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

By

Thanveer Moosa Mohammed

A THESIS

**Submitted to
Michigan State University
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ABSTRACT

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

By

Thanveer Moosa Mohammed

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 operations. 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

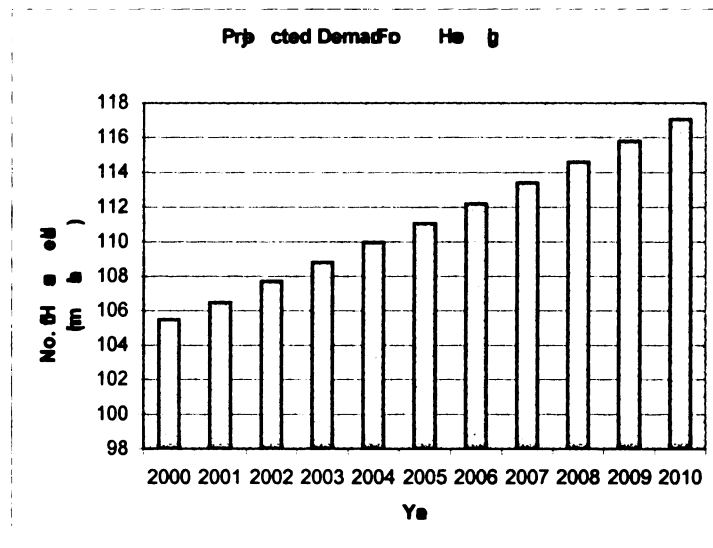


Table 1.1 Projected demand for housing

(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.

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 system³, 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).

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 workflow⁴ 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

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).

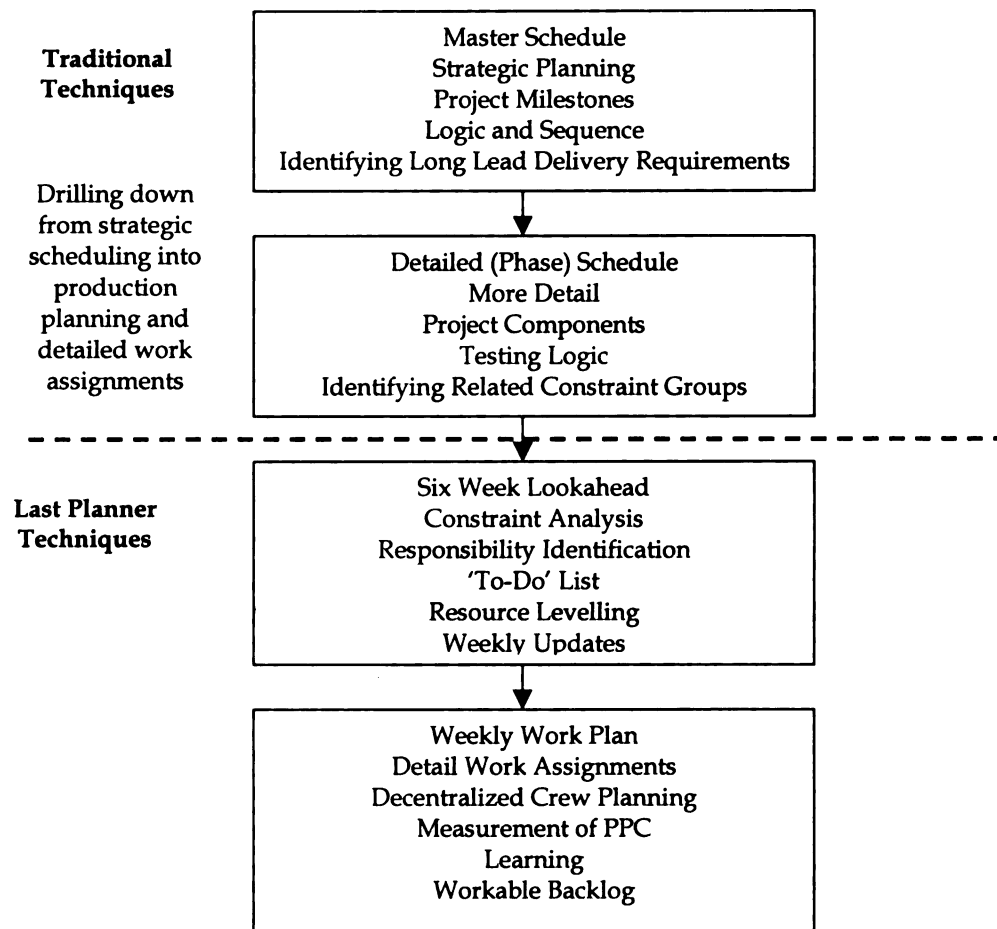


Fig 2.1: Construction Planning vs. Last Planner
(Modified: Kaufman Consulting Group, LLC)

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: definition⁵, sequencing⁶, soundness⁷ and size⁸. 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

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 the correct constructability order (Ballard, 2000).*

⁷ *Soundness: the materials design and prerequisites 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.

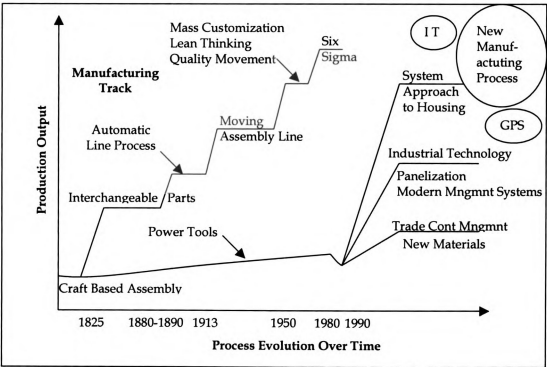


Fig 2.2 Evolution of residential construction

(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 perceived 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- σ measure. Sigma (σ) 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 1 misspelled 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:

$$Y_{RT} = \prod_{i=1}^m Y_i \quad \dots(i)$$

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:

$$Y_{RT} = \prod_{i=1}^m Y_i \quad \dots(i)$$

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:

$$Y_{norm} = \sqrt[m]{Y_{RT}} \quad (ii)$$

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

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

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

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

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:

$$\text{rolled PPC} = \prod_{i=1}^m \text{PPC}_i \quad (\text{v})$$

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

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

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

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

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

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

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 occurrence. 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.

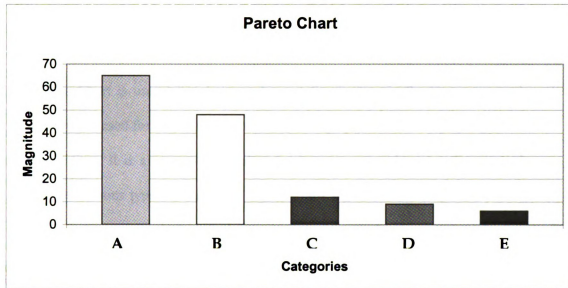


Figure 3.2 Typical Pareto Chart

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 $1 - \text{PPC}$ 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):

$$\blacksquare \quad Std_dev = \sqrt{\frac{PPICavg(1 - PPICavg)}{Tasks_assigned}} \quad \dots(ix)$$

$$\text{where, } PPICavg = \frac{\sum Tasks_incomplete}{\sum Tasks_assigned} \quad \dots(x)$$

$$\blacksquare \quad UCL = PPICavg + Std_dev \quad \dots(xi)$$

$$\blacksquare \quad CL = PPICavg \quad \dots(xii)$$

$$\blacksquare \quad LCL = PPICavg - Std_dev \quad \dots(xiii)$$

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.

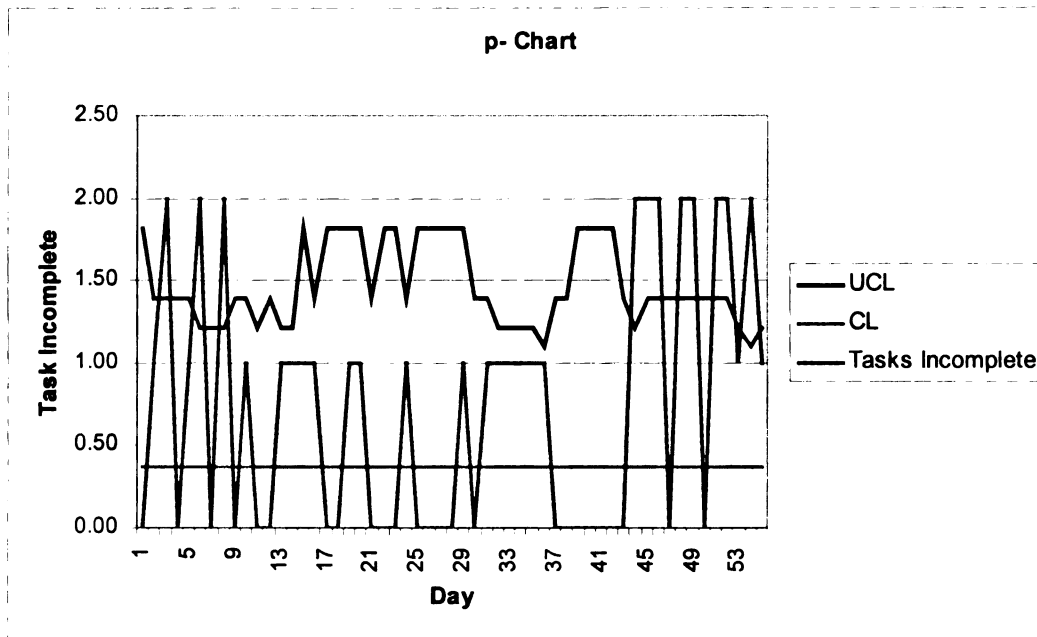


Figure 3.4 Sample p-chart

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.

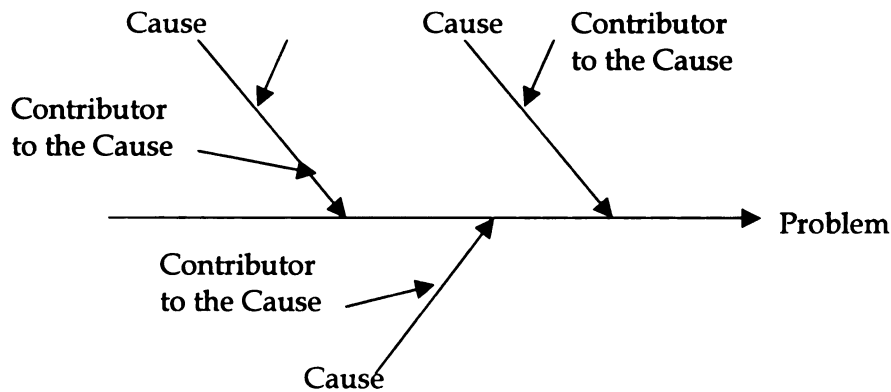


Figure 3.5 General structure of a cause and effect diagram
(Source: Evans et al., 2002)

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.

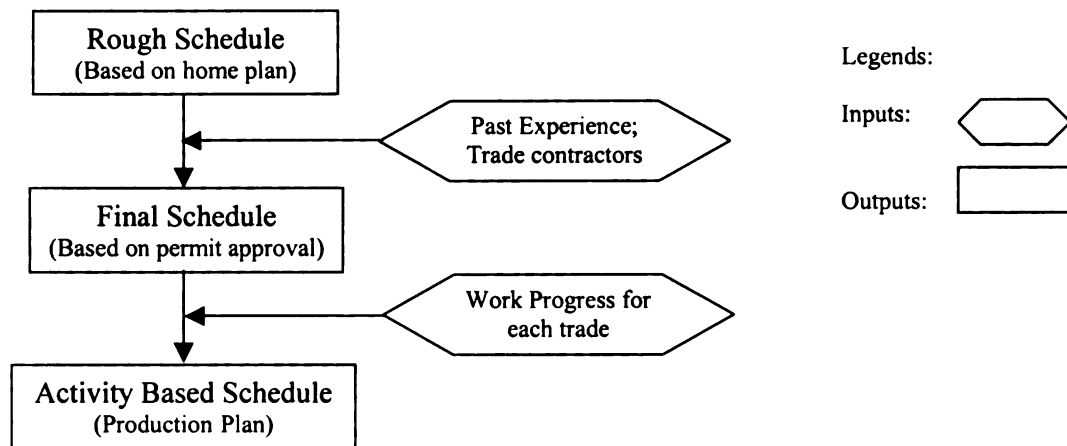


Figure 4.1: Flow Chart Representing Production Planning for Small Homebuilding Company

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.

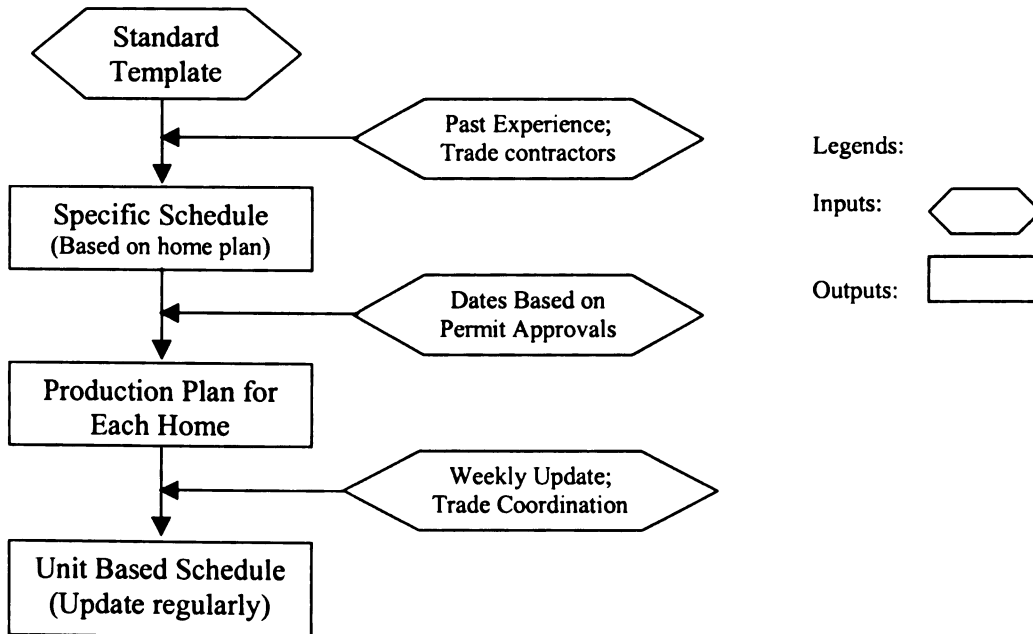


Figure 4.2: Flow Chart Representing Production Plan for Medium Homebuilding Company

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.

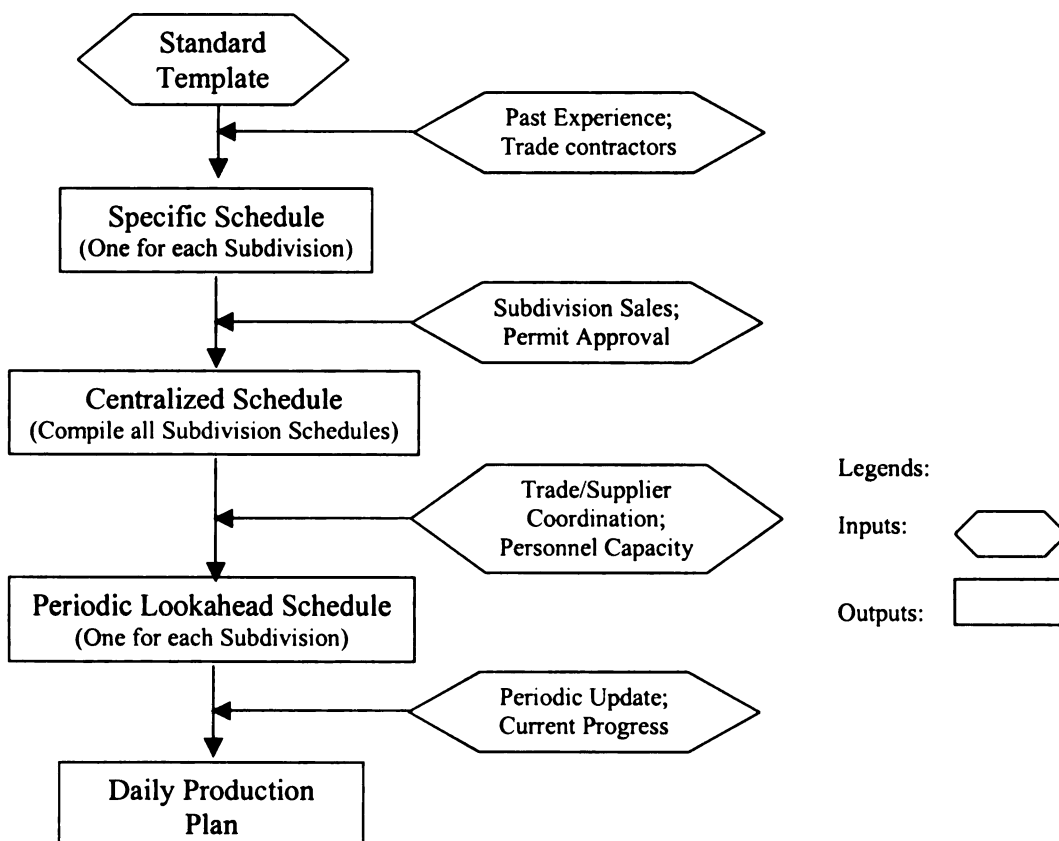


Figure 4.3: Flow Chart Representing Production Plan for Large Homebuilding Company

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			
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 Conformance			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.

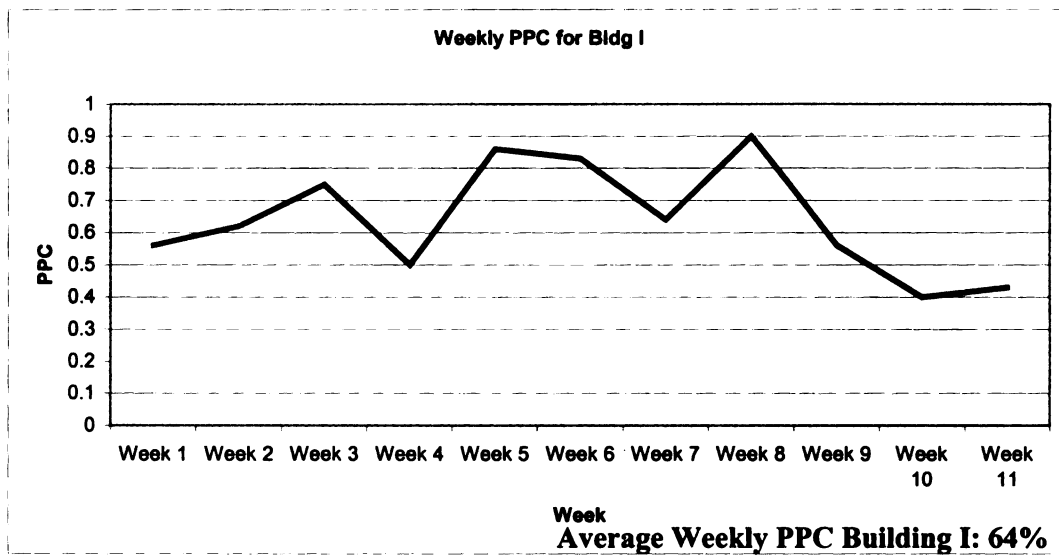


Figure 4.6: Graph Showing Weekly PPC for Building I

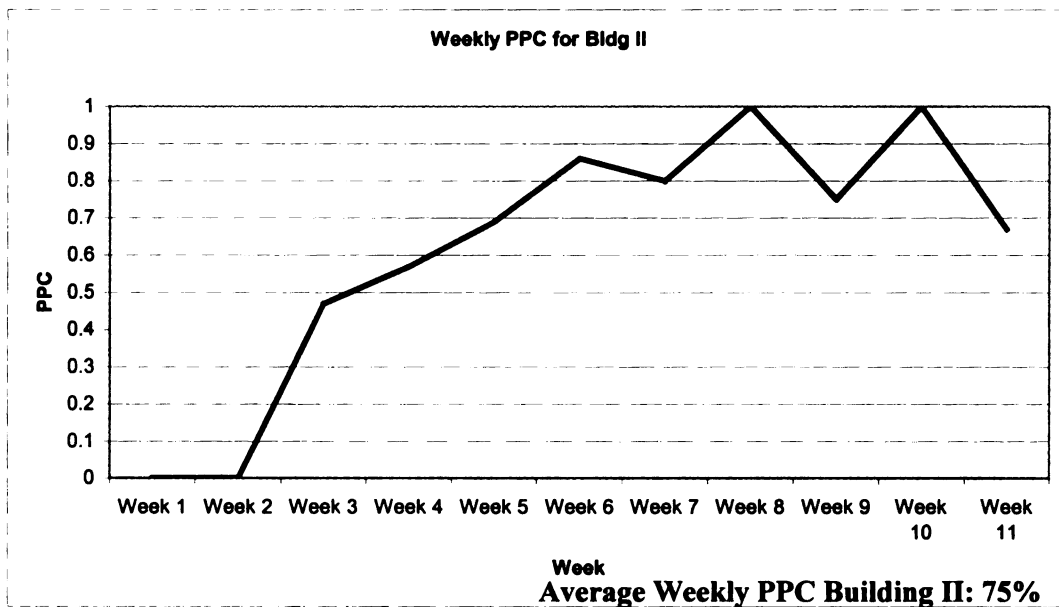


Figure 4.7: Graph Showing Weekly PPC for Building II

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.

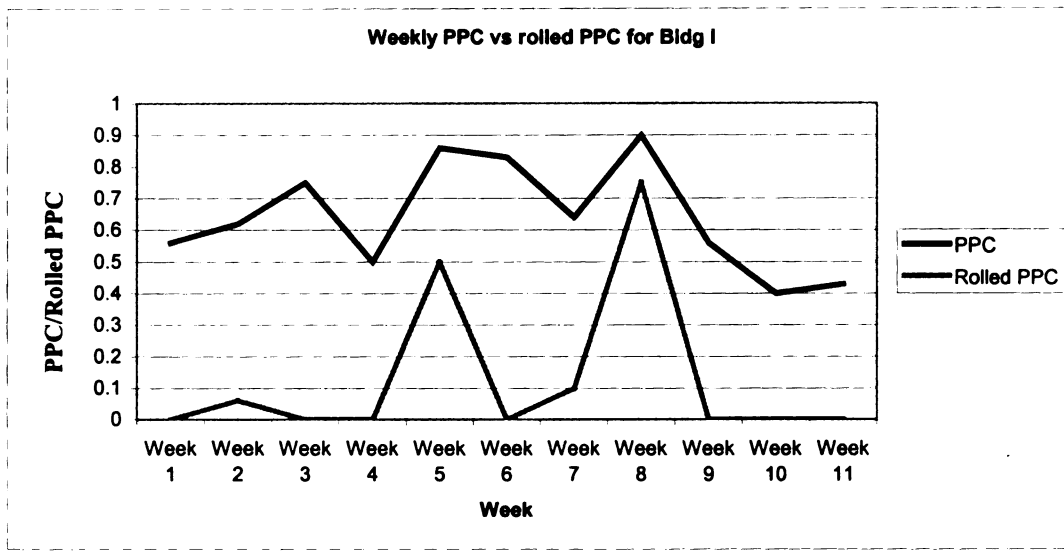


Figure 4.8: Graph of PPC and *rolled* PPC for Building I

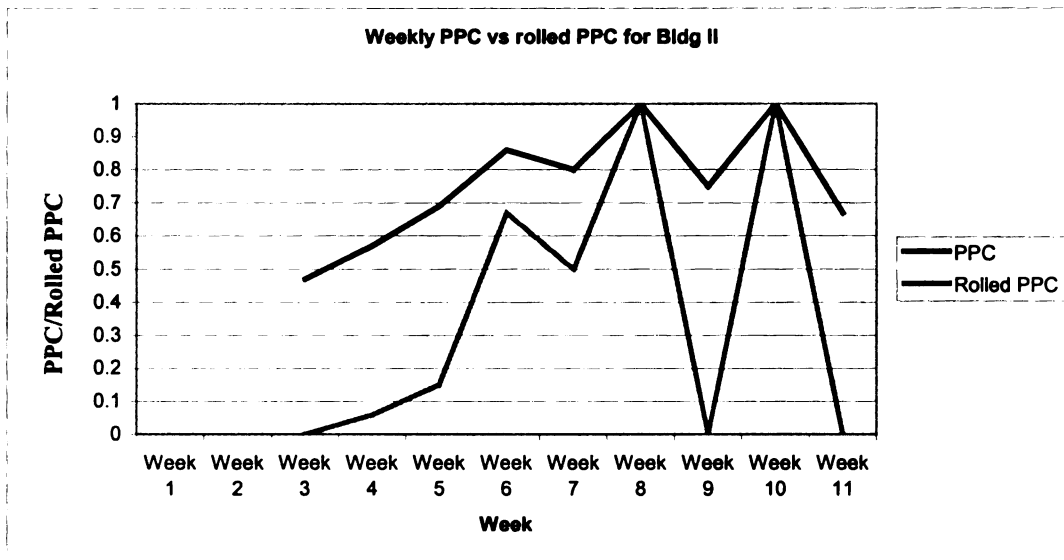


Figure 4.9: Graph of PPC and *rolled* PPC for Building II

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.

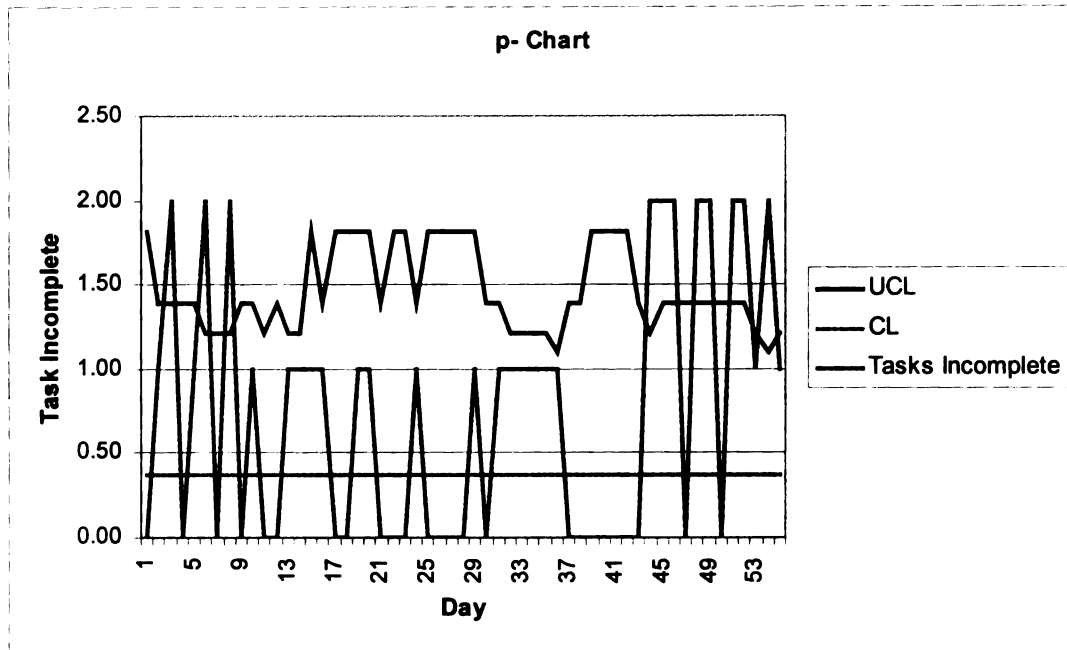


Figure 4.10: p-Chart for Task Incomplete in Building I

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

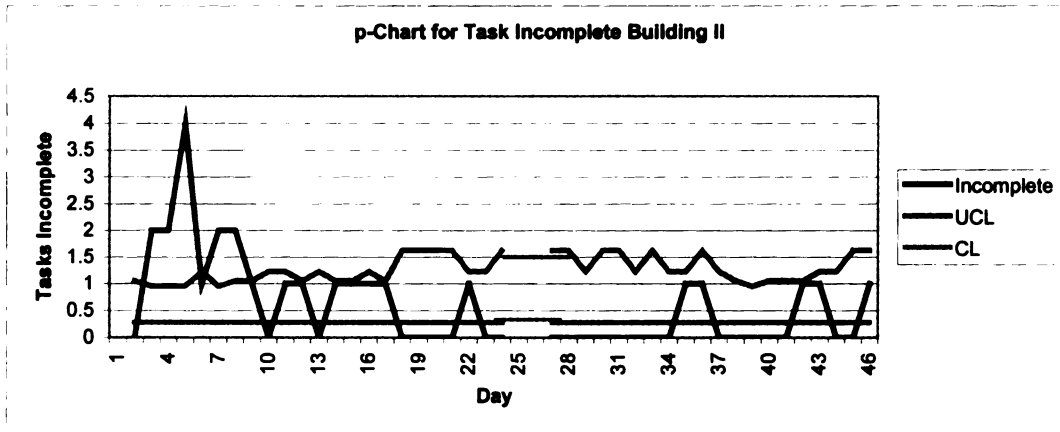


Figure 4.11: p-Chart for Task Incomplete in Building II

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 Building Inspection Insulation Interior Drywall Stocking	Truss repair completed with fault have to be redone Inspector No Show Insulation could not proceed without inspection Drywall Stocking could not proceed without inspection
6	4	2	Truss Bracing Building Inspection Insulation Interior Drywall Stocking	Inspector No Show 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.

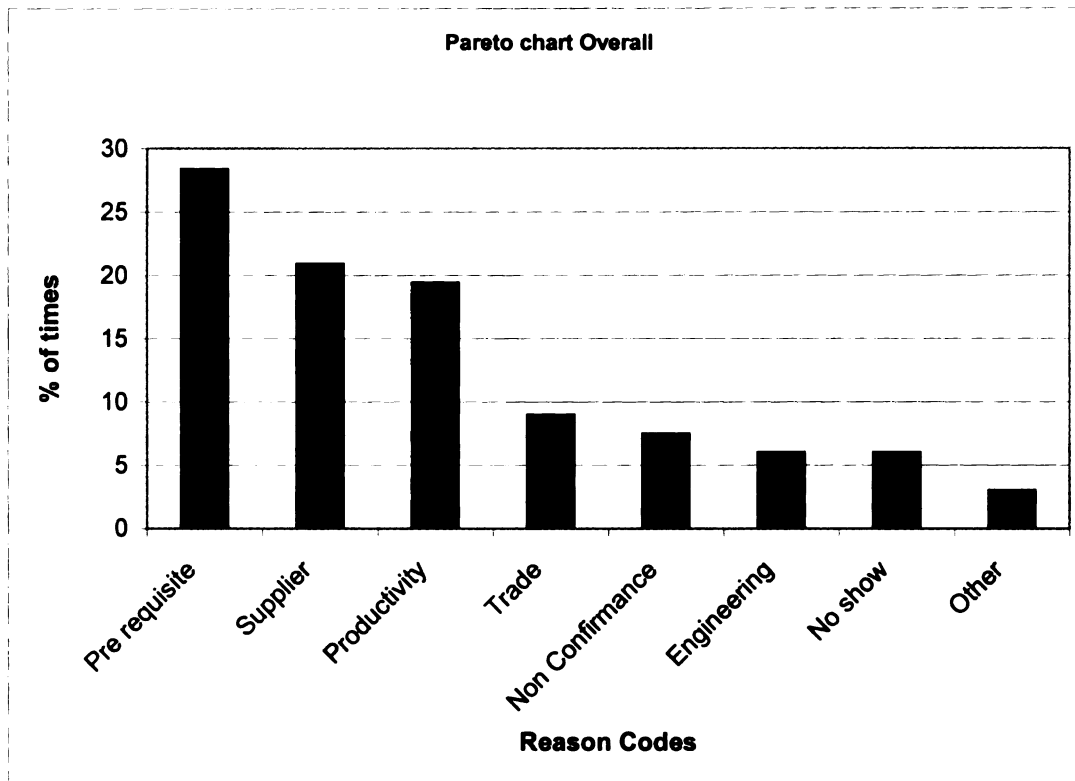


Figure 4.12 Pareto Chart for Reason Codes

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.

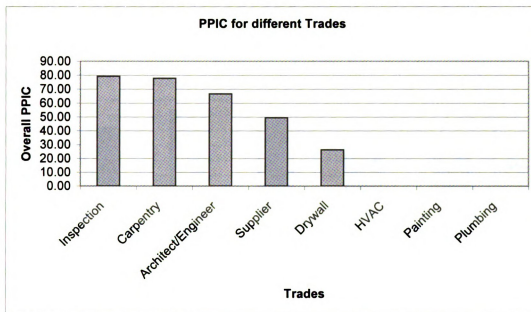


Figure 4.13 Pareto Chart for Trades

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.

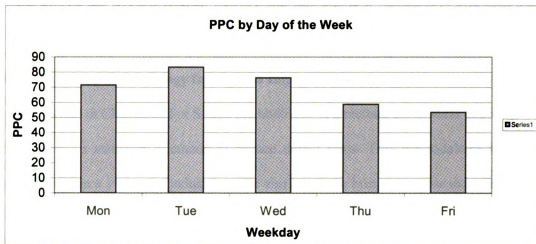


Figure 4.14: Graph of PPC vs. Weekday

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.

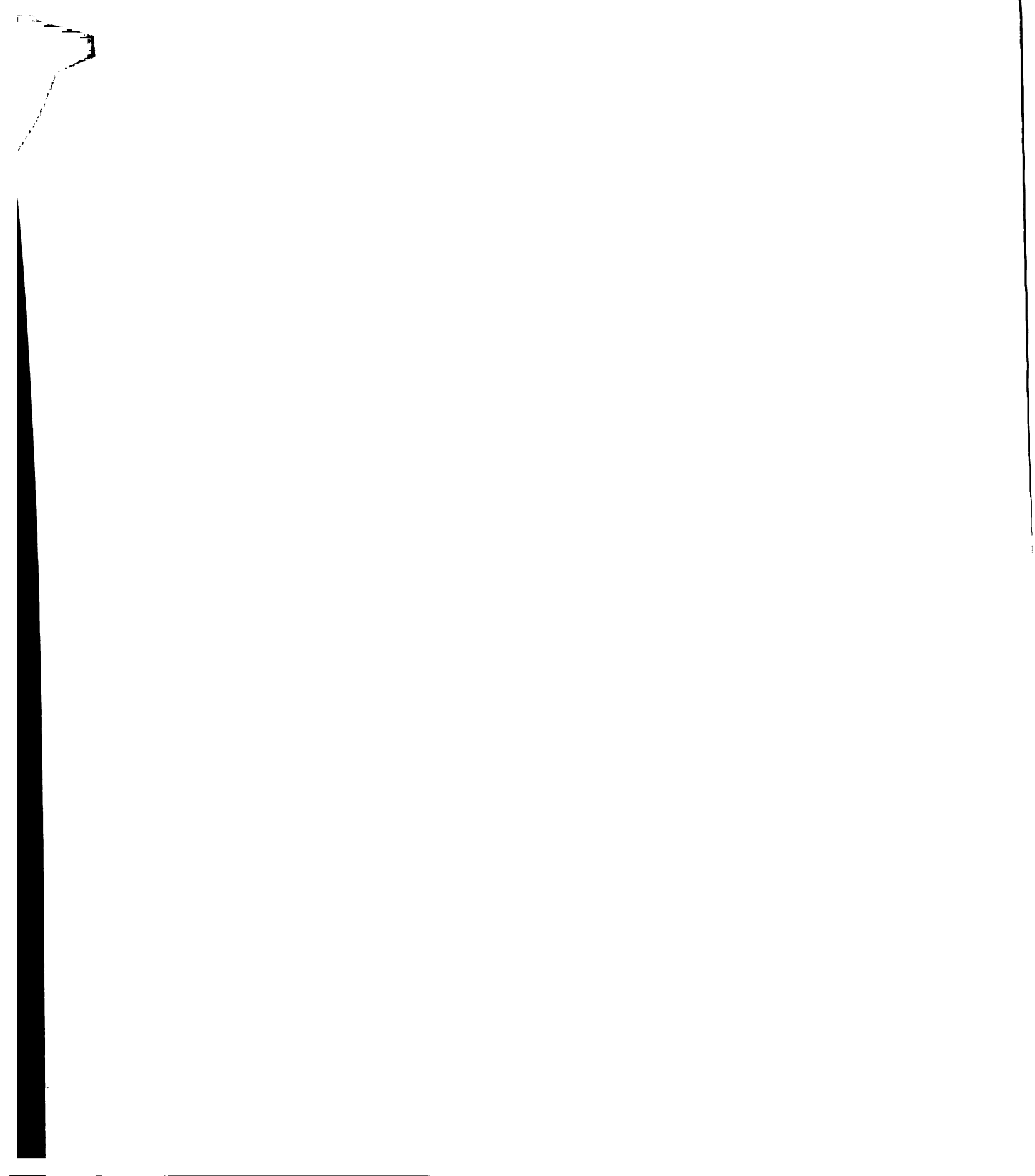
Define

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.

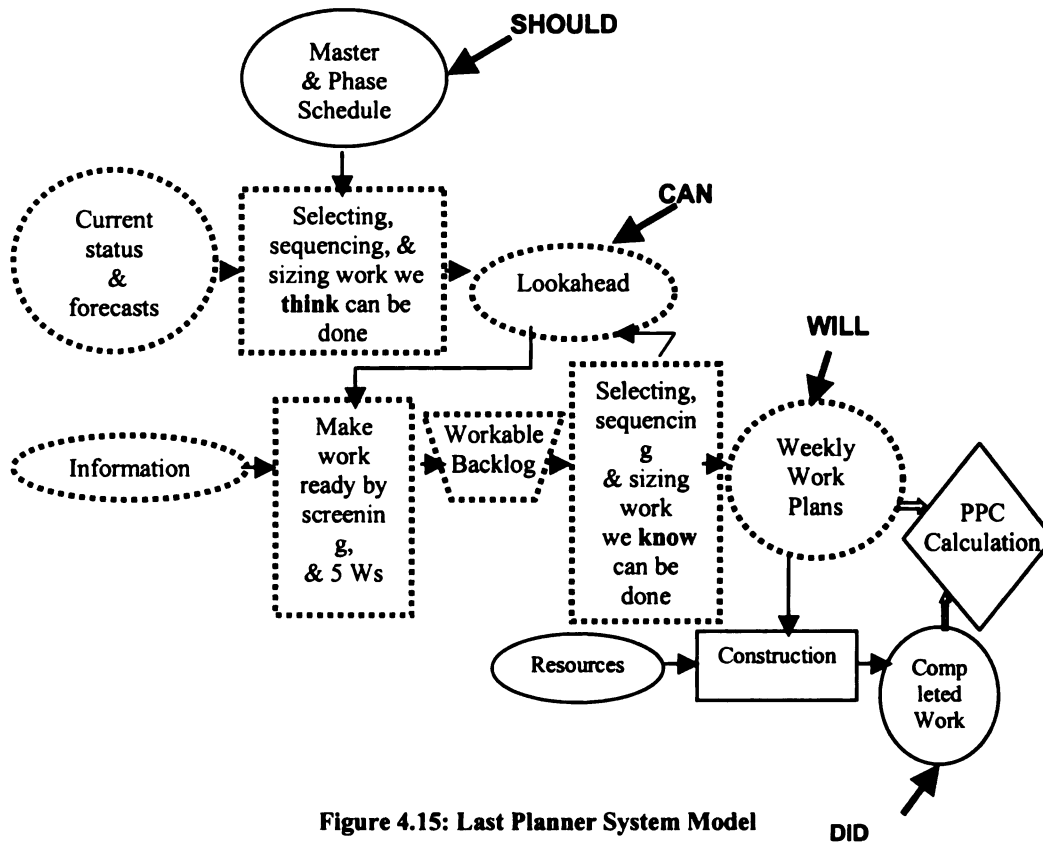


Figure 4.15: Last Planner System Model

(©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,

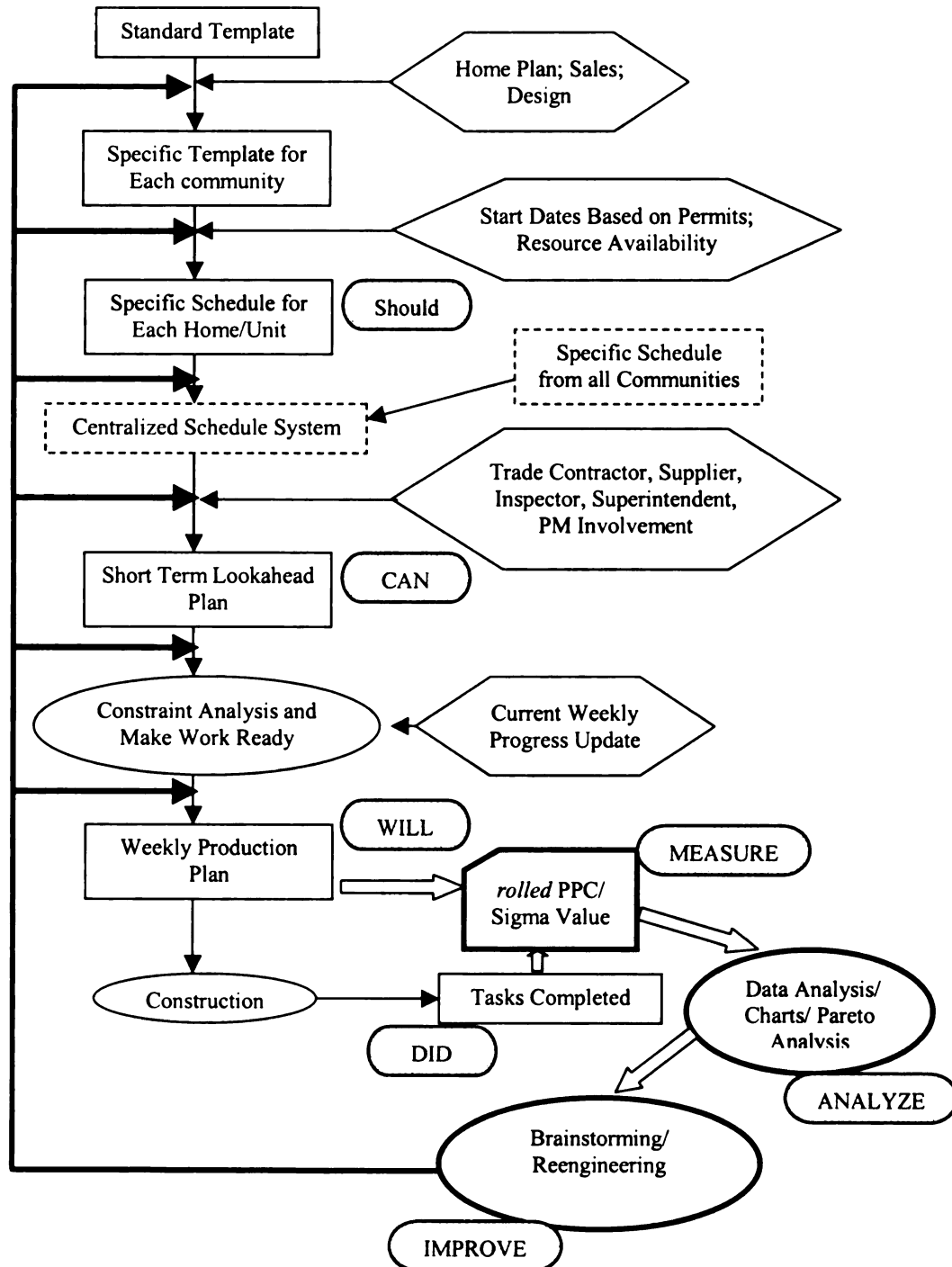


Figure 4.16: Production Planning Process Model

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 incompleteness 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 its 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

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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:

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

- 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

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

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:

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

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

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

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

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

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

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

Where, Z_{norm} is the standard normal value corresponding to the 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 review 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	Superintendent	Superintendent
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

#	Questions	ABC 11	
		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	Superintendent	VP's 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 separated 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	Superintendent	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	Superintendent 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. Occasionally material

ABC 11		XYZ 11		XYZ 12	
#	Questions	XYZ 11	XYZ 12	XYZ 11	XYZ 12
35	If subcontractor's performance is the cause how do you handle it	Meetings with SubCs	Meetings with SubC. Give another chance if good quality of work.	Meetings with SubC. Give another chance if good quality of work.	Meetings 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	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	30 days of contingency built in overall	Critical activities like concrete 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	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	None
40	Have you worked in other homebuilding companies	Yes		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		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	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.	for custom homes: scope of work, owners selections.	SubC performance is key. Home owners selection process. Accountability of home owner
44	Is it better to have a general plan for all homes or specific plans for each home		Specific	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 continuous improvement	Refining the process, highlighting the best practices in the industry leading to continuous improvement	Yes. Company does not follow a formal process of innovation. But it is an ongoing process discussed in meetings.

#	Questions	ABC 22	XYZ 22
1	Interviewee's name, Position	XYZ 21 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 mil\$)	
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, censx, 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)

#	Questions	ABC 22	
		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 Mgmt 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	1 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 weather interference
42	What according to you is a good practice for planning in a homebuilding company like yours	Even flow schedule, Centralized scheduling, Mgmt reports showing trends & progress, communicating all this info amongst key players	Live the schedule throughout the each day. Use palm pilots to update include all departments. Communicate with SubC.
43	What factors influence the planning process	External govt agencies, Demand and sales, supplier problems	Performance of trade contractors, weather, superintendent, 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	
		XYZ 31	XYZ 32
#	Questions	General Manager of Finance and Administration	Project manager
1	Interviewee's name, Position	27 yrs	3 years
2	Number of years with the company	ABC 33; Bloomfield Hills, MI	ABC 33; Bloomfield Hills, MI
3	Company name, Location		
4	Brief about the company	6 subdivisions	3 (under PM); 6 (Overall for company)
5	Number of subdivisions currently work undergoing		
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; (mil\$ / 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

ABC 33		XYZ 32	
#	Questions	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; Adjustments 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 i/s/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 sucesor 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

ABC 33		XYZ 31		XYZ 32	
#	Questions				
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	

#	Questions	ABC 44	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	XYZ 42
#	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 depends 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. Refocusing 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 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	Purchasing 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	
		XYZ 51	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 Availability, 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; Prioritize 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 1

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

Building 1

	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 not approved by inspector	All complete with approval	Insulation not complete	All Complete	Less Productivity
	Inspector approval not obtained				

Building 1

	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 equipment	Supplier didn't respond

Building 1

	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	Supplier didn't get the right equipmnt	All Complete	All Complete	Heating not available (hooked up in the first 6 units)	Heating not available (hooked up 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 finishing 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 of proper heating	All Complete

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 start	All Complete

Building 1

	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			
	Stocked but not the right ones		Supplier didn't respond	Supplier didn't respond	Supplier didn't respond

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

Building I

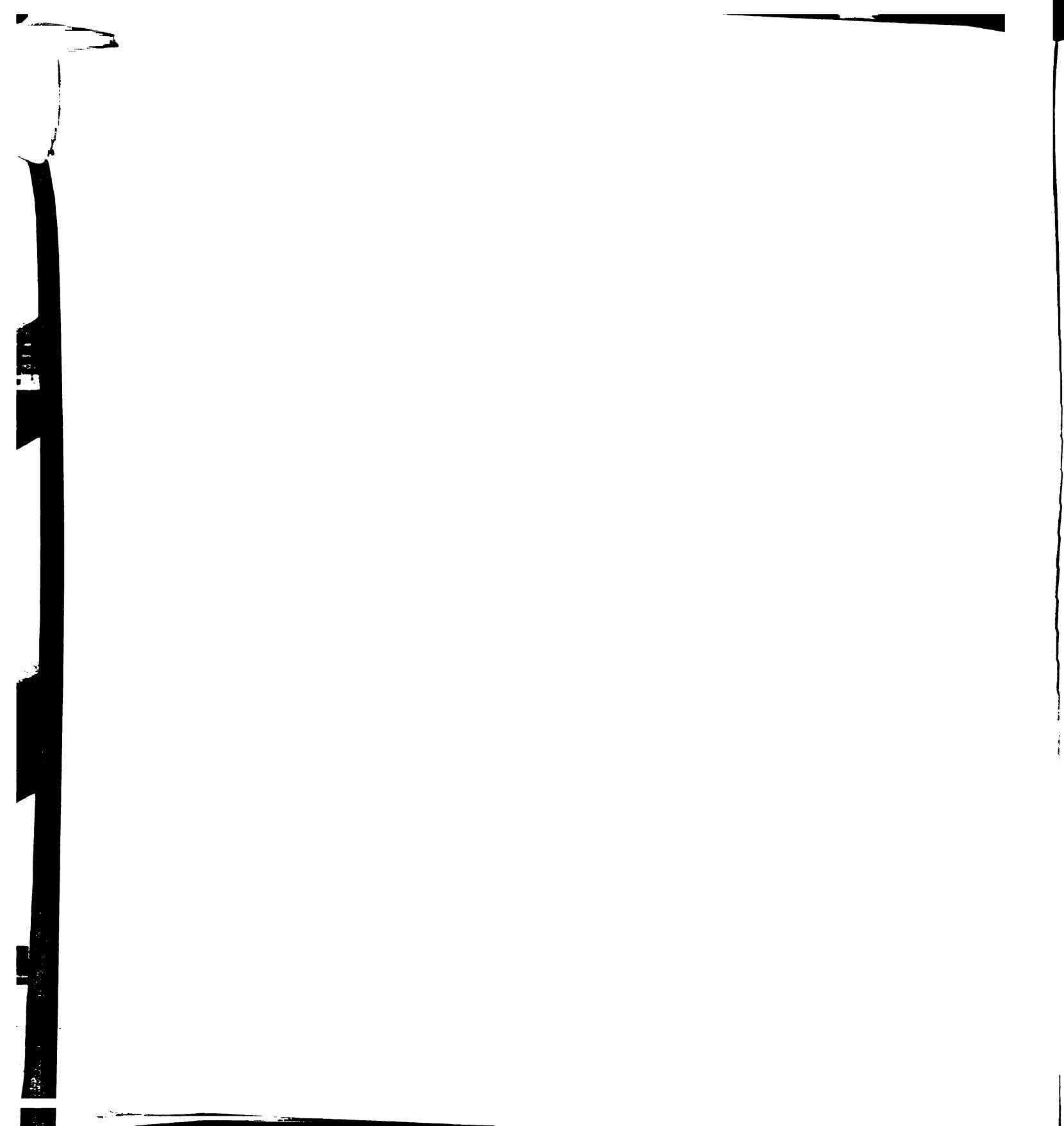
	10-May	11-May	12-May	13-May	14-May
Activities planned	Punchlisting	Drywall repair	Drywall repair Stock Counter tops and cabinets	Stock Doors Install doors in 3 units Install Countertops	Install doors in 3 units Install Countertops
Incomplete activities and reasons	All Complete	All Complete	All Complete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

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 units				

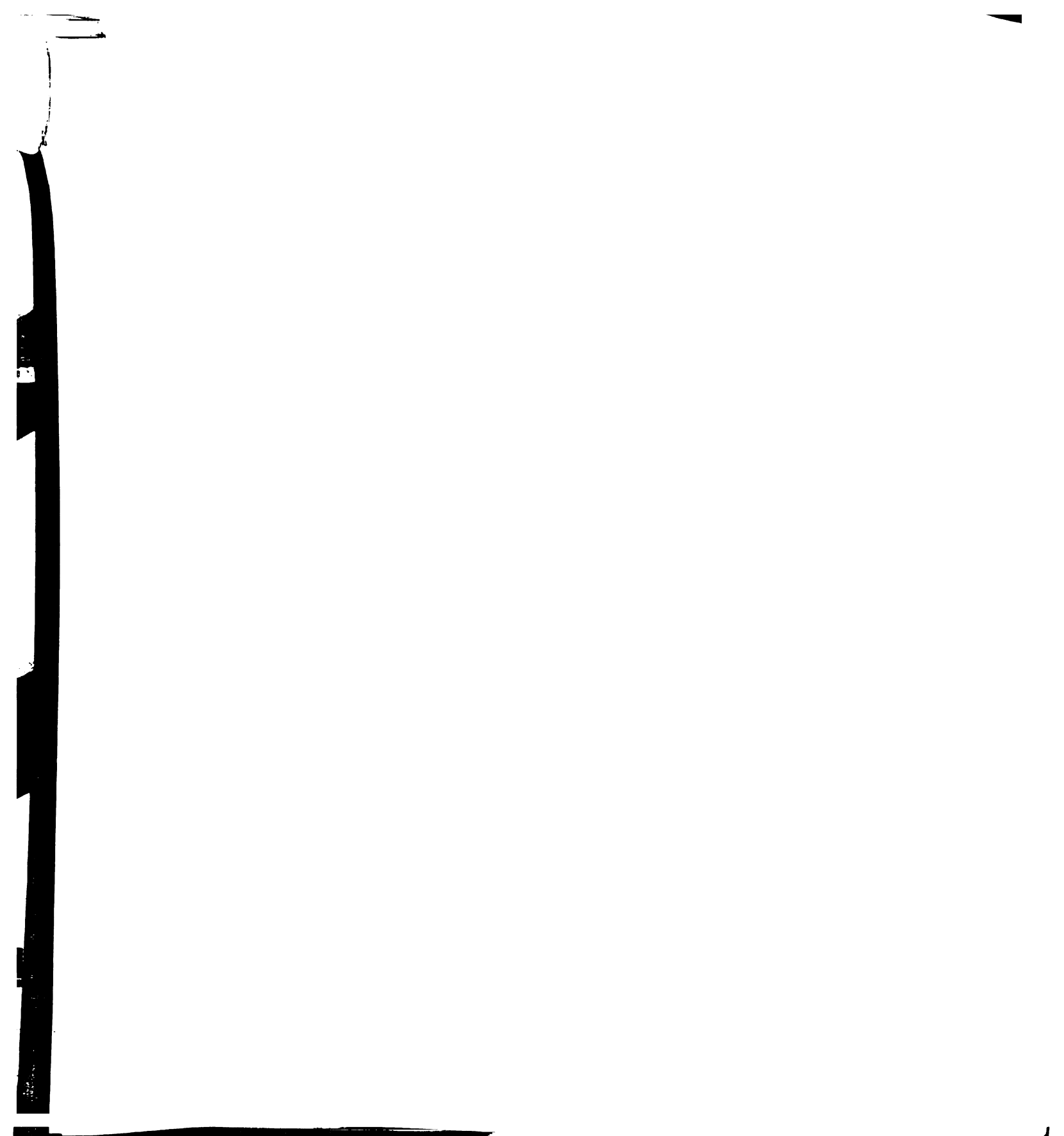
Building I

	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
Incomplete activities and reasons	all around the building completing small jobs			Install doors in 2 units	
		Less manpower	Previous work; paint	Design problem	Manpower elec
				Manpower elec	



Building II

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



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	
Incomplete activities and reasons		Create B-Vent	B vent	Drywall Stocking	
	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	Truss Repair needs engineering	Inspector No Show	
		Create B vent incomplete as more		Insulation could not proceed without inspection	
		than a days work			

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 inspection happened only in the evening	All Complete	Slow Job: Crew left early
	Supplier didn't respond	slow productivity			

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

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		

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

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

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	
	Finishing Earlier work	More drywall repairs	Finishing Earlier work		Carpentry 2 units
	Drywall repairs				
Incomplete activities and reasons	More leak and thus more repairs	More leak and thus more repairs	All Complete	All Complete	Less manpower

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	3	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 Confirmation				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 Confirmation														
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	1	1	1	1	2	Weekly
Tasks Completed	2	1	1	1	1		1	1	1	0	2	
PPC (%)	100	100	100	50	100	0.50	100	100	100	0	100	0.83
Productivity												
Engineering												
Non Conformance												
Owner Decision												
Weather												
Pre requisite										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	4	2	2	1	1	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	75	100	100	100	100	0.90
Productivity												
Engineering												
Non Conformance												
Owner Decision												
Weather												
Pre requisite												
No show												
Trade												
Supplier	1	1	1	1	1		1					
Space												
Other												

Building 1

	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 Conformance														
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														
Non Conformance				1										
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	rolled	Weekly	22-Mar	23-Mar	24-Mar	25-Mar	26-Mar	PPC
Tasks Planned														
Tasks Completed														
PPC (%)														
Productivity														
Engineering														
Non Conformance														
Owner Decision														
Weather														
Pre requisite														
No show														
Trade														
Supplier														
Space														
Other														

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

Building II

Tasks Planned	12-Apr	13-Apr	14-Apr	15-Apr	16-Apr	PPC		19-Apr	20-Apr	21-Apr	22-Apr	23-Apr	PPC	
Tasks Completed	3	2	3	3	2	rolled	Weekly	3	1	1	1	1	rolled	Weekly
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 Conformance														
Owner Decision														
Weather														
Pre requisite								1						
No show														
Trade			1		1									
Supplier														
Space														
Other														

Tasks Planned	26-Apr	27-Apr	28-Apr	29-Apr	30-Apr	PPC		3-May	4-May	5-May	6-May	7-May	PPC	
Tasks Completed	2	2	1	0	0	rolled	Weekly	1	1	2	1	1	rolled	Weekly
PPC (%)	50	100	100	100	100	0.50	0.80	100	100	100	100	100	1.00	1.00
Productivity														
Engineering														
Non Conformance														
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 Conformance														
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 Conformance														
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					

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 Confirmation							
Owner Decision							
Weather							
Pre requisite							
No show							
Trade							
Supplier							
Space							
Other							

Figure F.2: PPC Calculation & Reason Codes

Appendix G

Production Planning Model

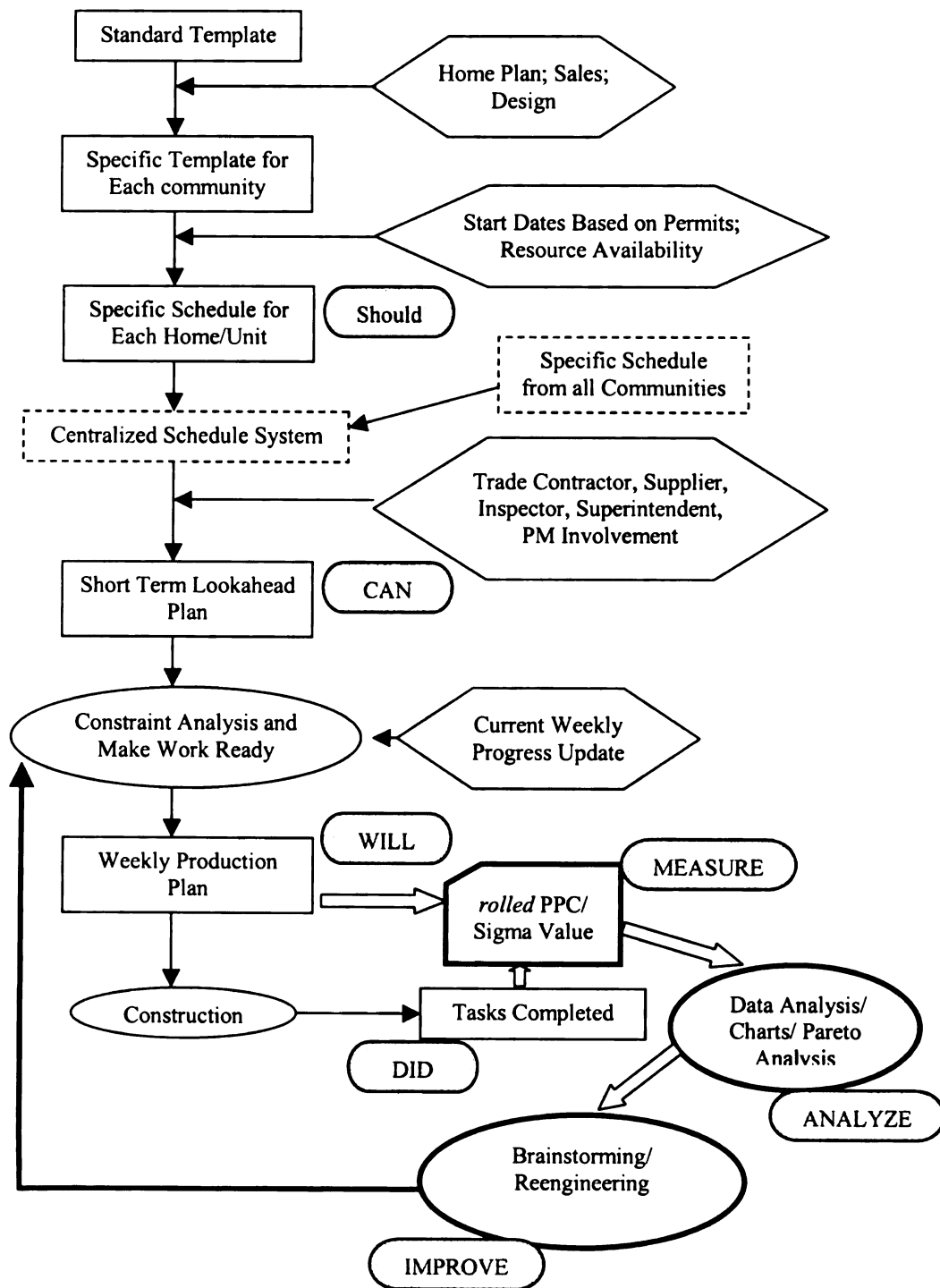
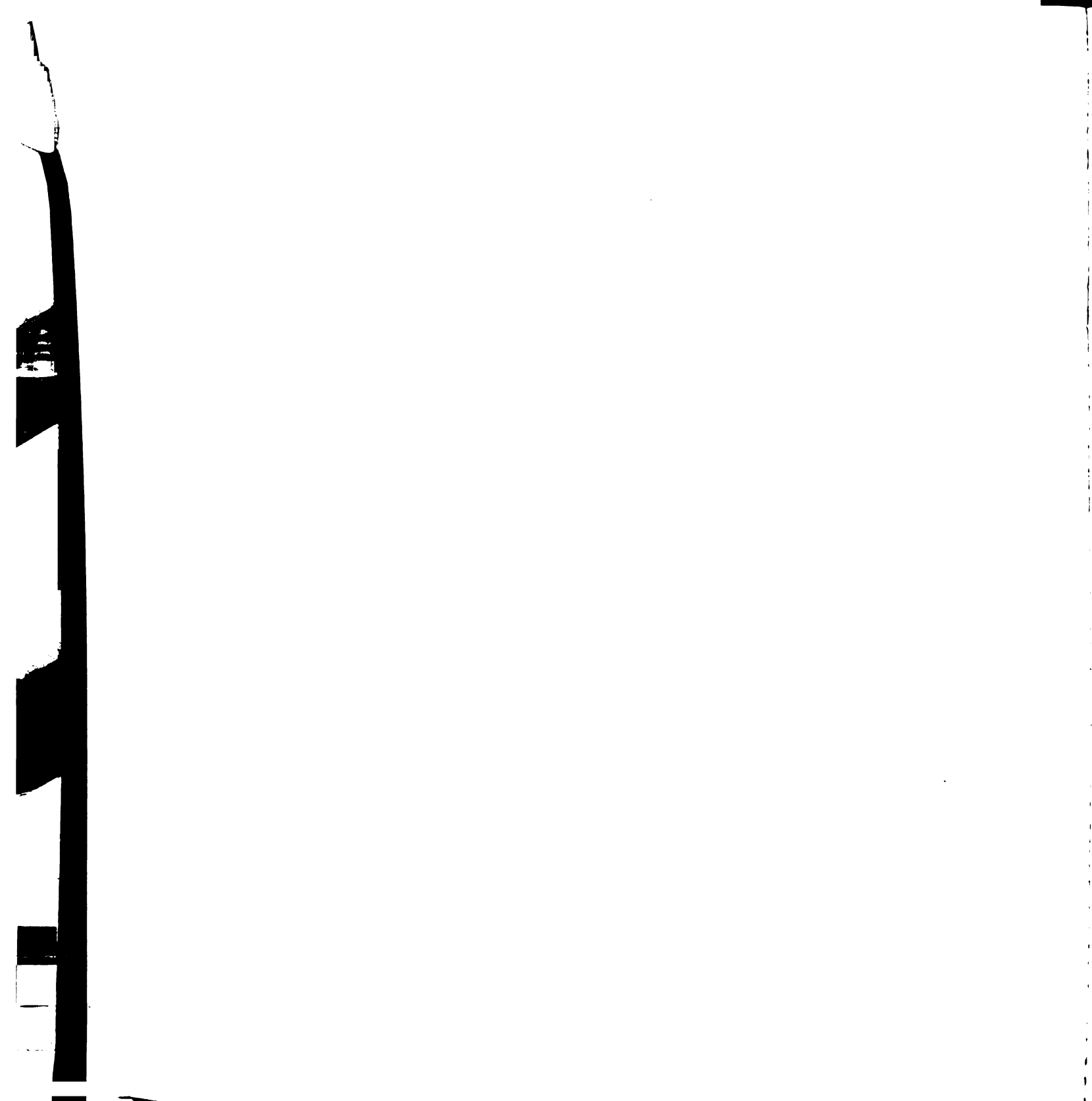


Figure 1: Production Planning Model



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