', which was based on these two studies. This new metric for performance assessment was adopted for this research based on its simplicity and its ability to assess the true performance of a production planning process.

The measurement of a process metric makes it easy to understand the current scenario and thus can be used to identify the areas that need improvement. This research also advocates the use of the sigma level metric, as explained in the Six Sigma methodology (Breyfogle, 1999, and Pande, et al, 2000). The conversion of the rolled PPC to a sigma level helps in quantifying the process capability, and also helps in comparison and benchmarking as explained in Chapter 2 and Chapter 3. The aim should be to reduce the unreliability of the production planning process to a state where the process will yield a 6-sigma or higher value.

***Analyze***

This step is used to analyze the current production planning process to identify the areas that need improvement. Chapter 3 of this report explains the step-by-step process of measurement and analysis. The data collection process included interviewing professionals from 4 homebuilding companies and data collection from one residential construction site. Previous sections of this chapter presented the data collection process adopted in this research and its analysis. The different steps used for data analysis are suitable for performance assessment of production planning process in a homebuilding company.

***Improve***

Once the measurement and analysis phases are completed, the next step is to improve the current production planning process based on the analysis results. This research has developed a production planning process model suitable for homebuilding companies based on the data collection and analysis. The model is explained in detail in a later section of this chapter. The model developed intends to improve the production planning process and it includes a system for performance measurement and analysis such that continuous improvement can be achieved.

***Control***

The production planning process was selected for improvement. A model was developed for the production planning process with the 'rolled PPC' measurement metric incorporated along with a system of analysis. Once this model is implemented for production planning, it is very important to keep the process in control. Continuous measurement, analysis and improvement cycle has to be achieved to keep the process in control. The measurement and analysis steps help in identifying the unreliability of the production planning process. It is important to find solutions to reduce this unreliability. The model for production planning can be modified to adapt any inconsistencies and achieve a higher sigma value for the process. Control is thus necessary in the overall improvement process.

### 4.6.2 Last Planner System

The Last Planner System® (LPS) provides a framework for management and workers to plan and control daily production assignments (Ballard 2000). Chapter 2 explains the LPS system in detail.

***Should-Can-Will-do Tasks***

The LPS model, as shown in Figure 5.1 has 4 categories of tasks: Should, Can, Will, and Did. The 'Should' tasks are those tasks identified on the Master/Phase schedules and must be completed at a specific time. This schedule is based on structural, technical, regulatory considerations, and sequencing. This step also takes inputs from current status and forecasts. The LPS model suggests a Lookahead process, where all the 'Should' tasks that are planned for a given period of time are scrutinized, such that all the work is declared constraint free.

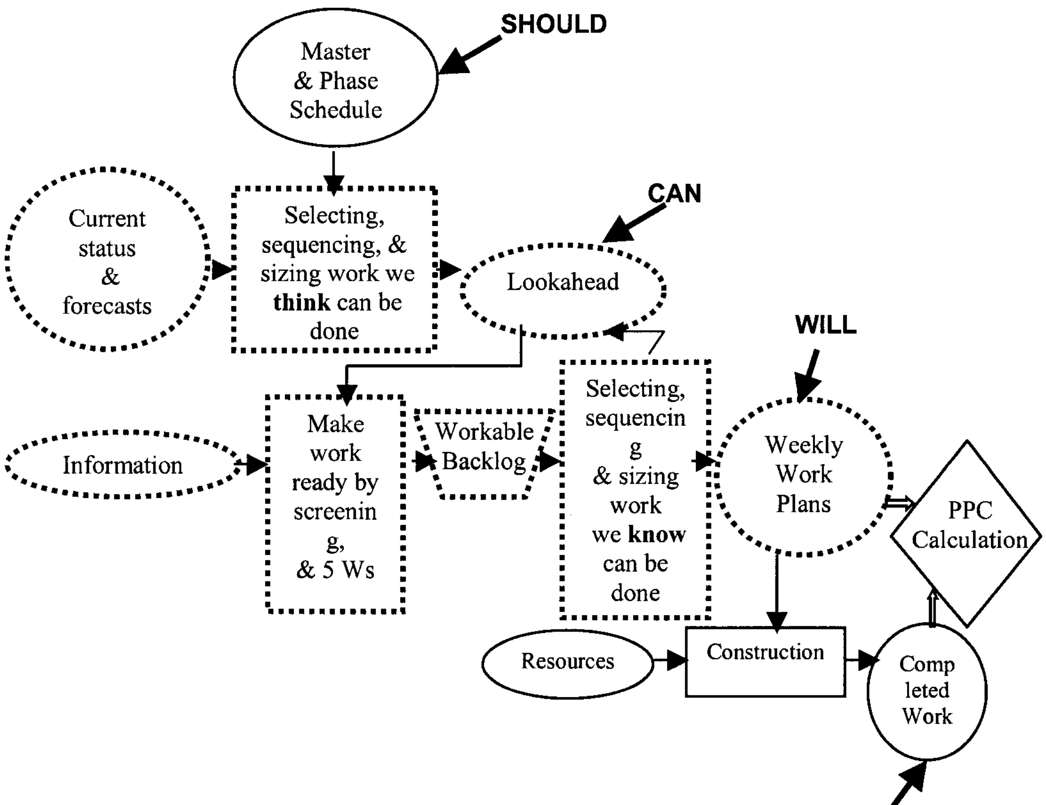


**Figure 4.15: Last Planner System Model**

**(©Lean Construction Institute)**

A constraint analysis is performed to find any constraints in completing an upcoming task. These tasks are termed as 'Can' do tasks. All constraints should be removed for the tasks before they enter into the workable backlog. The workable backlog is a set of tasks that are constraint free and doable. These tasks are sized properly and all prerequisites for the task should be available at the time of its execution. The foreman responsible for performing an activity should only commit to tasks. These are known, as 'Will-do' tasks. The tasks that are actually completed are known as 'Did' tasks.

The LPS system uses the PPC metric for performance measurement. The PPC value can be calculated by dividing the number of tasks actually completed by the number of activities committed to. The number of assignments completed to those that should be done is also tracked.

The production planning model developed in this research is based on the LPS Model and the Six Sigma Process Improvement Model. The following section describes this Production Planning Model in detail.

**4.6.3 Production Planning Process Model Description**

One of the objectives of this research was to develop a model for production planning process. This model is based on Six Sigma Process Improvement methodology and the Last Planner System. Both of these are explained in the previous two sections. The production planning process model is a combination of both these systems, and is tailored to meet the needs of homebuilding industry. Information of the production planning process prevalent in the homebuilding industry was necessary to develop the new model. This was facilitated by the interviews conducted. Opinions and concerns received in the interviews were addressed and have been incorporated in the Production Planning Process Model.

Production planning in most homebuilding companies starts from a standard template for a particular type of home (Single home, apartment, condominium, etc.). Once the home design and plans are selected for construction, the standard template can be modified into a specific template for that particular community or set of homes. The company then submits plans and details for permits and approvals for each home. This determines the start date for construction. The availability of resources (trade contractors,

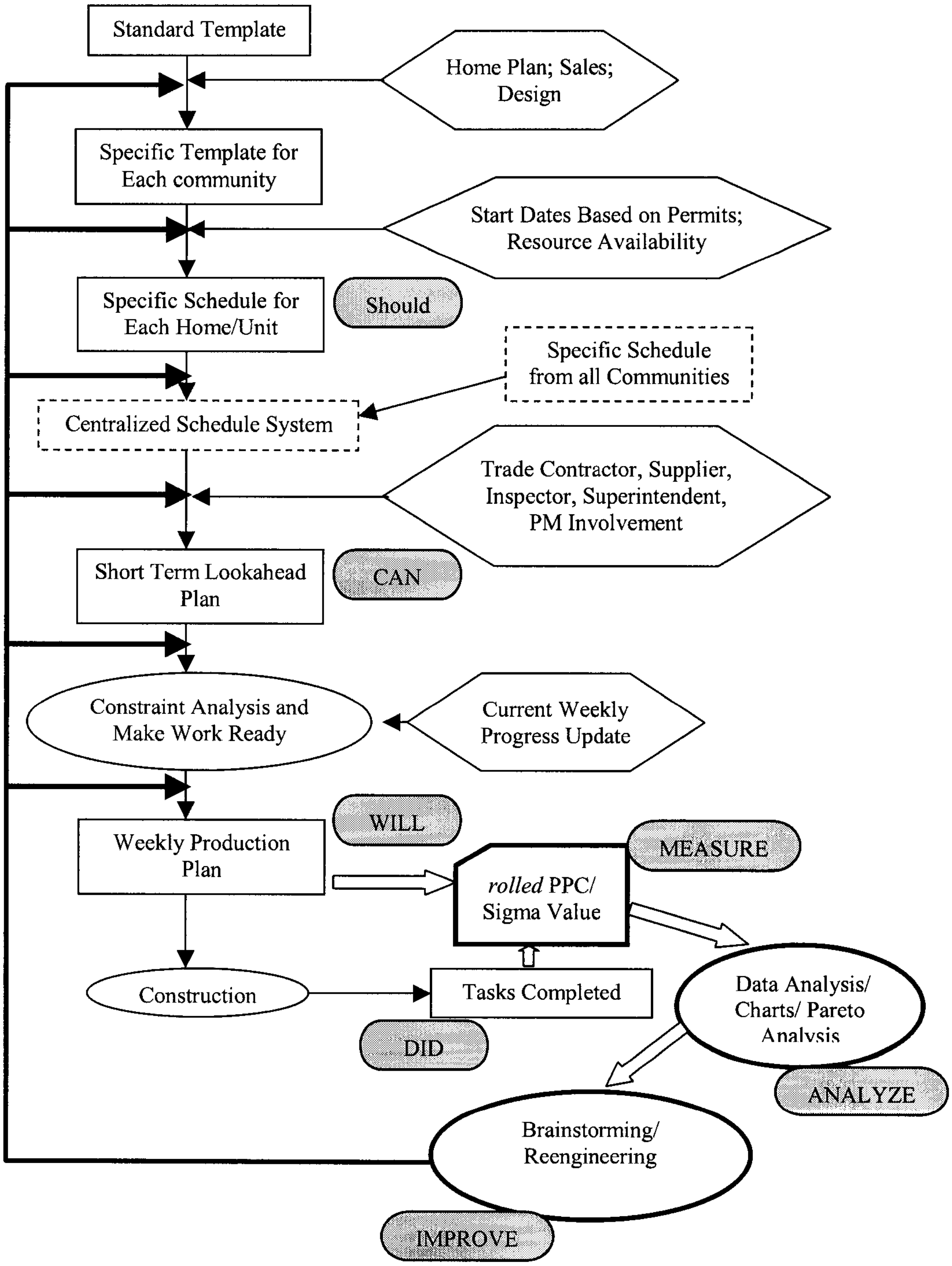


**Figure 4.16: Production Planning Process Model**

suppliers, etc.) has to be considered also for obtaining a specific schedule for each home or unit. This schedule represents the Master schedule in the LPS. Thus, this can be termed as the 'Should' do tasks. In case of large companies having multiple communities it is advantageous to compile a centralized schedule based on inputs from all communities.

This helps in scheduling resources centrally and avoids resource conflicts between production plans of different communities. Thus, some constraints are removed right at the beginning. The specific schedule for each home should be scrutinized in a Lookahead Plan. This plan is a breakup of the master schedule and it is for a shorter period of time. This process involves inputs from the trade contractors, suppliers, superintendents, and project managers. The trade contractors and suppliers agree to certain tasks they think can be done. These tasks form the 'Can' do work.

The project manager's, and superintendent's aim should be to make the 'Can' do tasks doable. The set of 'Can' do tasks have to be further analyzed to identify the constraints to completion of tasks as planned. A complete Constraint Analysis should be performed so as to make the work ready for the trades. This involves making available the prerequisites for each task, and proper sizing of tasks, thus making the work doable. Only tasks that are free from constraints can pass through this process as assignments to be completed. The trade contractors, superintendents, and the foremen should commit to these assignments, and these forms the Weekly Production Plan. These are tasks that have been committed to, and thus are identified, as 'Will' do tasks.

The weekly production plan should be passed on to each and every supplier involved. These tasks are then completed during the week. As the day for performing each tasks approaches, the superintendent should make sure that all constraints identified are completely removed. In case of delays or weather calamities, the resources should be assigned to new production tasks that had been identified as doable but not assigned yet. Such a workable backlog should be kept available with the Weekly production plan.

At the end of each day or week (depending on resource availability) a planned versus completed sheet should be filled out. This could be in the format shown in Figures 4.4 and 4.5. This forms the 'Measure' phase of the model. The simple form can be used to keep track of the daily progress, and to measure the PPC for each day and hence the weekly rolled PPC. This can be converted into a Sigma level. The reasons for incompletion of tasks should be categorized to identify major causes of delay. A complete data analysis can be performed as explained in Chapter 4 of this thesis. This forms the 'Analyze' phase of the model. The results from the analysis can be used to conduct a brainstorming session and identify the root causes for the problems.

The analysis and brainstorming sessions could lead to a complete re-engineering of the process or modifications to the process. For example, if productivity is the highest reason causing delays, either the sizing of tasks could be faulty, or the trade workers do not perform well, or it could be that some unidentified constraint is restricting the trade to be more productive. A brainstorming session with the trade workers, suppliers, and superintendent could lead to the root causes for low productivity. Other statistical analysis, as explained in Chapters 3 and 4, could lead to various problem areas that can be identified and eliminated or reduced. This forms the 'Improve' phase of the model.

It is important to keep the whole process under control such that variations do not occur, and thus reduce defects in the process. Superintendents are well positioned to do this. Once, the whole process is under control, the superintendents should maintain the whole process of developing a doable weekly plan, measuring, analyzing, and improving. The superintendents in turn can be motivated by rewarding them with some kind of recognition on a regular basis for continuous improvement. Larger companies can create competitions between the superintendents by comparing the sigma value for each site.

### 4.6.4 Validation

A 'light' validation was conducted with the objective of getting inputs from homebuilding companies with respect to the applicability, adaptability, and completeness of the model. Personnel from two homebuilding companies validated the Production Planning Process Model developed in this thesis. The validation was done by an interview with the personnel from each of the two companies. The following section summarizes the result of the validation process.

Both the interviewees appreciated the layout of the model. According to them, the model could be readily applied and put into use with minor additions, rather than changes. Market sampling, and production absorption studies were recommended as an additional input to develop the specific template for each community. Sales being one of the foremost drivers of the whole process for most homebuilding companies, it would be a good idea to include the sales department in the process. The sales input could come at a stage before the specific schedule for each home or unit is developed. The various options provided by the companies to the customer is communicated through the sales department. Hence, 'Sales' should have inputs into the process at various levels, like the short term lookahead plan development phase. Both the interviewees were of the opinion that the sales personnel represent the buyer's viewpoint and thus it is a key to achieving an overall value.

The format proposed for data collection on site was well received due to it's ease of use and simplicity. The reason codes list could include few more reason for delays such as the sales change or customer's option changes. both interviewees are of the opinion that the model is ready to go on a general basis and then can be modified by different companies based on the company's organization. The practice of daily PPC and rolled PPC calculations is possible only if the format is simple and if it is not time consuming. On seeing the format developed by this research, the interviewees accepted that it is "as simple as it could get".

Neither of the companies does the Analyze, Improve, and Control phase of the process. But they are in agreement that this is a vital portion of the whole process and that it would "complete the circle". The brainstorming session suggested in the model could be incorporated in the weekly meetings. This is possible only if certain agenda or reason codes were to be tackled at a time. The model is considered to be a control tool and would thus help reduce the amount of resources spent on traditional "fire-fighting" approach.

The model seems to be complete in most terms, except to including inputs from the sales department for the planning process. The charts developed for the case study was shown to illustrate the use of the analyze phase in the model. Both the interviewee were of the opinion that if such tools were made available to the superintendent, it would ease the communications between the office management and the field personnel.

The validation process gives insightful comments on the applicability and adaptability of the production planning process model in homebuilding companies. The suggestions received in the interviews could be applied to the model and this process of improvement of the model should continue throughout the model's life.

## 4.7 Summary

This chapter describes the Six Sigma methodology and the Last Planner System. The above sections describe in detail the steps involved in the production planning process. Homebuilding companies can use the model developed and aim for continuous improvement. The Production Planning Process Model is presented and explained in detail. The validation interviews were summarized in this chapter. The next chapter will summarize the whole research report and present conclusions, contributions, and limitations of this research.

# Chapter 5

## Summary and Conclusion

## Summary and Conclusion

### 5.1 Overview of Report

Residential construction is booming and the projected growth of the industry calls for a more scientific approach to develop tools for production planning. As indicated in Chapter 1, residential construction companies in the United States are building homes with a manufacturing-like production or what is commonly known as production homebuilding. The goal of this research was to develop a tool for performance assessment of the production planning process in the homebuilding industry. Literature review in this area was available, but mostly for automobile and other industries. Literature for production planning in the construction industry was limited to general construction and there were no formal production planning tool for the residential construction sector.

Interviews were conducted with professionals from the homebuilding industry to understand the prevalent production planning process. Data collection was conducted to demonstrate the methodology developed in the research. The data collected was analyzed to find areas of improvement. A production planning process model for homebuilding industry was developed using the results of the research.

### 5.2 Research Goal and Objectives

The goal of this research was to assess the effectiveness of the production planning process in the residential construction industry. To attain this goal, the production planning process prevalent in the industry was documented by interviewing homebuilders and through site visits and observations. A framework for production planning performance assessment and identification of process improvement opportunities was also developed through a literature review and adaptation of tools and techniques used for measuring and analyzing production performance. The developed framework was implemented using data collected during field visits. Implementation results were analyzed to identify process improvement opportunities.

### 5.3 Contributions

***Process Maps***

This study contributed to the understanding of the prevalent practices for production planning in the homebuilding industry. Three different production planning processes were documented based on practices in companies of different sizes. This documentation will be a good resource for future studies in this area to understand the production planning process in homebuilding companies.

***Performance Assessment Tool***

Another outcome of this research is a tool for production planning performance assessment. An easy-to-use metric, *rolled* PPC, was developed for production planning performance assessment. The '*rolled* PPC' metric can be modified and tailored to measure performance of various other processes.

A format for data collection was developed and is shown in Figure F.1 (Appendix F). This format was developed for data collection and was modified with inputs from site. The format is simple and easy to use. Figure F.2 (Appendix F) shows a format for calculations of PPC and '*rolled* PPC'. This also includes categories of reasons that caused incomplete activities. These categories can be used as is, or can be modified to accommodate any factors that are not included or if it misrepresents the scenario on site for any homebuilding company.

The set of tools mentioned can be used for analyzing the data collected on site for a homebuilding company. These tools can be used separately or together to find areas needing improvement. These tools can be implemented and modified to adapt the specific needs of the company.

### *Production Planning Process Model*

A production planning model was developed in this research based on the knowledge assimilated through literature review, interviews, data collection, and data analysis. The Production Planning Model is shown in Figure 4.15 of this report and also presented in Appendix G for easier reference. This model accommodates the production planning performance assessment metric and the analysis tools.

This model focuses on continuous improvement. The process of Constraint Analysis included in the model can be improved based on the analysis conducted and this cycle has to be followed continuously to keep the production planning reliable and efficient. The model can thus be used to achieve a reliable production plan. This model can also be used for improving other processes in the company after specific modifications.

### *Synergies between Lean Construction and Six Sigma*

Six Sigma and Lean Construction are both powerful tools. Lean Construction seeks to achieve reliable workflow by eliminating inefficient work and Six Sigma focuses on reducing variability in a process using scientific methods to identify areas that are root causes for the variability. The combination of both tools can lead to a very useful methodology to improve any process. This integration was first suggested by Abdelhamid (2003). This research further developed the ideas in Abdelhamid (2003) by applying the power of both methods to the production planning process in residential construction. Both Lean Construction and Six Sigma were used in conjunction to develop the Production Planning Model. The aim was to develop a system that helps in identifying defects in a process, eliminating it and thus create a zero-defect process. Continuous improvement of the process is also important to keep the process in control and make it efficient.

**5.4 Research Limitations**

This research is focused on homebuilding companies. This is due to the lack of research conducted in the areas of production performance for homebuilding companies. Although the results can be useful for different industries, it is primarily suitable for the residential construction industry.

Interviews conducted for this research were limited to five homebuilding companies due to time and budget restraints. All of these companies were in the vicinity of Michigan State University, Lansing, MI. The small sample size in the research is consistent with the research goal, which was not to generalize any of the findings. Rather, the research was concerned with understanding the current production planning process prevalent in the homebuilding industry, developing a framework for assessing the performance of the production planning system, and identifying opportunities for improvements. There was no case study conducted to implement specific improvement opportunities to find root causes.

The following section presents some pointers that are the by-products of this research. It is an attempt to discuss some information gathered, or developed during the whole process of doing this research.

## 5.5 Discussions

This section presents information gathered by the author during the course of this research other than the conclusions. The author intends to share this knowledge accumulated.

### *Research Area*

The author started off this research process by doing literature review in the field of interest. Being a novice in the field of research, while reviewing various research work the author would very often be tempted to use a particular methodology or tool used to solve a problem and then look around for problems that could be solved using the particular method. Later on, with much needed guidance, the author learned to curb the temptation and followed the reverse by first setting a goal and then developing a list of objectives to achieve the goal. Literature review was in the specific area made it easier to find similar research and methodologies used to achieve similar goals. The author shared this knowledge with some of his fellow graduate students who were new to this experience too and they found it useful. Thus, the author intends to share this with new researchers reading this report.

### *Data Collection*

For the purpose of this research the author conducted interviews and site visits. The author interviewed two personnel each from five homebuilding companies, one from the home office and other from the field. This was done with a purpose to capture ideas from people involved at a macro level and at a micro level. The author feared a biased response from the interviewees either to project a good image of the company or due to the fear that upper management would see the report. To avoid a biased response, the author had to convince the interviewee about the purpose of the interview.

For data collection the author performed site visits over a period of time. During these site visits the author gathered information from the site superintendent. As the upper management directed this, the superintendent was under the impression that it was an audit and the reports would go back to the upper management. One way to tackle this problem was by making it clear that it was for a research the author was doing as part of his graduate program. The author spent time bringing the superintendent into confidence by encouraging informal discussions. Besides, the author had to verify the information given by the superintendent by visiting the work location where work was in progress or where it was planned. Talking to site crewmembers also helped to verify the information. The reasons for incomplete activities generally were explained more in detail by the crewmembers. The superintendent tried to hide his faults, if there was any, that lead to incomplete activities or work not performed as planned.

***Analysis***

The goal of this research was to develop a framework for assessment of effectiveness of production planning in residential construction. Hence data collected on site was mainly analyzed with the objectives in mind. The data could be analyzed in different ways to find other facts. One such output was the overall PPIC for different trades. As shown in Figure 4.13, the highest PPIC was for Inspection. Inspectors from the building department are generally contacted at various stages for inspecting the code compliances. The site superintendent generally schedules the inspector to arrive based on the progress of the particular trade before the inspection. Superintends are not confident of the production plan to an extent where he or she can schedule an exact date for the inspection much ahead of time. Thus, this is generally done on a short-term basis because the site superintendent would not want to arrange an inspection and cancel at the last minute because the job was not complete. This hampers the progress because generally on a short-term notice it is difficult to schedule an inspection, and as the inspection is necessary the trades cannot proceed until it is done and satisfied. If on the other hand the superintendent schedules an inspection and then have to cancel it, the inspector can be rescheduled only after a longer time. Sometimes, as a deadline is set before the inspection, the trade contractor might tend to ignore on quality to complete that portion of work before inspection. Thus, it is a difficult decision to make for the superintendent. If the production plan were more effective this would have been easier.

### 5.6 Research Conclusions

This study sheds light on the necessity of more research for the homebuilding industry. The study acknowledges the effort and work done by various researchers in this field, but the requirement of more research in production planning is addressed.

Interviews conducted reveal that companies generally perceive higher production yields than actual. This is due to the traditional approach of looking at productivity. As explained in this thesis, the rolled PPC and sigma level approach to assess production planning reliability captures the extra work required to complete previously incomplete work. The aim should be to reduce and eliminate the root causes leading to an incomplete activity. The process maps also supports the need for more a robust planning model in the homebuilding industry.

The site visited by the author for purpose of this research was functioning at a low sigma level and there was certainly a need for major improvement in the process. Identifying such problems early could save a lot of resources. The analysis revealed that task pre-requisites, coordination with suppliers, and overestimating productivity were major causes for unreliable production planning. For the site visited, Inspection, Carpentry, and Engineering trades caused the most incomplete activities.

### 5.7 Recommendations for Future Research

Research plays an important role in developing any field of study and related industries. The residential industry in the United States is growing at a very fast rate and this growth can be leveraged with proper research supporting it. It is very important for homebuilding companies to implement the right processes to attain the maximum returns for clients. Future research is necessary for the residential construction sector for developing processes that are efficient and reduce overall waste.

This research focused on the production planning process in residential construction. Future research can focus on different processes. Some areas that can be studied for future research in residential construction sector includes: Design Process, Pre-Construction Process, and Construction process. Generally, in residential construction, sale of homes controls the whole cycle of construction. Improvement in the sales process for residential companies can be an area of research that will be of interest to all homebuilding companies. In addition, customer satisfaction is a very important factor for popularity of homebuilders. The Warranty Process, which is a part of all homebuilding companies, could be another useful area for future research to improve process.

The '*rolled* PPC' metric used in this research can be further studied and analyzed. This metric can be modified and future research could include improvement of this metric for production planning process performance assessment. Future research could identify other processes and tailor the metric to suit the necessities of these processes. The metric can also be modified and tailored to be used in other sectors of the construction industry. Researching more areas that uses different metrics for measurement can develop new metrics for process performance assessment.

Research can be conducted to implement and improve the Production Planning Model developed in this study. New models can also be developed based on this model for other processes. This research has initiated a study to use Six Sigma and Lean Construction in the residential construction industry. Future research can adopt more tools from the Six Sigma Methodology and Lean Construction. The combination of the two methods promise to be a very powerful instrument in improving processes in the construction industry.

**5.8 Summary**

This chapter concluded the thesis by giving an overview of results, conclusions and recommendations. It also reported the limitations of the research. This chapter also includes future research areas that can be inspired by this study.

The importance of research to improve production planning process in residential construction was first described in the literature review and was re-emphasized in the interview responses. This thesis concludes by describing the contribution of the production planning process model as follows:

- Use of the Production Planning Model for a more reliable production plan

- Use of Six Sigma tools in Lean Construction Systems to obtain a powerful production planning process
- Use of '*rolled* PPC' metric for process performance assessment
- Possible improvement in the production planning process in homebuilding

**References**


Abdelhamid, T. S. (2003). *"Six Sigma in Lean Construction Systems: Opportunities and Challenges."* Proceedings IGLC-11, Aug. 2003, Blacksburg, Virginia.

Ahmed, S. M., Mitrani, J. D., Azhar, S., and Roldan, J. (2001). *"Development of a Risk Management Model for Florida Contractors and Subcontractors."* Department of Community Affairs, State of Florida.

Allen, E. (1999). " Fundamentals of Building Construction Materials and Methods." Wiley, New York, NY.

Allen, E., and Thallon, R. (2002). *"Fundamentals of Residential Construction."* Wiley, New York, NY.

Ballard, H. G. (2000). *"The Last Planner System of Production Control"* University of Birmingham.

Bashford, H. H., Sawhney, A., Walsh, K. D., and Kot, K. (2003a). *"Implications of even flow production methodology for U.S. housing industry."* Journal of Construction Engg. And Management May/June 2003.

Bashford, H. H., Walsh, K. D., and Sawhney, A. (2003b). *"Relationships between system loading and cycle time in a residential construction production system."* Proceedings of Construction Research Congress, March 2003.

Bassioni, H. A., Price, A. D. F., and Hassan T. M. (2004). *"Performance Measurement in Construction."* Journal of Management in Engineering, ASCE, April 2004.

Bernades, M. M. S., and Formoso, C. T. (2002). "Contributions to the evaluation of production planning and control systems in building companies." Proceedings IGLC-10, August 2002, Gramado, Brazil.

Breyfogle, F. W., Cupello, J. M., Meadows, B. (2001). "Managing Six Sigma: A practical Guide to understanding, Assessing and Implementing the strategy that yields bottom line success." Wiley, New York, NY.

Breyfogle, F. W. (1999). "Implementing Six Sigma: Smarter Solutions Using Statistical Methods." Wiley, New York, NY.

Chitla, V. R. (2003). "Performance assessment of planning process during manufactured housing production operations using Lean production principles." Michigan State University, E. Lansing, MI.

Cox R. F., Issa R. A., and Ahrens D. (2003). *"Managements Perception of Key Performance Indicators for Construction."* Journal of Construction Engineering Management, March/April 2003.

Evans, J. R., and Lindsay, W. M. (2001). *"The Management and Controls of Quality-Fifth Edition"* South-Western, Cincinnati, OH.

Goldratt, E. (1992). *"The Goal, 2nd Edition, Revised."* North River, Great Barrington, Mass.

Harris, B. B., Ioannou, P.G. (1998). *"Scheduling Projects with repeating activities."* Journal of Construction Engg. And Management July/Aug 1998.

Hinze, W. J. (1998). *"Construction Planning and Scheduling."* Prentice Hall Inc., NJ.

Hopp W., and Spearman, M. (1996). *"Factory Physics: Foundations of Manufacturing Management."* Irwin/McGraw Hill, Boston, 668 pp.

Howell, G., and Ballard, G. (1998). *"Implementing Lean Construction: Understanding and Action."* Proceedings IGLC '98, Guaruja, Brazil.

Koskela L. (1992). "Application of the New Production Philosophy to Construction." Tech. Report No. 72, CIFE, Stanford University, CA.

Koskela, L. (1999). *"Management of Production in Construction: A Theoretical View."* Proceedings of the 7th Annual Conference of the International Group for Lean Construction, University of California, Berkeley, CA. p. 241-252.

Koskela, L. (2000). "An exploration towards a production theory and its application to construction." Helsinki University of Technology, Finland.

Linderman, K., Shroeder, R. G., Zaheer, S., and Choo, A. S. (2003). *"Six Sigma: A Goal-theoretic Perspective."* Journal of Operations Management, Elsavier Science, 21,193-203.

Love, A. Thomas (1995). *"Scheduling Residential Construction."* Washington: Home Builder Press, WA.

NAHB (1993). *"Cycle-time reduction in the residential construction process."* National Association of Home Builders Research Center, June 4, 1993.

Pande, P. S., Neuman, R. P., and Cvanagh, R. R. (2000). "The Six Sigma Way: How GE, Motorola, and Other Top Companies are Honing their Performance." McGraw-Hill, New York, NY.

Patrick, C. (2004). *"Construction Project Planning and Scheduling."* Pearson Prentice Hall, Inc., NJ.

Peterson D. (1993). *"IS-464"*, Course Notes, Colorado State University, Fort Collins, CO.

Picard, H. E. (2002). *"Construction Process Measurement and Improvement."* Proceedings IGLC-10, Aug. 2002, Gramado, Brazil.

Seidel, A. W. (1999). "Production Planning Methodologies for Large Homebuilding Firms." Michigan State University, E. Lansing, MI.

Syal, M. (2003). *"BCM-823: Advanced Project Management."* Course Notes, Michigan State University, E. Lansing, MI.

Willenbrock, J. H., Manbeck, H. B., and Suchar, M. G. (1998). *"Residential Building design and Construction."* Prentice Hall Inc., NJ.

# Appendices

# Appendix A

# Interview Questionnaire

## INTERVIEW QUESTIONNAIRE

Interviewee's name, Position:
Number of years with the company:

**Background (demographics)**

- Company name, Location:
- Brief about the company:
- Number of subdivisions currently work undergoing:

**Company long term plans**

- Goal for the company in 5 years:
- Goal for the company this year:
- On what basis is the goal set?
- How do you predict the demand?
- Did the company fulfill demand/goal for the previous year?

**Subdivision plans**

- Name one subdivision you would like to discuss regarding planning:
- Goal for this subdivision:
- When do you start planning for one subdivision?
- When do you start planning for a single house?
- Do you have a schedule (representation) for a subdivision/single home?
- Who/which department is responsible for planning?

**Construction process**

- What work is done by the company and what work is subcontracted?
- On what basis is a supplier selected?
- On what basis is a subcontractor selected?
- How many subcontractors for one single task (eg: framing) in this subdivision?

**Planning process**

- What is the procedure for planning the activities for a single home?
- Who are involved while planning these activities?
- How are trades coordinated when working on multiple homes?
- How is the plan passed on to the members involved?
- What softwares are used?
- Who decides the day to day activities to be completed?
- What parameters are considered while assigning activities on daily basis?
- In general, what percentage of assigned work per day is completed as per plans?
- Do you have a format for recording planning performance?
- How is the plan changed in case of an incomplete assignment the previous day?

- Do you maintain records of day-to-day activities?
- Do you use these records for future planning?
- Are progress meetings conducted on a regular basis in this subdivision?
- What are the major causes of delays in this subdivision?
- If subcontractor's performance is the cause how do you handle it?
- If supplier delays are the cause how do you handle it?
- What time contingency is given in a plan for environmental delays?
- What time contingency is given in a plan for inspection and permit delays?
- What are the incentives of completing a house in time?

**Opinions**

- Have you worked in other homebuilding companies? (Yes/No)
- What was good/bad about other companies with regards to production planning process?
- What according to you is a good practice for planning in a homebuilding company like yours?

- What factors influence the planning process? (Also most critical and why?)

- Is it better to have a general plan for all homes or specific plans for each home?

- At this juncture, do you think innovation/research will help to improve the production planning process? What steps are your company taking?

# Appendix B

# Calculations for Sigma Quality Value

## Calculations for Sigma quality value

The sigma quality level for a process can be calculated using the following set of equations. For detailed discussions on these equations see Breyfogle (2002). These equations are essentially for a process using rolled throughput yield metrics. The modified equations used for this research using PPC value is shown thereafter.

**Sigma level calculations:**

- Firstly, the rolled throughput yield is calculated from the yields of different sub-processes as follows:

$$Y_{RT} = \prod_{i=1}^{m} Y_i$$

Where, $Y_{RT}$ = Rolled throughput yield

$Y_i$ = Yield of sub-process 'i'

- The rolled throughput yield is normalized by finding the geometric mean as follows:

$$Y_{norm} = \sqrt[m]{YRT}$$

- The normalized yield is then converted to Defects Per Unit (DPU) using the following equation:

$$DPU_{norm} = -\ln (Y_{norm})$$

- To determine the sigma quality level, also called as $Z_{benchmark}$, for the process, the following equation is used

Sigma quality level = $Z_{norm} + 1.5$

Where, $Z_{norm}$ is the standard normal value corresponding to the $DPU_{norm}$ found using the standard normal table.

**Modified calculations using PPC**

- Firstly, the rolled PPC is calculated from the PPCs of different sub-processes as follows:

$$rolled\ \text{PPC} = \prod_{i=1}^{m} \text{PPC}_i$$

- The rolled PPC is normalized by finding the geometric mean as follows:

$$\text{PPC}_{norm} = \sqrt[m]{\text{rolled PPC}}$$

- The normalized PPC is then converted to Defects Per Unit (DPU) using the following equation:

$$\text{DPU}_{norm} = -\ln(\text{PPC}_{norm})$$

- To determine the sigma quality level, also called as $Z_{benchmark}$, for the process, the following equation is used

$$\text{Sigma quality level} = Z_{norm} + 1.5$$

Where, $Z_{norm}$ is the standard normal value corresponding to the $\text{DPU}_{norm}$ found using the standard normal table.

# Appendix C

# Interview Summary Table

| | | ABC 11 | |
|---|---|---|---|
| # | **Questions** | XYZ 11 | XYZ 12 |
| 1 | Interviewee's name, Position | VP | VP construction |
| 2 | Number of years with the company | 7 yrs | 3.5 yrs |
| 3 | Company name, Location | ABC 11; Brighton, MI | ABC 11; Brighton, MI |
| 4 | Brief about the company | | |
| 5 | Number of subdivisions currently work undergoing | 4 subdivisions | 4 subdivisions |
| 6 | Goal for the company in 5 years | 50 homes | 40-60 homes |
| 7 | Goal for the company this year | 17 homes | 20 homes |
| 8 | On what basis is the goal set | Company's capacity, Market trends, demands | booked sales, anticipated demands |
| 9 | How do you predict the demand | Employment growth, competition | Combination of discussions with realtors and reiew of NAHB report |
| 10 | Did the company fulfill demand/goal for the previous year | Yes | Yes but not profitable |
| 11 | Name one subdivision you would like to discuss regarding planning | AM | AM |
| 12 | Goal for this subdivision | 9 homes | 9 homes |
| 13 | When do you start planning for one subdivision | 45-60 days prior to construction | Winter |
| 14 | When do you start planning for a single house | 30-45 days prior | Typically 2weeks - 1 month before permit submission |
| 15 | Do you have a schedule (representation) for a subdivision/single home | Yes | Yes |
| 16 | Who/which department is responsible for planning | Superintendant | Superintendant |
| 17 | What work is done by the company and what work is subcontracted | Most of the work is subcontracted | Most of the work is subcontracted |
| 18 | On what basis is a supplier selected | Price, service | Price, service, quality, relationship |
| 19 | On what basis is a subcontractor selected | Price, service | Price, service, quality, relationship |
| 20 | How many subcontractors for one single task (eg: framing) in this subdivision | 2 on an average | 2 for each trade. Framers 3-4 |

| | | ABC 11 | |
|---|---|---|---|
| # | **Questions** | XYZ 11 | XYZ 12 |
| 21 | What is the procedure for planning the activities for a single home | Fill spreadsheet for each home based on experience. Knowledge of subcontractors capability, predictability | Fill spreadsheet for each home based on experience. Knowledge of subcontractors capability, predictability |
| 22 | Who are involved while planning these activities | Superintendant | VPs and SubC |
| 23 | How are trades coordinated when working on multiple homes | Schedule a week in advance, give lead time to trade as required | Most of the homes are seperated for trades. Talking to subC. |
| 24 | How is the plan passed on to the members involved | Verbal | Schedule start dates are passed onto subCs personally. Daily inputs of progress from SubCs |
| 25 | What softwares are used | No | No |
| 26 | Who decides the day to day activities to be completed | Superintendant | 1/3 rd of the time VP, remaining subCs |
| 27 | What parameters are considered while assigning activities on daily basis | Space, interference | Succeeding trades space and coordination of other trades in the same home. |
| 28 | In general, what percentage of assigned work per day is completed as per plans | 75% | 75% |
| 29 | Do you have a format for recording planning performance | No | No |
| 30 | How is the plan changed in case of an incomplete assignment the previous day | Superintendant adjusts | Calls and adjustments make the subC aware of the delay. Buffer days help. |
| 31 | Do you maintain records of day-to-day activities | Yes | Yes |
| 32 | Do you use these records for future planning | No | No |
| 33 | Are progress meetings conducted on a regular basis in this subdivision | weekly | weekly |
| 34 | What are the major causes of delays in this subdivision | Trades not showing up. Weather | Weather, SubCs' commitments with other builders. Occasionaly material |

| # | Questions | ABC 11 | |
|---|---|---|---|
| | | XYZ 11 | XYZ 12 |
| 35 | If subcontractor's performance is the cause how do you handle it | Meetings with SubCs | Meeting with SubC. Give another chance if good quality of work. |
| 36 | If supplier delays are the cause how do you handle it | Change if bad and does not improve | Mostly supplier problems are for custom homes, so no repeats are expected. |
| 37 | What time contingency is given in a plan for environmental delays | 30 days of contingency built in overall | Critical activities like concreete walls and framing are given 2-4 days as buffer |
| 38 | What time contingency is given in a plan for inspection and permit delays | Included in the 30 days contingency | No. Final inspection 10 days before closing. |
| 39 | What are the incentives of completing a house in time | None | None |
| 40 | Have you worked in other homebuilding companies | Yes | No |
| 41 | What was good/bad about other companies with regards to production planning process | Bigger company: thus more detailed, incentives provided. Production based planning | N/A |
| 42 | What according to you is a good practice for planning in a homebuilding company like yours | Use schedules, updates on weekly basis. Plan ahead for subsequent weeks | Set milestones track progress according to milestones track performance. |
| 43 | What factors influence the planning process | for custom homes: scope of work, owners selections. | SubC performance is key. Home owenrs selection process. Accountabilty of home owner |
| 44 | Is it better to have a general plan for all homes or specific plans for each home | Specific | Specific . House by house |
| 45 | At this juncture, do you think innovation/research will help to improve the production planning process? What steps are your company taking | Refining the process, highlighting the best practices in the industry leading to continous improvement | Yes. Company does not follow a formal process of innovation. But it is an ongoing process discussed in meetings. |

| # | Questions | ABC 22 | |
|---|---|---|---|
| | | XYZ 21 | XYZ 22 |
| 1 | Interviewee's name, Position | Senior VP | Senior PM |
| 2 | Number of years with the company | 8 yrs | 10 yrs |
| 3 | Company name, Location | ABC 22; Novi, MI | ABC 22; Novi, MI |
| 4 | Brief about the company | | |
| 5 | Number of subdivisions currently work undergoing | 17 subdivisions | 12 subdivisions |
| 6 | Goal for the company in 5 years | 1000 homes (110-250 mill$) | |
| 7 | Goal for the company this year | 500 homes | 475 homes |
| 8 | On what basis is the goal set | Projects ready to go, sales, history | Developed lots, sales, prediction |
| 9 | How do you predict the demand | No. of households, employment growth, % homeownership, censex, competition | Marketing Dept |
| 10 | Did the company fulfill demand/goal for the previous year | Yes | Yes, over by 20 |
| 11 | Name one subdivision you would like to discuss regarding planning | JL | JL |
| 12 | Goal for this subdivision | 8-12 homes/month | 110 homes |
| 13 | When do you start planning for one subdivision | 3-6 mths | After site plan approval |
| 14 | When do you start planning for a single house | 2 mths | 2-3 weeks prior to construction |
| 15 | Do you have a schedule (representation) for a subdivision/single home | Yes | Yes |
| 16 | Who/which department is responsible for planning | Construction dept/centralised sched | Centralised scheduling |
| 17 | What work is done by the company and what work is subcontracted | Everything subcontracted | Everything subcontracted |
| 18 | On what basis is a supplier selected | Cost, warranty, meeting schedule, history, quality | Price, Quality of work |
| 19 | On what basis is a subcontractor selected | Cost, warranty, meeting schedule, history, quality | Price, Quality of work |
| 20 | How many subcontractors for one single task (eg: framing) in this subdivision | 1 usually | 1 subC (sometimes with multiple crews) |

| | | ABC 22 | |
|---|---|---|---|
| # | **Questions** | XYZ 21 | XYZ 22 |
| 21 | What is the procedure for planning the activities for a single home | Based on sales; template is used and modified as per site | Template on excel, put in the start date, prepares schedule,updates on a daily basis |
| 22 | Who are involved while planning these activities | Construction dept | VP, PM inputs from SubC |
| 23 | How are trades coordinated when working on multiple homes | Horizontal and vertical scheduling | Each trade linked between homes and scheduled |
| 24 | How is the plan passed on to the members involved | email | Printouts and fax |
| 25 | What softwares are used | MS Excel, Prodn Mgmnt System software | MS Excel |
| 26 | Who decides the day to day activities to be completed | PM | SubC |
| 27 | What parameters are considered while assigning activities on daily basis | Sales, Units sold, other activities | Successor activities |
| 28 | In general, what percentage of assigned work per day is completed as per plans | 95% delivery; 80% construction | 90% |
| 29 | Do you have a format for recording planning performance | Yes | Yes |
| 30 | How is the plan changed in case of an incomplete assignment the previous day | Update, make up on weekends | Work around it, work on weekends, else adjust update and inform central |
| 31 | Do you maintain records of day-to-day activities | Yes | Yes |
| 32 | Do you use these records for future planning | Yes | Yes |
| 33 | Are progress meetings conducted on a regular basis in this subdivision | 2 weeks | 2 weeks |
| 34 | What are the major causes of delays in this subdivision | House not sold as planned, weather | Weather |

| # | Questions | ABC 22 | |
|---|---|---|---|
| | | XYZ 21 | XYZ 22 |
| 35 | If subcontractor's performance is the cause how do you handle it | Depends on past relation, verbal. | Depends case by case. Replace if bad |
| 36 | If supplier delays are the cause how do you handle it | Email supplier a performance report every quarter | Depends case by case. Replace if bad |
| 37 | What time contingency is given in a plan for environmental delays | None in main template. Could add in schedule after carpenter's activity | None |
| 38 | What time contingency is given in a plan for inspection and permit delays | For final inspection and after drywall activity | I month for 1st building permit. 1 week after final inspection for occupancy |
| 39 | What are the incentives of completing a house in time | None | None |
| 40 | Have you worked in other homebuilding companies | No | Yes. 3 |
| 41 | What was good/bad about other companies with regards to production planning process | N/A | 2 of them unorganized and way behind. One in Las Vegas was better but had a fixed production plan and it worked because of less weathe interference |
| 42 | What according to you is a good practice for planning in a homebuilding company like yours | Even flow schedule, Centralized scheduling, Mgmnt reports showing trends & progress; communicating all this info amongst key players | Live the schedule throuhgout the each day. Use palm pilots to update include all departments. Communicate with SubC. |
| 43 | What factors influence the planning process | External govnmt agencies, Demand and sales, supplier problems | Performance of trade contractors, weather, superintendant, other depts, inspector (all equal) |
| 44 | Is it better to have a general plan for all homes or specific plans for each home | Specific plan | Specific plans developed from a common template |
| 45 | At this juncture, do you think innovation/research will help to improve the production planning process? What steps are your company taking | More technology, internet, relationship building with trades | Yes. Computers, technology, one person in the company part time dedicated to such development |

| | | ABC 33 | |
|---|---|---|---|
| # | **Questions** | XYZ 31 | XYZ 32 |
| 1 | Interviewee's name, Position | General Manager of Finance and Administration | Project manager |
| 2 | Number of years with the company | 27 yrs | 3 years |
| 3 | Company name, Location | ABC 33; Bloomfield Hills, MI | ABC 33; Bloomfield Hills, MI |
| 4 | Brief about the company | | |
| 5 | Number of subdivisions currently work undergoing | 6 subdivisions | 3 (under PM); 6 (Overall for company) |
| 6 | Goal for the company in 5 years | 110 mill $ | $ 125 mill |
| 7 | Goal for the company this year | 235 homes (76 mill $) | 185 homes |
| 8 | On what basis is the goal set | Staffing; (mill$ / employee) | Sales; Staff support available |
| 9 | How do you predict the demand | History, Competitive survey; site visits | Sales pace/ customer traffic; previous years record |
| 10 | Did the company fulfill demand/goal for the previous year | NO, Job growth in area was negative | Sales was below the goal; production budget was above |
| 11 | Name one subdivision you would like to discuss regarding planning | RC | RC |
| 12 | Goal for this subdivision | 26 homes | 25 units |
| 13 | When do you start planning for one subdivision | 6 months before construction in the project start meeting | 1 month prior to first home to be built |
| 14 | When do you start planning for a single house | 1 month before construction | 3 to 4 weeks before construction |
| 15 | Do you have a schedule (representation) for a subdivision/single home | Yes | Yes |
| 16 | Who/which department is responsible for planning | Superintendent on site | Production Department |
| 17 | What work is done by the company and what work is subcontracted | Everything subcontracted except Quality Control | Everything subcontracted except Quality Control |
| 18 | On what basis is a supplier selected | Price, supplying capacity, Past relation | Price; Service quality, Workload capacity |
| 19 | On what basis is a subcontractor selected | Price, Production capacity, Past relation | Price; Service quality, Workload capacity |
| 20 | How many subcontractors for one single task (eg: framing) in this subdivision | 1 subC | Framing more than 1; 1 for others |

| # | Questions | ABC 33 | |
|---|---|---|---|
| | | XYZ 31 | XYZ 32 |
| 21 | What is the procedure for planning the activities for a single home | Template from software is cloned; start date is input; Adfjustments based on subdivision; Weekly updated | A new template built based on similar past projects, 1 template for each type of homes, fax out schedules, weekly update |
| 22 | Who are involved while planning these activities | Superintendent (PM oversees) | Inputs from Superintendent is used by PM to plan. GM approves |
| 23 | How are trades coordinated when working on multiple homes | Each trade contractor is faxed is/her schedule | The software produces schedule which takes care of coordination between units for a Sub C |
| 24 | How is the plan passed on to the members involved | Fax schedule | Fax the schedule |
| 25 | What softwares are used | Build-Software Enterprise / MS Access | Builder Works Software |
| 26 | Who decides the day to day activities to be completed | Superintendent | Superintendent based on Schedule |
| 27 | What parameters are considered while assigning activities on daily basis | Delays of predecessors; Weather conditions | Space; Critical path |
| 28 | In general, what percentage of assigned work per day is completed as per plans | 95% | 80-90% |
| 29 | Do you have a format for recording planning performance | NO | NO |
| 30 | How is the plan changed in case of an incomplete assignment the previous day | Weekly updates reflect changes; Super on site would take care | Superintendent notifies the succesor trade by fax or telephone |
| 31 | Do you maintain records of day-to-day activities | No | Daily logs are prepared |
| 32 | Do you use these records for future planning | N/A | No; schedule templates for new subdivisions are built based on past schedule |
| 33 | Are progress meetings conducted on a regular basis in this subdivision | PM/Super (weekly); All trade/Pm/Super (2 months) | once a week |
| 34 | What are the major causes of delays in this subdivision | Weather | Sales; Weather |

| # | Questions | ABC 33 | |
|---|---|---|---|
| | | XYZ 31 | XYZ 32 |
| 35 | If subcontractor's performance is the cause how do you handle it | Use of spreadsheet for ranking trades; 3 chances | Quarterly Rating (color coding) |
| 36 | If supplier delays are the cause how do you handle it | Use of spreadsheet for ranking trades; 3 chances | Color coding dictates the method to handle. (Blue: On site; Yellow: Purchase Mgr handles; Red: Fired) |
| 37 | What time contingency is given in a plan for environmental delays | None | Typically none |
| 38 | What time contingency is given in a plan for inspection and permit delays | Depends on subdivisions. | Differs from subdivision to subdivision |
| 39 | What are the incentives of completing a house in time | None | None |
| 40 | Have you worked in other homebuilding companies | Yes | Yes |
| 41 | What was good/bad about other companies with regards to production planning process | Time based schedules; faster the better (bad practice) | Lack of consistency; NO Training |
| 42 | What according to you is a good practice for planning in a homebuilding company like yours | Hiring the right person; using the best system | Understand the product/customer;Understanding expectations and time involved; |
| 43 | What factors influence the planning process | Human Communication; Pre-start meeting amongst all key players | Money to be generated; Sale progress |
| 44 | Is it better to have a general plan for all homes or specific plans for each home | Ideal to use from a template and change case to case | General plans |
| 45 | At this juncture, do you think innovation/research will help to improve the production planning process? What steps are your company taking | Yes. Research should involve Human behaviour. Use of softwares. Company working on integrating different aspects. | Yes. Quality Control; Computers; Database systems; Human Factor; Panelized Construction |

| | | ABC 44 | |
|---|---|---|---|
| # | **Questions** | XYZ 41 | XYZ 42 |
| 1 | Interviewee's name, Position | VP of Construction & Purchasing | Project Manager |
| 2 | Number of years with the company | 8 years | 3 years |
| 3 | Company name, Location | ABC 44; Lansing, MI | ABC 44; Lansing, MI |
| 4 | Brief about the company | | |
| 5 | Number of subdivisions currently work undergoing | 10 subdivisions | 10 subdivisions |
| 6 | Goal for the company in 5 years | 4500 units | 700 units/ year |
| 7 | Goal for the company this year | 400 units | 400 units |
| 8 | On what basis is the goal set | Past exp; Future Planning | Sales/ Historic Data |
| 9 | How do you predict the demand | Number of developments approved | Number of permits/ Market Data |
| 10 | Did the company fulfill demand/goal for the previous year | Yes | Yes |
| 11 | Name one subdivision you would like to discuss regarding planning | TE | TE |
| 12 | Goal for this subdivision | 144 units | 144 units |
| 13 | When do you start planning for one subdivision | 2-3 months prior to construction | Site development |
| 14 | When do you start planning for a single house | 2-3 months prior to construction | Once permits are acquired |
| 15 | Do you have a schedule (representation) for a subdivision/single home | Yes | Yes |
| 16 | Who/which department is responsible for planning | Construction | Construction and Planning |
| 17 | What work is done by the company and what work is subcontracted | All Trades | All Trades |
| 18 | On what basis is a supplier selected | References/ Pricing/ Quality | Price and Service |
| 19 | On what basis is a subcontractor selected | References/ Pricing/ Quality | Price and Service |
| 20 | How many subcontractors for one single task (eg: framing) in this subdivision | One per trade | Mostly 1 per trade |

| | | ABC 44 | |
|---|---|---|---|
| # | **Questions** | XYZ 41 | XYZ 42 |
| 21 | What is the procedure for planning the activities for a single home | Schedule of work from trades. Compile and organize. Sequence the trades as per logic. | Trades submit their respective schedule and then it is compiled and sequenced |
| 22 | Who are involved while planning these activities | PM; Superintendent and trades | PM; Superintendent and trades |
| 23 | How are trades coordinated when working on multiple homes | Working it out with trades, Discussions and meetings | The successor trades are notified when they are scheduled via fax or phone |
| 24 | How is the plan passed on to the members involved | Distribute in progress meetings (bi-weekly) | Schedules are distributed among subcontractors |
| 25 | What softwares are used | MS Project | MS Project |
| 26 | Who decides the day to day activities to be completed | Superintendent | Superintendent |
| 27 | What parameters are considered while assigning activities on daily basis | Activities based on schedule, Predecessor activities, Material, weather, and inspection | materials, Schedule, Availability |
| 28 | In general, what percentage of assigned work per day is completed as per plans | 90% | 90% |
| 29 | Do you have a format for recording planning performance | Updates every other week | No |
| 30 | How is the plan changed in case of an incomplete assignment the previous day | Adjustments done in field | Successor trades are notified if work is not available for them |
| 31 | Do you maintain records of day-to-day activities | Yes | Yes. Daily Reports |
| 32 | Do you use these records for future planning | No | No |
| 33 | Are progress meetings conducted on a regular basis in this subdivision | Weekly | Weekly |
| 34 | What are the major causes of delays in this subdivision | Weather. Lack of Communication. Improper Planning | Weather, Materials arrive late, subcontractors delays |

| | | ABC 44 | |
|---|---|---|---|
| # | **Questions** | XYZ 41 | XYZ 42 |
| 35 | If subcontractor's performance is the cause how do you handle it | Notice to perform is issued. If problem persists, removed and replaced | Notice to perform is issued |
| 36 | If supplier delays are the cause how do you handle it | Same | Supplier is notified and then changed if they continue the same |
| 37 | What time contingency is given in a plan for environmental delays | None | None |
| 38 | What time contingency is given in a plan for inspection and permit delays | A float is given to the critical path. It depdends from township to township | A lag is built in |
| 39 | What are the incentives of completing a house in time | Bonus | Bonus, more responsibilities |
| 40 | Have you worked in other homebuilding companies | Yes | Yes |
| 41 | What was good/bad about other companies with regards to production planning process | Less thought and organization to production planning. No trade involvement in planning | Less coordination between various members involved |
| 42 | What according to you is a good practice for planning in a homebuilding company like yours | Trade Involvement, monitoring and updating | Involvement of all members who play a part in construction. Reflceting back to find inadequacies. |
| 43 | What factors influence the planning process | Communications and organization | Weather, trade productivity |
| 44 | Is it better to have a general plan for all homes or specific plans for each home | A combination. A general plan should be used to develop a specific plan | Specific Plan |
| 45 | At this juncture, do you think innovation/research will help to improve the production planning process? What steps are your company taking | Yes. More research is necessary. Softwares should be explored to find a best fit for the industry. More techniques to tie up all players involved in the field. | Yes. More softwares should be used to make it easy for planning. |

| # | Questions | ABC 55<br>XYZ 51 | XYZ 52 |
|---|---|---|---|
| 1 | Interviewee's name, Position | Purchasing Manager | Superintendent |
| 2 | Number of years with the company | 2 years | 2 years |
| 3 | Company name, Location | ABC 55; Troy, MI | ABC 55; Troy, MI |
| 4 | Brief about the company | | |
| 5 | Number of subdivisions currently work undergoing | 32 Subdivisions | 32 Subdivisions |
| 6 | Goal for the company in 5 years | 1500 units/year | 1400-1500 units/year |
| 7 | Goal for the company this year | 800 units | 800 units |
| 8 | On what basis is the goal set | Production Rate/ Sales | Sales/ Last Year Forecast |
| 9 | How do you predict the demand | Market Sampling/ Product Absorption | History/ Sales Previous Year/ Market growth |
| 10 | Did the company fulfill demand/goal for the previous year | Exceeded by 44 Units | Exceeded demand/goal |
| 11 | Name one subdivision you would like to discuss regarding planning | CP | CP |
| 12 | Goal for this subdivision | 48 units | 10 for this year |
| 13 | When do you start planning for one subdivision | During Land Acquisition | During Land Planning |
| 14 | When do you start planning for a single house | Post Paving/ Permit for Model | When field work is done |
| 15 | Do you have a schedule (representation) for a subdivision/single home | No | Yes |
| 16 | Who/which department is responsible for planning | Purchaing Manager/ Purchasing department/ Sales | Purchasing with inputs from field and advice from Division Manager |
| 17 | What work is done by the company and what work is subcontracted | Everything is subcontracted | Everything is subcontracted |
| 18 | On what basis is a supplier selected | Reasonable Vendor/ Track Record | Past Records/ Supply & Demand |
| 19 | On what basis is a subcontractor selected | Prequalifications; Reasonable Vendor | Price and Quality of Work |
| 20 | How many subcontractors for one single task (eg: framing) in this subdivision | Mostly one | Generally 2 Framing subcontractors, else only one |

| # | Questions | ABC 55<br>XYZ 51 | <br>XYZ 52 |
|---|---|---|---|
| 21 | What is the procedure for planning the activities for a single home | Once Permits are acquired Field takes over | After permits are acquired, Foundation and Framing is scheduled, the rest follows |
| 22 | Who are involved while planning these activities | Purchasing Manager, Site Superintendent | Superintendent |
| 23 | How are trades coordinated when working on multiple homes | Fax | Fax and follow-up Phone calls |
| 24 | How is the plan passed on to the members involved | Email and Fax | Email and Fax |
| 25 | What softwares are used | MS Excel | MS Excel |
| 26 | Who decides the day to day activities to be completed | Superintendent | Superintendent |
| 27 | What parameters are considered while assigning activities on daily basis | Field Superintendent decides based on progress | Material Availabilty, Weather, and Trade |
| 28 | In general, what percentage of assigned work per day is completed as per plans | Should be 100% | Close to 100% |
| 29 | Do you have a format for recording planning performance | Superintendent records | In an Excel spreadsheet |
| 30 | How is the plan changed in case of an incomplete assignment the previous day | Lag times built in to cover delays | Schedule has lag times built in and also work on weekends if needed |
| 31 | Do you maintain records of day-to-day activities | Yes | Yes- Daily reports |
| 32 | Do you use these records for future planning | Yes | Yes |
| 33 | Are progress meetings conducted on a regular basis in this subdivision | Weekly | Weekly |
| 34 | What are the major causes of delays in this subdivision | Weather | Weather/ Water Table in few lots |

| | | ABC 55 | |
|---|---|---|---|
| # | **Questions** | XYZ 51 | XYZ 52 |
| 35 | If subcontractor's performance is the cause how do you handle it | We Issue a non-performance notice | Warning is given, then a non-performance notice is issued |
| 36 | If supplier delays are the cause how do you handle it | Non- Performance Notice | Non- Performance Notice |
| 37 | What time contingency is given in a plan for environmental delays | 2 weeks | Lag of atleast couple of weeks is built in |
| 38 | What time contingency is given in a plan for inspection and permit delays | Schedule starts based on permits, so no contingency | None |
| 39 | What are the incentives of completing a house in time | Bonus | Bonus for superintendent |
| 40 | Have you worked in other homebuilding companies | No | Yes |
| 41 | What was good/bad about other companies with regards to production planning process | N/A | The firm decides plan based on sales. Plans should be developed based on production, else capacity should be increased if sales increase |
| 42 | What according to you is a good practice for planning in a homebuilding company like yours | Organization Skills; Priorotize activities | Team Management; Attention to details |
| 43 | What factors influence the planning process | Framing/ Mechanical | Permits/ Weather/ Framing trade |
| 44 | Is it better to have a general plan for all homes or specific plans for each home | General Plan | Site specific |
| 45 | At this juncture, do you think innovation/research will help to improve the production planning process? What steps are your company taking | Yes. Assessing ways to improve production by incorporating/ partnering with trades. Looking towards incorporating 'Lean & JIT' ideology to reduce waste; reliable production techniques | Teaming with reliable trades to complete process on time and within budget |

## Appendix D

## Data Collection Summary Table

**Building I**

| | 15-Mar | 16-Mar | 17-Mar | 18-Mar | 19-Mar |
|---|---|---|---|---|---|
| Activities planned | Drywall Stocking | Drywall Stocking | Drywall 2 units | Fire protection | Truss repair |
| | | Inspection | Inspection | Hvac Repair | Fire caulking |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | All Completed | Inspection Incomplete | Drywalling not started | All Completed | Truss repair incomplete |
| | | (Inspector didn't turn up) | (Pre drywalling approval not granted) | | (engineering of truss required) |
| | | | | | |
| | | | Inspector approval not obtained | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Building I**

| | 22-Mar | 23-Mar | 24-Mar | 25-Mar | 26-Mar |
|---|---|---|---|---|---|
| Activities planned | Engineering of truss | Truss repair | Insulation | Hanging Drywall unit 1 | Hanging Drywall unit 3 |
| | Truss repair | Inspection | Drywall unit 1 | Hanging Drywall unit 2 | Hanging Drywall unit 4 |
| | Inspection | Insulation | Drywall unit 2 | | |
| | | | | | |
| Incomplete activities and reasons | Truss repair completed but | All complete with approval | Insulation not complete | All Complete | Less Productivity |
| | not approved by inspector | | | | |
| | | | | | |
| | Inspector approval not obtained | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Building I**

| | 29-Mar | 30-Mar | 31-Mar | 1-Apr | 2-Apr |
|---|---|---|---|---|---|
| Activities planned | Hanging Drywall unit 4 | Hanging Drywall unit 7 | Hanging Drywall unit 9 | Hanging Drywall unit 11 | Arrange for heating |
| | Hanging Drywall unit 5 | Hanging Drywall unit 8 | Hanging Drywall unit 10 | Hanging Drywall unit 12 | |
| | Hanging Drywall unit 6 | | Taping 1 | Arrange for heating | |
| | | | | | |
| Incomplete activities and reasons | All Complete | All Complete | Heating not arranged for | Supplier brought in wrong | Supplier didn't respond |
| | | | | equipment | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Building I**

| | 5-Apr | 6-Apr | 7-Apr | 8-Apr | 9-Apr |
|---|---|---|---|---|---|
| Activities planned | Arrange for heating | Arrange for temporary heating | Taping all joints and angles 6 units | Taping all joints/angles 6 units | Taping all joints/angles 6 units |
| | Material stocking for finishing activity | | | | |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | | All Complete | All Complete | Heating not available (hooked up | Heating not available (hooked up |
| | Supplier didn't get the right equipmnt | | | in the first 6 units) | in the first 6 units) |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Building I**

| | 12-Apr | 13-Apr | 14-Apr | 15-Apr | 16-Apr |
|---|---|---|---|---|---|
| Activities planned | Arrange for more heating | 1st coat finishing 6 units | 1st coat finishing 6 units | 2nd coat finsihing all | Sanding |
| | Taping all joints and angles 6 units | | | Sanding | |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | All Complete | All Complete | All Complete | Not dried enough due to lack | All Complete |
| | | | | of proper heating | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Building I**

| | 19-Apr | 20-Apr | 21-Apr | 22-Apr | 23-Apr |
|---|---|---|---|---|---|
| Activities planned | Painting Primer coat 4 units | Painting Primer coat 4 units | Painting Primer coat 4 units | Vinyl Floor | Trim Carpentry 1&1/2 units |
| | | | | | Vinyl Floor |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | All Complete | All Complete | All Complete | Had to fix some stuff before | All Complete |
| | | | | start | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Building I**

| | 26-Apr | 27-Apr | 28-Apr | 29-Apr | 30-Apr |
|---|---|---|---|---|---|
| Activities planned | Trim Carpentry 1&1/2 units | Trim Carpentry 1&1/2 units | Trim Carpentry 1&1/2 units | Trim Carpentry 1&1/2 units | Trim Carpentry 1&1/2 units |
| | Stock Doors and cabinets | Fix doors and cabinets | Stock the right kind of doors | Stock the right kind of doors | Stock the right kind of doors |
| | | Trim additional 1 unit Carpentry | Trim additional 1 unit Carpentry | Trim additional 1 unit Carpentry | Final coat paint |
| | | | | | |
| Incomplete activities and reasons | All Complete | Wrong doors and cabinets | Supplier didn't respond | Supplier didn't respond | Supplier didn't respond |
| | Stocked but not the right ones | | | | |
| | | | | | |
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**Building I**

| | 3-May | 4-May | 5-May | 6-May | 7-May |
|---|---|---|---|---|---|
| Activities planned | Doors in place | Carpentry 4 units | Carpentry 4 units | Carpentry | Carpentry |
| | Trim carpentry 4 units | caulking 4 units | caulking 4 units | | |
| | finish paint | | | | |
| | caulking 4 units | | | | |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | Will get it only by Thursday | All Complete | All Complete | All Complete | All Complete |
| | | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |

**Building I**

| | 10-May | 11-May | 12-May | 13-May | 14-May |
|---|---|---|---|---|---|
| Activities planned | Punchlisting | Drywall repair | Drywall repair | Stock Doors | Install doors in 3 units |
| | | | Stock Counter tops and cabinets | Install doors in 3 units | Install Countertops |
| | | | | Install Countertops | |
| | | | | | |
| Incomplete activities and reasons | All Complete | All Complete | All Complete | Stocking most of the day | Less manpower |
| | | | | time enough to install 1 unit | Installed in only one unit |
| | | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |

**Building I**

| | 17-May | 18-May | 19-May | 20-May | 21-May |
|---|---|---|---|---|---|
| Activities planned | Install doors in 3 units | Install doors in 2 units | Install doors in 2 units | Install doors in 2 units | Install doors in 2 units |
| | Install Countertops | Install Countertops | Install Countertops | Install Countertops | Install Countertops |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | Less manpower | All Complete | Supplier didn't supply right type | Supplier didn't supply right type | All Complete |
| | Installed in only two unit | | | | |
| | | | | | |
| | | | | | |
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| | | | | | |
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**Building I**

| | 24-May | 25-May | 26-May | 27-May | 28-May |
|---|---|---|---|---|---|
| Activities planned | Install doors in 3 units | Install doors in 2 units | Plumbing | Plumbing 3 | Plumbing 3 |
| | Install Countertops | Install Countertops | HVAC | HVAC 3 | HVAC 3 |
| | | | Electrical | Electrical 3 | Electrical 3 |
| | | | | Install doors in 2 units | |
| Incomplete activities and reasons | all around the building completing | Less manpower | Previous work: paint | Design problem | Manpower elec |
| | small jobs | | | Manpower elec | |
| | | | | | |
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**Building II**

| | 15-Mar | 16-Mar | 17-Mar | 18-Mar | 19-Mar |
|---|---|---|---|---|---|
| Activities planned | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | | | | | |
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|---|---|---|---|---|---|
| Activities planned | | | | | |
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| | | | | | |
| Incomplete activities and reasons | | | | | |
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**Building II**

| | 29-Mar | 30-Mar | 31-Mar | 1-Apr | 2-Apr |
|---|---|---|---|---|---|
| Activities planned | Inspection (Ext Wall) | Insulation Ext Walls | Building Inspection | Truss Repair | Truss Repair |
| | Truss Engineering | HVAC inspection full | Insulation Ext Wall | Building Inspection | Building Inspection |
| | HVAC inspection (exterior) | Truss Repair | Truss Repair | Insulation Interior | |
| | | Create B-Vent | B vent | Drywall Stocking | |
| Incomplete activities and reasons | All Completed | Truss incomplete for the need of | Building Inspection not possible | Truss repair completed with fault | Inspection 1st floor approved |
| | | some more clarification with | without truss repairs | have to be redone | 2nd floor not approved |
| | | engineering | | Inspector No Show | |
| | | | Truss Repair needs engineering | | |
| | | Create B vent incomplete as more | | Insulation could not proceed without | |
| | | than a days work | | inspection | |
| | | | | | |

**Building II**

| | 5-Apr | 6-Apr | 7-Apr | 8-Apr | 9-Apr |
|---|---|---|---|---|---|
| Activities planned | Truss Bracing | Building Inspection | Insulation Interior | Hanging Drywall unit 1 | Hanging Drywall unit 3 |
| | Building Inspection | Insulation Interior | Building Inspection | Hanging Drywall unit 2 | Hanging Drywall unit 4 |
| | Insulation Interior | Drywall Stocking | Hanging Drywall unit 1 | | |
| | Drywall Stocking | | | | |
| Incomplete activities and reasons | Inspector No Show | Inspector No Show | Hanging drywall didn't start because | All Complete | Slow Job; Crew left early |
| | | | inspection happened only in the evening | | |
| | Supplier didn't respond | slow productivty | | | |
| | | | | | |
| | | | | | |
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| | | | | | |

**Building II**

| | 12-Apr | 13-Apr | 14-Apr | 15-Apr | 16-Apr |
|---|---|---|---|---|---|
| Activities planned | Hanging Drywall unit 4 | Hanging Drywall unit 6 | Hanging Drywall unit 8 | Hanging Drywall unit 10 | Hanging Drywall unit 12 |
| | Hanging Drywall unit 5 | Hanging Drywall unit 7 | Hanging Drywall unit 9 | Hanging Drywall unit 11 | Taping 1 |
| | Hanging Drywall unit 6 | | Taping 1 | Hanging Drywall unit 12 | |
| | | | | | |
| Incomplete activities and reasons | Couldn't complete all three activities | All Complete | Resources tied up in Bldg 1 | Couldn't complete all three activities | Resources tied up in Bldg 1 |
| | in one day | | | in one day | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Building II**

| | 19-Apr | 20-Apr | 21-Apr | 22-Apr | 23-Apr |
|---|---|---|---|---|---|
| Activities planned | Material Stocking for finishing | Taping all joints and angles 6 units | Taping all joints and angles 6 units | 1st coat finishing 6 units | 1st coat finishing 6 units |
| | Arrange Heating | | | | |
| | Taping all joints and angles 6 units | | | | |
| | | | | | |
| Incomplete activities and reasons | Final touch ups for drywall required | All Complete | All Complete | All Complete | All Complete |
| | | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |

**Building II**

| | 26-Apr | 27-Apr | 28-Apr | 29-Apr | 30-Apr |
|---|---|---|---|---|---|
| Activities planned | 2nd Coat Finishing all | Sanding | Sanding | | |
| | Sanding | Touch up Coat | | | |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | All Complete | All Complete | All Complete | | |
| | | | | | |
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| | | | | | |

**Building II**

| | 3-May | 4-May | 5-May | 6-May | 7-May |
|---|---|---|---|---|---|
| Activities planned | Painting Primer coat 4 units | Painting Primer coat 5 units | Painting Primer coat 2 units | Vinyl Flooring 6 units | touch up with paint |
| | | | Vinyl Flooring 6 units | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | All complete and one more | All Complete | All Complete | All Complete | All Complete |
| | | | | | |
| | | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |

**Building II**

| | 10-May | 11-May | 12-May | 13-May | 14-May |
|---|---|---|---|---|---|
| Activities planned | Punch listing | Drywall Repairs | Stock Carpentry material | Stock Doors | Drywall Repairs |
| | drywall repairs | | Stock Cabinets | Carpentry 1.5 units/day | |
| | | | | | |
| | | | | | |
| Incomplete activities and reasons | All Complete | All Complete | All Complete | More drywall repairs to be done | More drywall to be finished |
| | (drywall is rework because of leaks) | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

**Building II**

| | 17-May | 18-May | 19-May | 20-May | 21-May |
|---|---|---|---|---|---|
| Activities planned | Drywall repair | Drywall repair | Stock countertop | Drywall repair | Drywall repair |
| | Taping earlier drywall repair | Taping earlier drywall repair | Drywall repair | Taping earlier drywall repair | Taping earlier drywall repair |
| | | Finishing Earlier work | Taping earlier drywall repair | Finishing Earlier work | Finishing Earlier work |
| | | | Finishing Earlier work | | |
| Incomplete activities and reasons | All Complete | All Complete | All Complete | All Complete | All Complete |
| | | | | | |
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| | | | | | |
| | | | | | |

**Building II**

| | 24-May | 25-May | 26-May | 27-May | 28-May |
|---|---|---|---|---|---|
| Activities planned | Taping earlier drywall repair | Finishing Earlier work | Taping earlier drywall repair | Finishing Earlier work | Carpentry 2 units |
| | Finishing Earlier work | More drywall repairs | Finishing Earlier work | | |
| | Drywall repairs | | | | |
| | | | | | |
| Incomplete activities and reasons | More leak and thus more repairs | More leak and thus more repairs | All Complete | All Complete | Less manpower |
| | | | | | |
| | | | | | |
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# Appendix E

# PPC Calculations and Reason Codes

**Building I**

| | 15-Mar | 16-Mar | 17-Mar | 18-Mar | 19-Mar | PPC | | 22-Mar | 23-Mar | 24-Mar | 25-Mar | 26-Mar | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 1 | 2 | 2 | 2 | 2 | rolled | Weekly | 3 | 3 | 3 | 2 | 2 | rolled | Weekly |
| **Tasks Completed** | 1 | 1 | 0 | 2 | 1 | | | 1 | 3 | 1 | 2 | 1 | | |
| **PPC (%)** | 100 | 50 | 0 | 100 | 50 | 0.00 | 0.56 | 33.33 | 100 | 33.33 | 100 | 50 | 0.06 | 0.62 |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | | | | | | | | | 1 | | |
| **Engineering** | | | | | 1 | | | | | | | | | |
| **Non Confirmance** | | | 1 | | | | | 2 | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | 1 | | | | | | | 2 | | | | |
| **No show** | | 1 | | | | | | | | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | | | | | | | | | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

| | 29-Mar | 30-Mar | 31-Mar | 1-Apr | 2-Apr | PPC | | 5-Apr | 6-Apr | 7-Apr | 8-Apr | 9-Apr | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 3 | 2 | 3 | 3 | 1 | rolled | Weekly | 2 | 1 | 1 | 1 | 1 | rolled | Weekly |
| **Tasks Completed** | 3 | 2 | 2 | 2 | 0 | | | 1 | 1 | 1 | 0 | 0 | | |
| **PPC (%)** | 100 | 100 | 66.66 | 66.66 | 0 | 0.00 | 0.75 | 50 | 100 | 100 | 0 | 0 | 0.00 | 0.50 |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | | | | | | | | | | | |
| **Engineering** | | | | | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | 1 | | | | | | | | 1 | 1 | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | | | | 1 | 1 | | | 1 | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

**Building I**

| | 12-Apr | 13-Apr | 14-Apr | 15-Apr | 16-Apr | PPC | | 19-Apr | 20-Apr | 21-Apr | 22-Apr | 23-Apr | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 2 | 1 | 1 | 2 | 1 | rolled | Weekly | 1 | 1 | 1 | 1 | 2 | rolled | Weekly |
| **Tasks Completed** | 2 | 1 | 1 | 1 | 1 | | | 1 | 1 | 1 | 0 | 2 | | |
| **PPC (%)** | 100 | 100 | 100 | 50 | 100 | 0.50 | 0.86 | 100 | 100 | 100 | 0 | 100 | 0.00 | 0.83 |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | | | | | | | | | | | |
| **Engineering** | | | | | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | | 1 | | | | | | | 1 | | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | | | | | | | | | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

| | 26-Apr | 27-Apr | 28-Apr | 29-Apr | 30-Apr | PPC | | 3-May | 4-May | 5-May | 6-May | 7-May | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 2 | 3 | 3 | 3 | 3 | rolled | Weekly | 4 | 2 | 2 | 1 | 1 | rolled | Weekly |
| **Tasks Completed** | 1 | 2 | 2 | 2 | 2 | | | 3 | 2 | 2 | 1 | 1 | | |
| **PPC (%)** | 50 | 66.66 | 66.66 | 66.66 | 66.66 | 0.10 | 0.64 | 75 | 100 | 100 | 100 | 100 | 0.75 | 0.90 |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | | | | | | | | | | | |
| **Engineering** | | | | | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | | | | | | | | | | | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | 1 | 1 | 1 | 1 | 1 | | | 1 | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

**Building I**

| | 10-May | 11-May | 12-May | 13-May | 14-May | PPC | | 17-May | 18-May | 19-May | 20-May | 21-May | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 1 | 1 | 2 | 3 | 2 | rolled | Weekly | 2 | 2 | 2 | 2 | 2 | rolled | Weekly |
| **Tasks Completed** | 1 | 1 | 2 | 1 | 0 | | | 0 | 2 | 0 | 0 | 2 | | |
| **PPC (%)** | 100 | 100 | 100 | 33.33 | 0 | 0.00 | 0.56 | 0 | 100 | 0 | 0 | 100 | 0.00 | 0.40 |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | 2 | 2 | | | 2 | | | | | | |
| **Engineering** | | | | | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | | | | | | | | | | | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | | | | | | | | | | 2 | 2 | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

| | 24-May | 25-May | 26-May | 27-May | 28-May | PPC | | 31-May | 1-Jun | 2-Jun | 3-Jun | 4-Jun | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 2 | 2 | 3 | 4 | 3 | rolled | Weekly | | | | | | rolled | Weekly |
| **Tasks Completed** | 0 | 0 | 2 | 2 | 2 | | | | | | | | | |
| **PPC (%)** | 0 | 0 | 66.66 | 50 | 66.66 | 0.00 | 0.43 | | | | | | | |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | | | | | | | | | | | |
| **Engineering** | | | | 1 | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | 2 | | 1 | | | | | | | | | | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | 2 | | 1 | 1 | | | | | | | | | |
| **Supplier** | | | | | | | | | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

**Building II**

| | 15-Mar | 16-Mar | 17-Mar | 18-Mar | 19-Mar | PPC | | 22-Mar | 23-Mar | 24-Mar | 25-Mar | 26-Mar | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | | | | | | rolled | Weekly | | | | | | rolled | Weekly |
| **Tasks Completed** | | | | | | | | | | | | | | |
| **PPC (%)** | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | | | | | | | | | | | |
| **Engineering** | | | | | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | | | | | | | | | | | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | | | | | | | | | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

| | 29-Mar | 30-Mar | 31-Mar | 1-Apr | 2-Apr | PPC | | 5-Apr | 6-Apr | 7-Apr | 8-Apr | 9-Apr | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 3 | 4 | 4 | 4 | 2 | rolled | Weekly | 4 | 3 | 3 | 2 | 2 | rolled | Weekly |
| **Tasks Completed** | 3 | 2 | 2 | 0 | 1 | | | 2 | 1 | 2 | 2 | 1 | | |
| **PPC (%)** | 100 | 50 | 50 | 0 | 50 | 0.00 | 0.47 | 50 | 33.33 | 66.66 | 100 | 50 | 0.06 | 0.57 |
| | | | | | | | | | | | | | | |
| **Productivity** | | 1 | | | | | | | 1 | | | 1 | | |
| **Engineering** | | 1 | 1 | | | | | | | | | | | |
| **Non Confirmance** | | | | 1 | 1 | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | 1 | 2 | | | | | | 1 | | | | |
| **No show** | | | | 1 | | | | 1 | 1 | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | | | | | | | | 1 | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

**Building II**

| | 12-Apr | 13-Apr | 14-Apr | 15-Apr | 16-Apr | PPC | | 19-Apr | 20-Apr | 21-Apr | 22-Apr | 23-Apr | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 3 | 2 | 3 | 3 | 2 | rolled | Weekly | 3 | 1 | 1 | 1 | 1 | rolled | Weekly |
| **Tasks Completed** | 2 | 2 | 2 | 2 | 1 | | | 2 | 1 | 1 | 1 | 1 | | |
| **PPC (%)** | 66.66 | 100 | 66.66 | 66.66 | 50 | 0.15 | 0.69 | 66.66 | 100 | 100 | 100 | 100 | 0.67 | 0.86 |
| | | | | | | | | | | | | | | |
| **Productivity** | 1 | | | 1 | | | | | | | | | | |
| **Engineering** | | | | | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | | | | | | 1 | | | | | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | | 1 | | 1 | | | | | | | | | |
| **Supplier** | | | | | | | | | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

| | 26-Apr | 27-Apr | 28-Apr | 29-Apr | 30-Apr | PPC | | 3-May | 4-May | 5-May | 6-May | 7-May | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 2 | 2 | 1 | 0 | 0 | rolled | Weekly | 1 | 1 | 2 | 1 | 1 | rolled | Weekly |
| **Tasks Completed** | 1 | 2 | 1 | 0 | 0 | | | 1 | 1 | 2 | 1 | 1 | | |
| **PPC (%)** | 50 | 100 | 100 | 100 | 100 | 0.50 | 0.80 | 100 | 100 | 100 | 100 | 100 | 1.00 | 1.00 |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | | | | | | | | | | | |
| **Engineering** | | | | | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | 1 | | | | | | | | | | | | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | | | | | | | | | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

**Building II**

| | 10-May | 11-May | 12-May | 13-May | 14-May | PPC | | 17-May | 18-May | 19-May | 20-May | 21-May | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 2 | 1 | 2 | 2 | 1 | rolled | Weekly | 2 | 3 | 4 | 3 | 3 | rolled | Weekly |
| **Tasks Completed** | 2 | 1 | 2 | 1 | 0 | | | 2 | 3 | 4 | 3 | 3 | | |
| **PPC (%)** | 100 | 100 | 100 | 50 | 0 | 0.00 | 0.75 | 100 | 100 | 100 | 100 | 100 | 1.00 | 1.00 |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | | | | | | | | | | | |
| **Engineering** | | | | | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | | 1 | 1 | | | | | | | | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | | | | | | | | | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | | | | | | | | | | | | | | |

| | 24-May | 25-May | 26-May | 27-May | 28-May | PPC | | 31-May | 1-Jun | 2-Jun | 3-Jun | 4-Jun | PPC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 3 | 2 | 2 | 1 | 1 | rolled | Weekly | | | | | | rolled | Weekly |
| **Tasks Completed** | 2 | 1 | 2 | 1 | 0 | | | | | | | | | |
| **PPC (%)** | 66.66 | 50 | 100 | 100 | 0 | 0.00 | 0.67 | | | | | | | |
| | | | | | | | | | | | | | | |
| **Productivity** | | | | | 1 | | | | | | | | | |
| **Engineering** | | | | | | | | | | | | | | |
| **Non Confirmance** | | | | | | | | | | | | | | |
| **Owner Decision** | | | | | | | | | | | | | | |
| **Weather** | | | | | | | | | | | | | | |
| **Pre requisite** | | | | | | | | | | | | | | |
| **No show** | | | | | | | | | | | | | | |
| **Trade** | | | | | | | | | | | | | | |
| **Supplier** | | | | | | | | | | | | | | |
| **Space** | | | | | | | | | | | | | | |
| **Other** | 1 | 1 | | | | | | | | | | | | |

# Appendix F

# Formats for Data Collection and PPC Calculations

| | 15-Mar | 16-Mar | 17-Mar | 18-Mar | 19-Mar |
|---|---|---|---|---|---|
| **Activities planned** | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| **Incomplete activities and reasons** | | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |

**Figure F.1: Daily Data Collection Sheet**

| | 15-Mar | 16-Mar | 17-Mar | 18-Mar | 19-Mar | rolled PPC | Weekly PPC |
|---|---|---|---|---|---|---|---|
| **Tasks Planned** | | | | | | | |
| **Tasks Completed** | | | | | | | |
| **PPC (%)** | | | | | | | |
| | | | | | | | |
| **Productivity** | | | | | | | |
| **Engineering** | | | | | | | |
| **Non Confirmance** | | | | | | | |
| **Owner Decision** | | | | | | | |
| **Weather** | | | | | | | |
| **Pre requisite** | | | | | | | |
| **No show** | | | | | | | |
| **Trade** | | | | | | | |
| **Supplier** | | | | | | | |
| **Space** | | | | | | | |
| **Other** | | | | | | | |
| | | | | | | | |

**Figure F.2: PPC Calculation & Reason Codes**

# Appendix G

# Production Planning Model

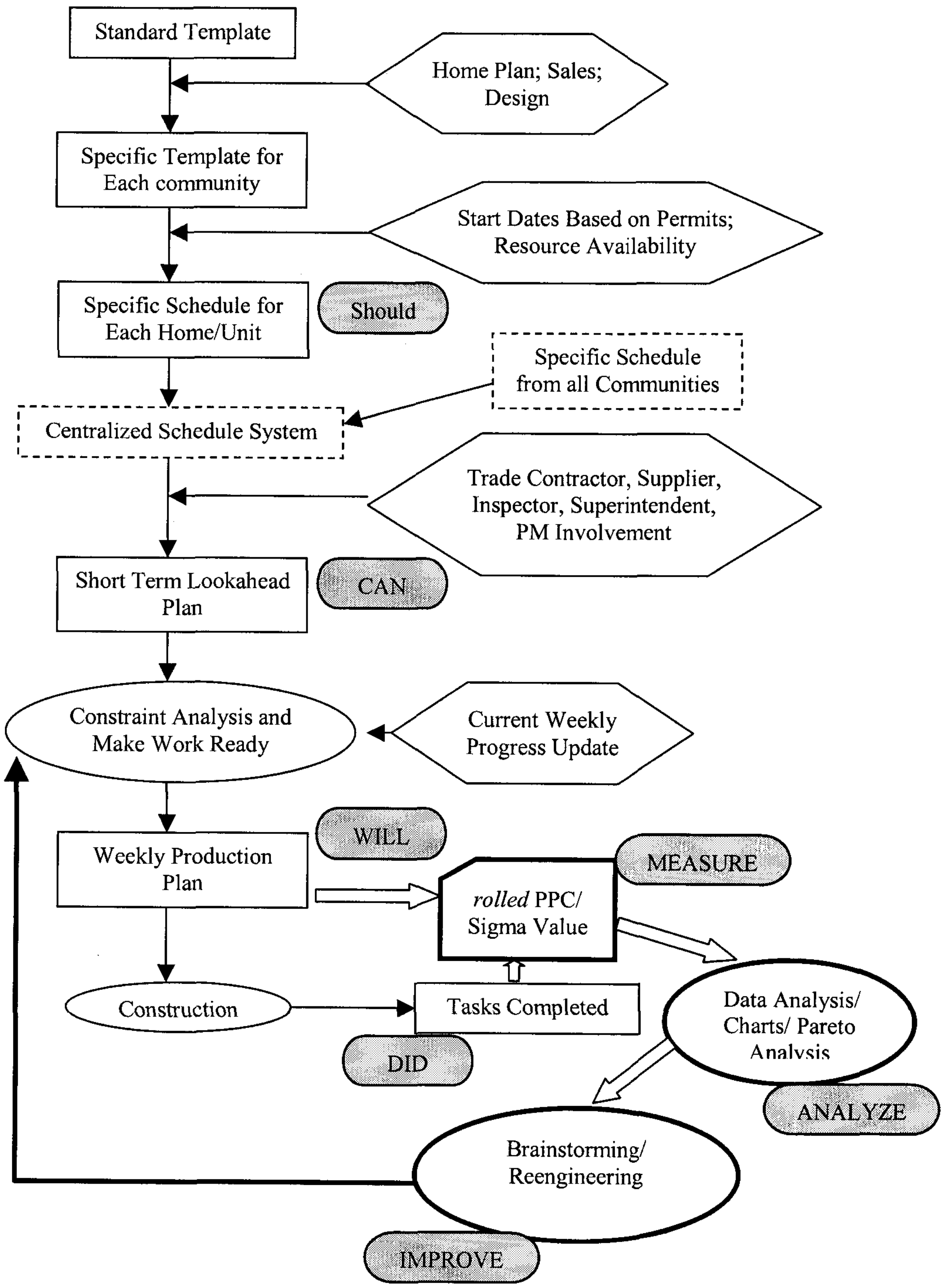


Figure 1: Production Planning Model