Time-Based Manufacturing System Design for Softwood Lumber Production

Henry Taylor Leonard III

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
In
Forest Products

D. Earl Kline

Brian H. Bond

Robert L. Smith

November 28, 2005
Blacksburg, VA

Keywords: Value-Stream Mapping, Softwood Lumber Production, Capital Inventory Requirement, Lead Time

Time-Based Manufacturing System Design for Softwood Lumber Production

Henry T. Leonard III

ABSTRACT

Manufacturing industries in the United States continue to experience increasing pressure from foreign competition. Through decreasing product lead time, U.S. manufacturers can achieve a sustainable competitive advantage. Southern yellow pine manufacturing is an example of an industry that can benefit from product lead time reduction. This project involved a case study of a southern yellow pine lumber manufacturer. Value stream mapping was used to evaluate the current lead time for the lumber manufacturer as well as design future state systems. Current state evaluation discovered an average lead time of 35.3 days according to six months of inventory data. Four future state systems were developed according to current demand and had lead times ranging from 10.8 to 14.9 days. Lead time reduction was achieved through more closely synchronizing and planing operations with sawmill output. To illustrate the impact of lead time on financial performance, the amount of capital invested in inventory was evaluated for the current state value stream as well as the future state value streams. All of the future state capital inventory requirements were less than 50 percent of the current state capital inventory requirement. Implementation of future state value streams would allow the manufacturer to benefit from having more available capital.

This research project also investigated the use of pull production at the softwood lumber manufacturing operation. Effective implementation of pull production would require improving headrig optimization programs, presorting material by grade before drying, little or no drying degrade, and reducing both drying and cooling time. Due to the technological requirements of pull production in lumber manufacturing, the system was not currently feasible for the lumber manufacturer. Future research efforts should be directed towards creating the technology necessary to economically implement pull production in the softwood sawmill industry.

Acknowledgements

I would like to thank the following people for their support of this research project:

My most sincere appreciation to Dr. D. Earl Kline and Dan Cumbo. They provided me with guidance and support throughout this research project.

My sincere appreciation to Dr. Brian H. Bond, and Dr. Robert L. Smith for serving on my committee and providing valuable input.

My sincere appreciation to Patrick Rappold who provided answers to all of my graduate student related questions.

Time-Based Manufacturing System Design for Softwood Lumber Production

Table of Contents

List of Tables and Figures

List of Tables:

List of Figures:

Time-Based Manufacturing System Design for Softwood Lumber Production

1. Problem Statement and Research Objectives

1.1 Problem Statement:

Manufacturing industries in the United States continue to experience increasing pressure from foreign competition. U.S. firms may attempt to increase their competitiveness through product differentiation, reduction of manufacturing costs, and rapid response to customer orders (Blackburn, 1991). In industries where product differentiation is difficult, rapid order response is a favorable method for firms to achieve a sustainable competitive advantage (Koufteros et al., 1998). Quick response to customer orders is possible through shortening product lead times (the time it takes a product to move completely through the manufacturing process).

Time is considered by many to be one of the most effective ways for American manufacturers to outperform foreign competition when selling goods inside the United States. Time is so highly regarded because U.S. firms have a closer geographic proximity to the domestic markets. American manufacturers do not always take advantage of close proximity, and many Japanese firms have maintained a manufacturing edge in the U.S. through the efficient use of time-based manufacturing. Effectively implementing time-based manufacturing requires the reduction of production lead times through the elimination of wasteful activities (Blackburn, 1991).

The softwood lumber industry is an example of a manufacturing sector where product differentiation is difficult, and shorter lead-times are advantageous. The softwood lumber market is a commodity market dominated by price-based competition. Price changes in softwood lumber can present favorable short-term market opportunities

(Maness, 1993). If lead times in sawmills are excessive, however, they are unable to capitalize on the changing softwood market. In addition, changing market prices may cause sawmill facilities to lose money if products take a long time to move through the production facility. While rapid order response offers a potential advantage to softwood lumber producers, there is evidence to suggest that some softwood sawmills may have excessively long lead times (Kline et. al, 2003).

In addition to poor market responsiveness, long lead times are directly related to large work in process inventory levels (Crandall and Burwell, 1993). There are various cost disadvantages associated with carrying large amounts of work in process inventory. While inventory has been traditionally used as a buffer between operations, increasing competition necessitates minimizing inventory to reduce costs. In addition to carrying costs, inventory occupies space, and reduces the flexibility of manufacturers to meet customer demands.

Another important aspect of carrying inventory is the capital requirement. Inventory requires a cash investment that cannot be recovered until a product is sold. Consequently, when inventory is excessive, large sums of cash are “tied up” in the inventory creating an opportunity cost. The opportunity cost is the cost of the potential return of investing inventory capital elsewhere (Cavinato, 1988).

While there are negative aspects to carrying inventory, it is often viewed as necessary to overcome uncertainties in supply and demand. Most manufacturing operations are subject to uncertainties that require holding inventory. These uncertainties may include, fluctuations in customer demand, or raw material supply. The challenge in inventory level setting is to allow a business to keep inventory levels at a minimum while not impeding the ability of the firm to properly service its customers (Smalley, 2004).

As mentioned previously, lead time and work in process inventory are directly related. While there is no published information citing lead times in sawmills, Holemo did identify the need for improved sawmill inventory management in 1971. Holemo offered a solution to determine optimum inventory stock, however he did not associate inventory with lead time and softwood market pricing opportunities (Holemo, 1971).

There are various ways that manufacturers can reduce lead time. Koufteros, et. al proposed that lead times can be reduced through seven practices; employee involvement in problem solving, reengineering set-ups, cellular manufacturing, quality improvement efforts, preventive maintenance, dependable suppliers and pull production. These practices have been associated with improving competitive manufacturing ability (Koufteros et. al, 1998).

While various lead-time reduction strategies have been developed, there is no published evidence to suggest these practices have been employed by the softwood sawmill industry.

1.2 Research Objectives:

The overall goal of this study was to provide a method for southern yellow pine sawmills to become more competitive by increasing throughput of high demand products. An investigation was required to evaluate the attractiveness of short product lead time, as well as how to alter production systems to promote faster throughput. Reducing lead time decreases capital investment in inventory and increases manufacturing responsiveness to customer demand. The project involved a case study of a southern yellow pine lumber producer located in Virginia. The specific research objectives were:

1) To perform a current state value stream evaluation of the southern yellow pine manufacturing system.

2) To design a future state value stream with reduced lead time and increased efficiency.

3) To evaluate the capital inventory requirement of the current and future state value streams.

Objective one involved the use of value stream mapping techniques as described by Rother and Shook (1999) to evaluate the southern yellow pine manufacturing operation. Objective two used information gathered from the current state evaluation to create four different future state value stream maps. The future states were divided into those requiring the purchase of additional equipment, and those not requiring additional equipment investment. Both current and future state value streams were evaluated based on the capital investment required by inventory (Objective 3).

2. Literature Review

2.1 Softwood Sawmill Overview

Softwood sawmills are usually more automated and advanced than hardwood sawmills. They are designed for high speed production, and generally require fewer employees per unit of output than hardwood sawmills. Process flow in softwood and hardwood sawmills is similar, however, the technological advancement of the equipment often differs. Typical process flow in a softwood sawmill is shown below in Figure 2.1 (Haygreen and Bowyer, 1996).

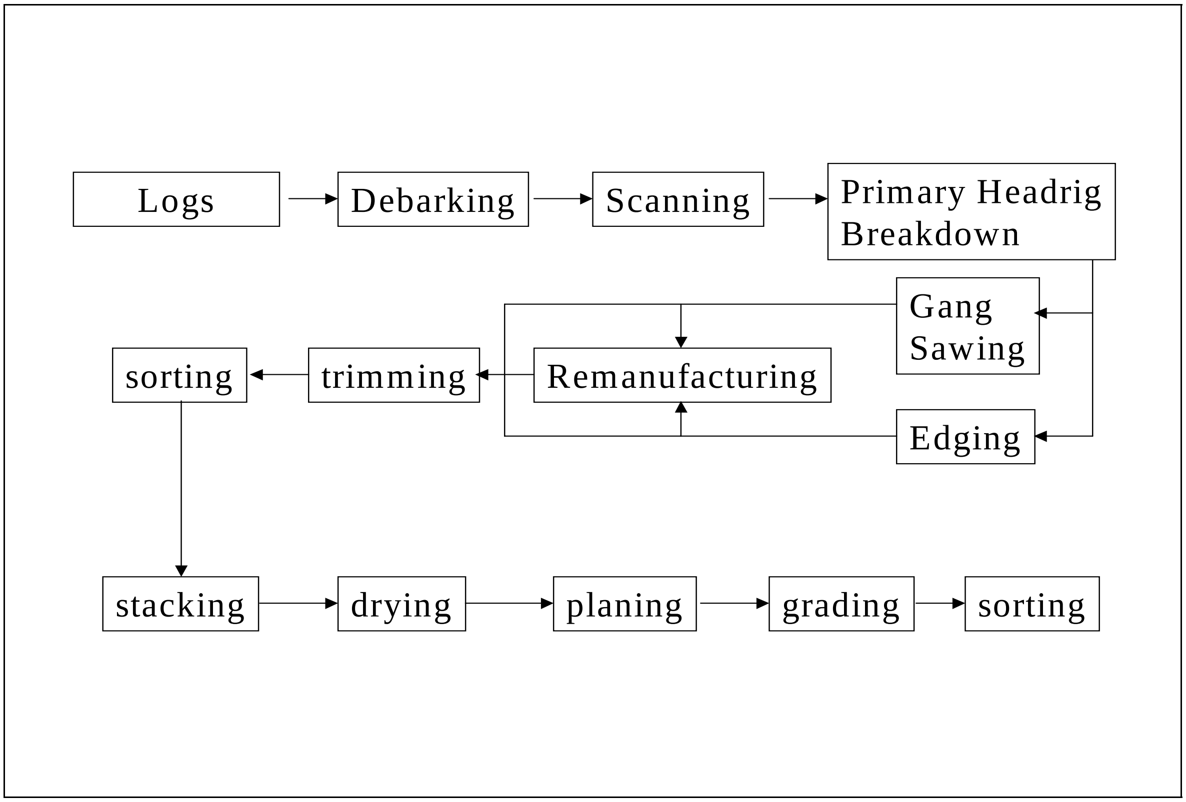


Figure 2.1. Typical softwood sawmill layout (Haygreen and Bowyer, 1996)

As shown by Figure 2.1, raw material enters the sawmill in the form of logs. Bark is first removed from the logs. After bark is removed logs are scanned to determine the most economical method of cutting. Softwood sawmills typically have scanning and software systems that will cut logs according to a combination of market price and yield. Market price is a common metric used by sawmills to reflect customer demand.

When the log is positioned economically for the headrig, the first cut is made and then lumber can follow a variety of paths depending on log size and grade. Ultimately, the lumber is edged and trimmed to length. After lumber nears the end of the sawmill, it is typically sorted by grade and size, then stacked for drying. Softwood lumber is commonly kiln-dried at very high temperatures and drying times are relatively short in comparison with most hardwood lumber species. In addition to drying, there are other ways that mills can add value to lumber. The dried lumber can then be planed, graded, or surfaced, and then sorted for shipment to the mill customer (Haygreen and Bowyer, 1996).

2.2 The Southern Yellow Pine Market

Softwood lumber is a commonly used building construction material. SYP lumber is typically graded in accordance with the southern pine inspection bureau grading rules (SPIB). The construction of single-family homes uses approximately 1/3 of total U.S. lumber production (McKeever and Anderson, 1992). Southern yellow pine dominates the softwood production in the South, while Douglas-fir comprises a significant portion of the western softwood lumber production (Lewandrowski et al., 1994).

Lumber labeled as southern yellow pine is typically one of the following four species: longleaf (*Pinus palustris*), slash (*Pinus elliotti*), shortleaf (*Pinus echinata*) and loblolly (*Pinus taeda*). Southern yellow pine products are often preservative treated for exterior applications. Southern pine is considered ideal for preservative treating because of its cellular structure, which allows deep penetration of preservative chemicals. In the year 2000, southern yellow pine represented 75% of the treated wood market (R.E. Taylor & Associates Ltd., 2002). According to a 1999 survey, treated southern yellow pine represented 66 percent of the U.S. residential decking market (R.E. Taylor & Associates Ltd., 2002).

There are several substitutes that compete with southern yellow pine for market share. Among these products are steel, naturally durable wood species, concrete, woodfiber-plastic lumber, untreated lumber, and plastic lumber. Research indicates that southern yellow pine lumber has recently been losing market share in the building construction industry, and that price, price stability, and declining quality are major concerns of SYP usage. One competitive advantage of SYP lumber is its warmth, attractiveness and environmental friendliness (Dunn, et al., 2003).

A recent survey of the 500 largest homebuilders in the U.S. (as of the year 2000) indicated that there are concerns of declining quality of southern yellow pine lumber. The results of the study indicated that while the majority of builders were still satisfied with quality, a growing number of homebuilders feel that SYP quality has declined in the last 50 years. The research also indicated that plantation lumber and poor kiln drying techniques were the most likely cause of declining product quality (Dunn, et al., 2003).

2.3 Softwood Lumber Pricing

Softwood lumber prices are traditionally seen as volatile, and fluctuate more than a number of other commonly used building materials (Irland, 1995). Uri and Boyd published research on softwood lumber demand, and the various factors that affect softwood lumber prices. The results of their research indicate that softwood lumber demand is influenced by lumber price. In the southern region, their model estimated that a 1 percent price increase in price results in a .2 to .3 percent decline in quantity demanded (Uri and Boyd, 1990). While they uncovered the relationship between price and demand, they seem to ignore the fact that producers are unable to influence market price, as indicated by Irland's research (Irland, 1995).

Demand for softwood lumber has traditionally been associated with the housing market. Uri and Boyd estimated that a 1 percent increase in housing starts results in a .27 to .45 increase in softwood lumber demanded (Uri and Boyd, 1990). McKillop et al. concluded similar results stating that a 1 percent increase in housing starts increased softwood lumber demand by .42 percent (McKillop et al., 1980).

The maintenance and remodeling market has also been linked to softwood lumber demand. The relationship between remodeling and softwood demand appears to be weaker than softwood lumber demand and housing starts. According to Uri and Boyd, a one percent increase in remodeling results in a .1 to .21 percent increase in softwood lumber demanded (Uri and Boyd, 1990). Uri and Boyd also found a weak relationship between softwood lumber demand and the price of substitutes in building construction. McKillop et al., however, did not find that substitute prices impact softwood lumber demand (McKillop et al., 1980).

There is evidence to suggest that lumber prices have been increasingly volatile since 1990 as a result of Canadian/U.S. softwood lumber trade disputes (Zhang and Sun, 2001). The impact of these disputes on the southern yellow pine market is uncertain. Since a large volume of southern yellow pine is sold as treated lumber, it may be possible that Canadian lumber prices and disputes have a minimal influence.

2.4 Preliminary investigation of the Southern Yellow Pine sawmill under case study:

The southern yellow pine sawmill researched for this project was first investigated in 2003. The assessment by Kline, et al. (2003) defined production flow for the sawmill and identified some of the "forms of waste" present in the manufacturing process. A flow diagram for the southern yellow pine sawmill is shown below in Figure 2.2. As shown by the figure, the lumber manufacturer's value adding processes include sawing, drying and planing. All of the different lumber products manufactured at the sawmill go through the same processing steps (with the exception of material occasionally sold in the rough green state).

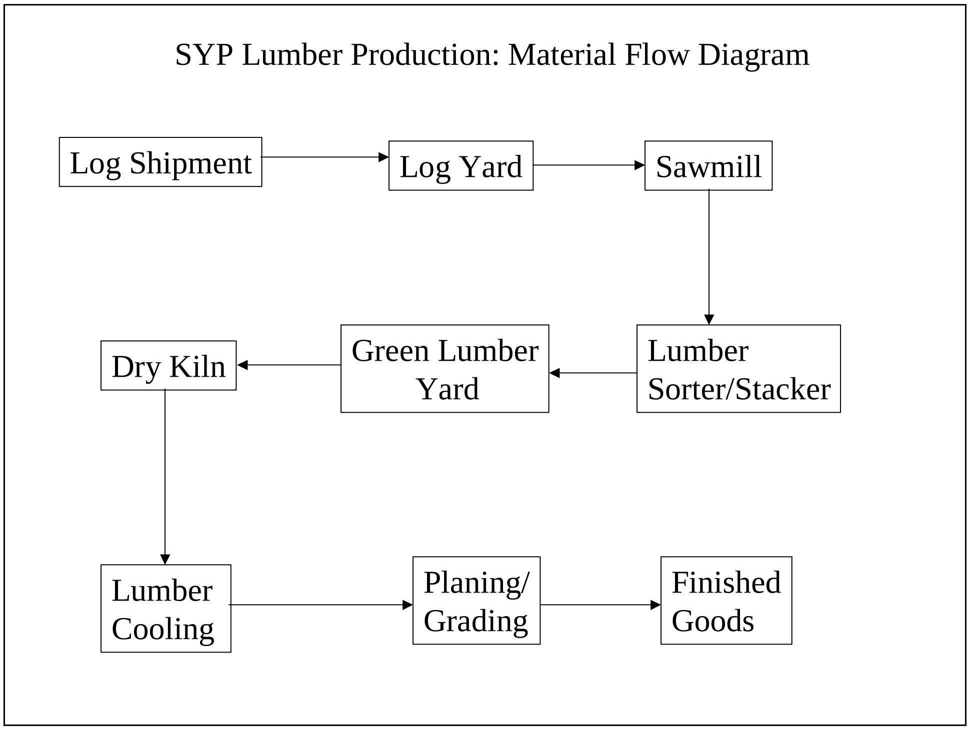


Figure 2.2. A flow diagram for the southern yellow pine sawmill under case study.

The preliminary investigation of the sawmill by Kline et al. (2003) identified some basic production inefficiencies at the lumber manufacturing facility. Unnecessary complications in production were identified from a time-based manufacturing perspective (further explanation of time-based manufacturing is given in section 2.6). Kline et al. exposed the following inefficiencies in the lumber manufacturing process:

1) Excess inventory in both work in process and finished goods.

2) Long lead time

3) Inefficient scheduling

4) Downtime at key work centers for maintenance and change over.

One goal of this research project is to further investigate these production issues and to provide solutions. While Kline et al. (2003) identified these problems, they did not offer a method to remedy the inventory situation or provide the framework for a more efficient mill with a reduced lead time and improved scheduling system. This research project will involve redesigning the production process to minimize inventory lead times. In addition, the project will uncover the constraints underlying these lead times and attempt to provide a deeper understanding of how these constraints affect the manufacturing process.

2.5 Capturing Value by Capitalizing on Lumber Price Changes:

Price changes for the southern yellow pine lumber industry typically occur on a weekly basis. Weekly price changes are recorded and published by Random Lengths (Random Lengths, June 2004). A competitive sawmill with a short lead time would be able to capitalize on favorable price changes by quickly moving products through the manufacturing system. Rapid processing allows the firm to better utilize headrig optimization programs. Headrig optimization programs saw lumber from a log in the most economical fashion based on yield and price. If a long period of time elapses between sawing and selling the lumber in a changing market, then the effectiveness of the optimization system becomes limited.

Maness (1993) identified the importance of market timing in the softwood industry where lumber price changes occur frequently. Maness cited market timing as a way to add value to commodity lumber. He also identified the need of sawmills to increase production output of products with relatively high prices by "responding quickly". Maness did not directly mention product lead time, however quick response requires that mills have a short product lead time and the ability to changeover frequently.

The first portion of Maness' study involved investigating historical random lengths data to determine if lumber price relationships stayed the same between products. The results indicated that these between-product price relationships tend to fluctuate, thus making a case for market timing and responsiveness. For example Maness' study found that the price difference between a 2 x 4 and 2 x 6 did not remain constant for a long period of time, thus firms must alter the output quantity of both 2x4 and 2x6 products to capitalize on changing markets. The study did not investigate the southern yellow pine market, and price relationships were only investigated for one year of random lengths data.

2.6 Reduction of Lead Time:

As mentioned previously, firms such as sawmills can achieve a sustainable competitive advantage through lead time reduction. Lead time reduction can be attained by employing time-based manufacturing practices. Time-based manufacturing utilizes various methods to reduce end-to-end production time (Daugherty and Pittman, 1995).

Total lead time has been traditionally viewed as the elapsed time from the moment when the order is placed, to when the customer receives shipment. Manufacturing lead time is the time elapsed from order preparation to when the product is completed (Daugherty and Pittman, 1995). This research project will focus specifically on manufacturing lead time at the southern yellow pine sawmill.

In 1998, Koufteros et al. proposed seven practices to reduce end-to-end production time. Their methods pooled the work of other researchers to provide a more comprehensive formula to reduce lead time. The seven time-based manufacturing practices are listed below (Koufteros et al., 1998). Each of the 7 elements are discussed in detail in following sections of this chapter:

1. Shop floor employee involvement in problem solving.
2. Reengineering setup
3. Cellular manufacturing
4. Preventive maintenance
5. Quality improvement efforts
6. Dependable suppliers
7. Pull production

2.7 Shop floor employee involvement in problem solving:

Involving shop floor employees in problem solving enables firms to utilize the other proposed methods of lead time reduction (Koufteros et al., 1998). Toyota, an automaker who has experienced tremendous success through time-based manufacturing, refers to their shop floor employee involvement as “Respect for Humanity”. Inputs from factory workers are appreciated, respected and expected to aid reengineering the manufacturing process. Toyota applies two major principles to shop floor employee involvement. The first is to “Give workers valuable jobs”, which implies that workers should strive to eliminate wasteful movements and tasks from their occupation. The second major principle is to open up lines of communication within the organization. This requires removing any formal communication barriers that tend to occur under traditional management (Monden, 1993).

Shop floor employee involvement is essential for cellular manufacturing, reengineering setup, preventative maintenance, quality improvement and creating dependable suppliers. All of these improvements enable firms to utilize pull production, which is also a method of lead time reduction. Pull production utilizes signals from downstream processes to produce products when the customer demands (Koufteros et al., 1998; Blackburn, 1991).

2.8 Reengineering Set-ups

Machine set-up can be the biggest obstacle in smoothing production and reducing lead time (Monden, 1993). Short set-up and changeover times allow firms to switch between products with minimum downtime, and ultimately make the manufacturer more responsive to customer needs. Reengineering set-ups can eliminate waste and benefit customers through lowered costs (Tu et al., 2001). Reduction of setup time has traditionally been shown to reduce work in process inventory when setup frequency is increased. However, if there is a large variance in setup times, work in process inventory may ultimately increase (Samaddar, 2001).

A systematic approach to setup reduction was created by Shingo (1985), who developed a method for reengineering setups at Toyota. Setup time reduction first involves identifying which setup activities are internal and external. External activities are tasks required for setup that must be performed when the machine is running, while internal activities must be performed while the machine is stopped. After this categorization, external activities can be arranged before or after internal setup. It may be necessary to redesign the relationship between the internal and external activities to lower set up time. Firms can further advance setup reduction by eliminating some unnecessary setup activities and performing others in parallel fashion. Additional capacity can also be used to reduce changeover and setup time (Samaddar, 2001).

2.9 Cellular Manufacturing

After investigating a wide range of industry and academic practice, Hyer and Brown (1999) defined a manufacturing cell as follows:

"Dedicating equipment, and materials to a family of parts or products with similar processing requirements by creating a work flow where tasks and those who perform them are closely connected in terms of time, space and information". The connection between people and tasks through time, space and information is considered a critical linkage (Yauch and Steudel, 2002). An example of cellular manufacturing in a sawmill would be a headsaw, edger, and trimmer linked by conveyance where one piece is processed at a time. The operators would be constantly aware of the cells production status through information linkage, and their processing times would be similar. In addition, machine operators would be in close physical proximity.

Cellular manufacturing is beneficial because it can reduce work in process inventory, throughput time, and enhance quality, all of which are necessary attributes for pull production (Koufteros et al., 1998). There has been extensive research on complex mathematical and computer based methods to design manufacturing cells. However, recent studies show that companies mainly depend on their own judgment, and process experience when approaching cell design (Yauch and Steudel, 2002).

Initiating cellular manufacturing can require major organizational change and commitment. Companies that attempt to implement work cells often struggle to achieve satisfactory results. While the technical aspects of cell design are important, cultural resistance to change can impede the success of cellular manufacturing (Yauch and Steudel, 2002).

2.10 Quality Improvement Efforts

Quality improvement is an important aspect of time-based manufacturing because it has been shown to reduce throughput time and increase competitiveness (Tu et al., 2001). Quality has a strong relationship to time-based manufacturing because poor quality parts must be remanufactured requiring excess production time. Quality errors are generally considered avoidable by constantly promoting quality throughout the production system. In addition, firms must have high quality production if they are using pull production since they tend to have less time to complete an order (Koufteros et al., 1998).

Product quality generally becomes more noticeable in short lead time environments. Production batches tend to be smaller as lead times decrease, and this makes defective products more conspicuous. When batches are large, defective products are often hidden, or the manufacturing company views the defects as merely small portions of the total output and says, “We’ll just make more” (Blackburn, 1991).

Quality control efforts in a short lead time environment must be a company wide commitment. Manufacturers can improve and sustain quality through emphasizing its importance in sales, manufacturing, enginerring, supply, distribution, etc. While quality is a satisfying attribute to the customer, it reduces costs for manufacturing firms by eliminating rework (Monden, 1993).

Toyota, who is typically known for effective quality management defined 8 steps of necessary business activities. They approached these 8 activities from a quality standpoint with a who, what, and where approach. The eight steps defined by Toyota are as follows (Monden, 1993):

1. Product Planning
2. Product Design
3. Manufacturing Preparation
4. Purchasing
5. Manufacturing for sales
6. Inspection
7. Sales and service
8. Quality Audit

The who, what and where approach applies to each step individually. For example who and where for product design would determine where quality monitoring would be conducted, and who would be managerially responsible. The “what” refers to what the quality assurance applies to and the methods to enforce it (Monden, 1993). Toyota’s approach appears somewhat generic, and could be performed at any manufacturing operation.

2.11 Preventive Maintenance

Preventive maintenance is important for lead time reduction because if equipment is not maintained, unexpected breakdown can result delaying the flow of material through the production system. To adjust production for machine downtime, manufacturers must increase work in process inventory, which ultimately increases product lead time. To avoid maintenance related dilemmas, manufacturers can design preventive maintenance programs (Weil, 1998). Preventive maintenance has become increasingly important in today's manufacturing environment due to the increasing complexity of machines, as well as the movement towards automation (Bockerstette and Shell, 1993). Also, as manufacturers reduce their inventory, they decrease their ability to buffer unexpected machine downtime with an excess finished goods stock.

According to Bockerstette and Shell, total productive maintenance (TPM) is a maintenance concept that fits well with time-based manufacturing. TPM applies product quality emphasis to maintenance, and is designed to support the equipment user. Bockerstette and Shell defined three major goals of TPM (Bockerstette and Shell, 1993):

1. Maximize equipment reliability – Eliminate waste involved in maintenance. This often requires decreasing changeover time, and eliminating non-value adding functions. Encourages efforts to simplify the routine maintenance process.
2. Develop a sense of ownership between operator and equipment through maintenance activity involvement. Requires that operators assume responsibility for the state of their equipment. They must understand causes

of poor performance, and may be required to collect data on the state of their equipment.

3. Promote continuous equipment improvement efforts through teamwork. Operators are paired with maintenance personnel and perhaps engineers to continuously improve machine reliability. Meetings often involve investigations into equipment failure and its causes.

The three principles mentioned previously involve both machine reliability and effectiveness. Reliability refers to the frequency of machine failure to produce and does not consider quality. Machine effectiveness refers to the ability of the machine center to produce quality products only.

2.12 Dependable Suppliers

Obtaining dependable suppliers that can delivery quickly can drastically reduce manufacturing lead time. When suppliers are not dependable, or they deliver goods infrequently, inventory must be stock piled to compensate, ultimately resulting in a higher lead time. Suppliers must also provide high quality parts that do not have to be returned, which would result in manufacturing delays (Koufteros et al., 1998).

Some experts suggest that supplier relationships should not be altered until after firms have implemented other manufacturing changes to reduce lead time. If suppliers are used as a means for lead time reduction, then they must ship material more frequently, and become part of the material flow scheme (Blackburn, 1991).

2.13 Pull Production and Production Smoothing

Pull production promotes the production of goods when the customer demands them. Production is based on a downstream demand signal. Pull systems are known to reduce the time that materials stay in the system by limiting the amount of inventory contained in the manufacturing process (Koufteros et al., 1998). Pull systems often utilize a supermarket pull system. A supermarket is an area of inventory. If a downstream process requires a unit contained in the supermarket, Kanban directs the upstream process to replenish what was needed by the downstream process. Kanban (Japanese for "signal") cards often track items that are pulled and replenished in the supermarket. These cards provide a very simple means of production scheduling and inventory regulation for various factory process. Kanban cards alert the upstream production process when material is pulled. By pulling exactly what a customer demands, the need for forecast and guesswork is reduced, eliminating the possibility for overproduction (Rother and Shook, 1999).

Supermarkets can be located at various places in a manufacturing facility. They are often used between areas where continuous flow is not possible due to differing cycle times and long travel distances between processes. Supermarkets are also located between shipping and finished goods areas (Rother and Shook, 1999)

2.14 Scheduling in a Pull Production Environment

One major advantage of a pull production system is that it provides a simple and more "on demand" method of production scheduling. In comparison with other manufacturing systems such as material requirements planning (MRP), pull systems governed by Kanban cards are simple to utilize. Pure pull systems do not require expensive and complicated software, and there is no need to forecast since products are pulled by customer demand. In addition, pull production systems do not require extensive office operations such as record keeping of inventory levels (Bolander and

Taylor, 2000). While pull scheduling systems reduces scheduling efforts and costs, they do not provide foresight of material and capacity requirements. In addition, it assumes inexpensive setups that promote small batch processing (Bolander and Taylor, 2000).

2.15 Leveling Production:

If manufacturers are trying to minimize inventory in a pull system, they can changeover products more frequently to level production. For example, if a sawmill was planing an equal amount of 2 x 4 and 1 x 6 lumber products in a week, they could process the material in smaller batches by alternating which type of lumber is planed each day. In manufacturing systems that do not employ time based manufacturing techniques, the 2 x 4's might be planed for the first 2.5 days of the week followed by the 1 x 6's for the remainder of the week. If production is changed over frequently, the amount of inventory required upstream from the process can be reduced, subsequently reducing lead time. Such measures of leveling production can improve quality, lead time, and also reduce costs (Rother and Shook, 1999). In such a case, management's area of focus must shift from inventory management and control to maintaining equipment effectiveness and set-up reduction.

2.16 Value Stream Mapping

Koufteros et al. (1998) confirmed the relationships of various practices to reduce lead time. Their research, however, did not mention methods to monitor lead time as well as its reduction. Value stream mapping is a tool used to monitor production lead time as well as identify areas of lead time reduction. Rother and Shook (1999) provide an overview of the steps to construct both current and future state value stream maps. A value stream map depicts all value and non-value added activities required to produce a product. Value-added activities are those that the customer considers valuable in terms of product quality or service. In addition to monitoring lead time, value stream mapping shows information flow as well (Rother and Shook, 1999).

Value stream mapping is done in two phases. The first phase is to create a current state value stream map, which represents the current manufacturing practices and flow. Current state mapping requires the collection of cycle times for each process, as well as lead times for inventory. The basic steps of current state mapping are listed as follows (Rother and Shook, 1999):

1. Determine customer requirements
2. Draw the processes required to produce the product being mapped. Inventory areas are also drawn. This step includes determining: cycle time, changeover time, uptime, product batch sizes, number of operators, number of product variations, pack size, working time, and scrap rate.
3. Record the method and frequency of supplier shipments.
4. Map the flow of information through the operation.
5. Develop the process and inventory timeline. Calculate lead time and value-added time.

The second phase is the creation of the future state value stream map, which represents an improved manufacturing state (Rother and Shook, 1999). The future state requires using information gathered in the current state assessment to move towards the goal of creating a system that contains individual processes linked to the customer demand through continuous flow or pull production (Rother and Shook, 1999).

2.17 The Role of Inventory:

Inventory in manufacturing facilities occurs in three forms:

1) Raw Materials – material that has not yet entered the manufacturing process

2) Work in Process – Material that has been processed by one or more manufacturing centers contained in the plant.

3) Finished Goods – Material that has successfully completed the manufacturing process

While there are many undesirable aspects of holding inventory in a manufacturing plant, there are 4 major reasons companies maintain inventory (Ainsworth and Deines, 2002):

1) To meet customer demand – If customer demand tends to fluctuate beyond the capabilities of the manufacturing operation excess inventory must be stored.

2) Smooth production scheduling – Certain amounts of raw materials are needed for production to operate smoothly. In situations were raw materials can sometimes be defective, the company must maintain an excess raw material inventory.

3) Take advantage of quantity discounts – Some companies buy large volumes of inventory to decrease per unit costs.

4) To hedge against price changes – Companies may buy or produce excess inventory if price changes are anticipated in the future.

2.18 Traditional Inventory Management:

One traditional method of inventory management is the economic order quantity (EOQ) model. Under the EOQ model, managing inventory requires balancing ordering and carrying costs. Ordering cost is the cost of obtaining one more order of inventory. Ordering cost typically varies with the quantity ordered. Carrying cost is the cost of carrying one additional unit of inventory. Carrying cost is the summation of storage cost, spoilage cost, inspection cost, batch-related costs, facility and product sustaining costs. Carrying costs and ordering costs used for the EOQ model are short-term costs only.

The EOQ model determines the order quantity placed every time inventory is ordered. The EOQ model is based on the following assumptions (Ainsworth and Deines, 2002):

- Uniform demand with no seasonal fluctuation
- Consistent lead time of supplier and manufacturer
- Partial orders are not possible
- There are no quantity discounts available
- There are no size limitations on inventory orders
- Batch-related, product-sustaining and facility-sustaining storage carrying costs are irrelevant.

Due to the various assumptions involved in the EOQ model, it is not suitable for many manufacturing facilities.

2.19 Inventory Management for Time-Based Manufacturing:

Manufacturers that employ time-based manufacturing practices hold inventory under closer scrutiny than those who employ the EOQ model. Due to the various costs incurred, excessive inventory is viewed as a form of waste. In addition, holding excessive inventory tends to conceal problems in the manufacturing process. According to time-based principles, inventory should arrive as needed in the appropriate quantity.

Long term carrying costs that are considered irrelevant under the EOQ model are emphasized and avoided in time-based manufacturing. Although carrying inventory is considered undesirable from the time-based perspective, it may be necessary to service customers (Ainsworth and Deines, 2002).

One modern tool of inventory management is ABC production analysis. Under the ABC production analysis, products are segmented based on customer demand. Products categorized as A, B, and C are characterized by high, medium, and low customer demand, respectively. Determining whether a product is high, medium, or low demand can be done by the manufacturer according to the demand distribution of different products. There are no quantitative figures to indicate what characterizes high, medium, and low demand. The relative demand categorization could vary with the operation so manufacturers must practice good judgment. There are different inventory management strategies that can be employed based on product segmentation (See Table 2.2) (Smalley, 2004).

Table 2.2. Inventory management based on ABC product segmentation.

Management Options	Advantages	Disadvantages
1) Hold finished goods inventory of A,B and C, make all products to stock	Ability to ship all items on short notice	Large space and inventory requirement
2) Hold zero finished goods inventory, make all products to order	Low inventory associated costs	Requires high process stability and short lead time
3) Hold only C products in inventory, make A and B products to daily order	Less inventory	Requires mixed production control and daily stability
4) Hold A and B products in finished goods inventory, produce C products to order	Moderate inventory	Requires mixed production control and daily stability
5) Hold B and C products in finished goods and make A products to daily order	Moderate inventory	Requires mixed production control and daily stability

6) Hold A products in finished goods and make B and C products to order	Moderate inventory	Requires mixed production control and daily stability

Once a manufacturing firm decides which inventory management option they want to pursue, they can calculate the inventory level of the products (if any) to be held in finished goods. The finished goods inventory needed to adequately service customers can be subdivided into cycle stock, buffer stock and safety stock. Cycle stock of finished-goods inventory is the amount required to service normal average customer demand. Buffer stock only accommodates demand fluctuations created by the customer, and safety stock is inventory necessary to cover internal uncertainties and errors. Internal processing errors may include downtime from machinery, and product losses due to quality (Smalley, 2004).

While there are various complicated mathematical formulas to determine the level of various inventory stocks, Smalley (2004) proposes a simple method to determine inventory stocks. An example of Smalley's finished goods calculations is given below in Table 2.3. Smalley's calculation shows that cycle stock is equivalent to daily demand multiplied by lead time, thus, firms with lower lead times need less cycle stock inventory.

Table 2.3. Finished goods inventory stock calculation (Smalley, 2004).

	Average daily demand * Lead Time to replenish (days)	**Cycle Stock**
+	Demand Variation as a % of cycle stock	**Buffer Stock**
+	Safety factor as a % of (Cycle stock + buffer stock)	**Safety Sock**
=		**Finished-goods inventory**

Buffer stock is used to counter a surge of demand. Standard deviations are used to determine the probability that demand will exceed a certain amount. The standard deviations can then be converted to a percentage of the cycle stock to determine the buffer stock required. Safety stock calculation requires data collection of the frequency of internal processing uncertainties. This information is converted to a percentage of the buffer and cycle stock.

2.20 Traditional Inventory Costing:

Inventory costs are typically itemized into the following costs (Ainsworth and Deines, 2002):

- purchase cost – The cost of manufacturing an item or buying it from an outside source. Includes direct labor, direct material and factory overhead.
- order/ setup cost – This includes the cost of production scheduling as well as arranging orders.
- holding cost – This is the cost of maintaining inventory, includes taxes, insurance, deterioration, etc.
- stockout cost – This is the cost of failing to fill an order because of insufficient inventory.

Holding costs are consequences of high lead times. High work in process and finished goods inventory resulting from long lead times increases the holding costs of manufacturing operations. If more inventory is stored, there is obviously more material subject to taxes and insurance charges. In addition, the longer material is stored, the more likely it is to deteriorate, be damaged, or lost.

While the above costs are commonly used to evaluate inventory cost, they fail to include some important cost factors and may not accurately reflect the true cost of inventory. One major drawback to typical inventory costing systems is that they do not quantify how inventory disrupts material flow in the manufacturing process. Often times, expensive systems are used to overcome and manage large inventories. Such systems include additional storage areas, material handling, bar coding, etc. High work in process inventory increases lead time, and the ability to quickly respond to customer orders. Increased storage space must be designated for products, extra operations added to deal with inventory, and material will need excessive handling to be sorted and reworked (O'Guin, 1991).

Another major downfall of holding excess inventory is the capital requirement. Capital invested in inventory cannot be recovered until products are sold. Cash dedicated toward inventory can be considered as a lost opportunity of investing an identical amount of money elsewhere. In addition, if companies have large amounts of money invested in inventory, they may have to borrow more capital or take longer to pay off mortgages (Cavinato, 1988).

Inventory turnover is a valuable measure to show how quickly products are moving through an operation. Inventory turnover represents how many times a company sold the average inventory for a specific period (Ainsworth, 2002). Inventory turnover can be calculated as follows:

Inventory Turnover = Annual Sales / Average Inventory

Whether or not inventory turns are considered poor or world class depends on the industry.

2.21 Sawmill Inventory

There is a direct relationship between lead time and work in process inventory. If manufacturing firms reduce their work in process inventory, they will experience a decreased lead time (Crandall and Burwell, 1993). Holemo (1971) recognized that there was a need for inventory improvements in sawmills as early as 1971. Holemo stated that sawmill inventory should be as small as possible while still providing adequate customer service. Holemo also noted that there was a need for increased inventory turns in sawmills (Holemo, 1971). Inventory turns in sawmills are calculated as the ratio of volume of annual sales to the average inventory volume. Inventory turns are often considered useful metrics of lead time. Manufacturers with shorter lead times will turn over inventory more frequently. Holemo's article was published before the rise of time-based manufacturing. Thus, he was unable to relate the attributes of time-based manufacturing to subsequent lead time reduction and thus more frequent inventory turns.

While there has been a significant shift in industrial systems to reduce response times, there is no current evidence to suggest that time based manufacturing practices are being utilized in softwood sawmills. Anecdotal evidence suggests that various batching constraints such as kiln drying provide challenges for lead time reduction in sawmills.

2.22 Sawmill Simulation

Simulation has been defined as "the imitation of the operation of a real-world process or system over time" (Banks et. al., 2002). Simulation models can be deterministic or stochastic. Simulation models not containing random components are deterministic, while stochastic models contain some random input components (Law and Kelton, 1991). Simulation models for analyzing sawmills were developed by Adams (1984, 1988), Aune (1974), Hall and Jewett (1988), Kempthorne (1978), Pennick (1969), Reeb (2003), Wagner and Taylor (1983), and Wagner et al. (1989).

Mwamakimbullah (2004) provided insight for reducing green lumber inventory. The study used Arena simulation to reduce green lumber inventory located upstream from the dry kiln. The results indicated that reduction of charge sizes could reduce green lumber inventory by 43.8 – 54%. Mwamakimbullah recognized the importance of inventory reduction to reduce capital required for manufacture, however he did not determine the cost savings associated with the inventory reduction.

2.23 Summary:

Time-based manufacturing practices provide methods to reduce lead time. Value stream mapping is a tool used to map current lead time and plan the future lead time for a manufacturing process. The softwood sawmill industry presents an opportunity for inventory and lead time reduction using time-based manufacturing process improvements and value stream mapping. Lead time and inventory reduction results in improved customer service, and a reduced capital inventory requirement. Lead time improvement also leads to opportunities to streamline operations with simple controls and lead to lower operating costs. Such improvements in the softwood sawmill industry could prove to be a valuable competitive advantage.

3. Methods:

This section contains the methodology related to the research objectives. The objectives of this research project were:

1) To perform a current state value stream evaluation of the southern yellow pine manufacturing system.

2) To design a future state value stream with reduced lead time and increased efficiency.

3) To evaluate the capital inventory requirement of the current and future state value streams.

3.1 Current State Evaluation

The first objective involved an assessment of the current manufacturing situation at the southern yellow pine sawmill. The current state evaluation is provided in Chapter 4. The mill was investigated based on the 7 time based manufacturing practices outlined by Koufteros et al. (1998) As mentioned previously, these practices, that have been shown to reduce lead time, include the following:

1. Shop floor employee involvement in problem solving.
2. Reengineering setup
3. Cellular manufacturing
4. Preventive maintenance
5. Quality improvement efforts
6. Dependable suppliers
7. Pull Production

Assessment of the current situation of dependable suppliers, shop floor employee involvement, preventive maintenance, quality, cellular manufacturing, and setups was based on observations as well as interviews with various mill employees. A list of questions related to these practices is provided in appendix D. The current evaluation of these practices provided a basis for improvement recommendations. All suggestions were derived to facilitate lead time reduction. Valid systems of quality, cellular manufacturing, etc. for time based manufacturing are outlined in Sections 2.6 – 2.14 of the literature review.

Value stream mapping was used to determine current lead times as well as design an improved production system for the southern yellow pine sawmill. The value stream mapping procedure described in Rother and Shook (2004) was used to create the current state value stream for the SYP sawmill under case study. Creation of the future state map began with the collection of a data set such as the one found in Rother and Shook. The data set contains details of the processes, customer requirements, available work time, and production control. A description of the information contained in the data set is:

Production Process

- List of products produced, and the processes they must go through
- Description of changeover constraints
- Supplier of materials and frequency of deliveries

Customer Requirements

- Customer orders on per month basis
- Quantity contained in customer shipments
- Frequency of shipments to customers

Work Time

- Work days per month
- Shifts per day at each process
- Frequency and length of standard employee breaks

Production Control Data

- Type of production control system and forecasting
- Frequency of receiving orders and method in which they are received
- Variables influencing production control
- Length of schedule and what processes receive the schedule

Process Information (each process contains its own data set with the following information)

- Operators required
- Cycle Time
- Changeover time if applicable
- Reliability
- Observed Inventory

Information from the data set was used to create a value stream map using the procedure outlined by Rother and Shook (2003). There are some differences however between the value stream mapping technique used in this research project and the ones described by Rother and Shook. The differences are:

- Product units were expressed in 1000 board feet (MBF) for this research project rather than discrete product units.

- Certain processes such as the sawmill and planermill have yield constraints. A yield adjustment was applied to the current state value stream map to accurately represent inventory levels.
- Calculation was used to determine cycle time instead of timing products with a stopwatch (See equation 1).
- Six months of average inventory and sales data were collected from mill management to develop a lead time, and value-added time timeline. Data were collected for March – August 2005 and provided a good representation of both high demand and low demand periods. Calculations employed for the value stream mapping timeline are:

$$\text{Cycle Time (MBF)} = \frac{\text{Available Daily Working Time (min)}}{\text{Avg Daily Production of Process (MBF)}} \qquad (1)$$

$$\text{Lead Time Non-finished Inventory (days)} = \frac{\text{Inventory at Storage Point (MBF)}}{\text{(Avg. Customer Daily Demand / Avg. Yield)}} \qquad (2)$$

*Avg. Yield - The average planer mill yield was 94.7%. The planer mill yield was used for calculating rough green, sorter, and cooling inventory lead times. For log inventory, a yield value of 82.5% or .825 was used.

$$\text{Lead Time Finished Goods Inventory (Days)} = \frac{\text{Finished Goods Inventory (MBF)}}{\text{Avg. Customer Daily Demand (MBF)}} \qquad (3)$$

3.2 Future State Manufacturing Systems

After the current state value stream map was developed for the southern yellow pine sawmill, future state maps were also developed. Future state maps use the same basic principles as current state value stream maps, however, they display the improved manufacturing system not yet in existence. The purpose of the current state map is to highlight areas that need improvement, while the future state map is an achievable system improvement goal. The objective of the future state value stream is to smooth and level production flow while implementing the shortest lead time, highest quality, at the lowest cost (Rother and Shook, 1999).

There were two groups of future state models developed for this research project. Both groups were designed based on achieving the shortest possible lead time. One group contained future state value streams that did not require additional investment by the lumber manufacturer. The other future state group contained value streams that required additional investment to implement.

Deterministic inventory simulations were performed in Excel for each future state except the mixed pull system to determine the lead time of air dry inventory. Determining lead time for other inventories was determined with equations 2 and 3. An example of air dry inventory simulation is shown in Table 3.1. The example in the table is less complex than the simulations used in subsequent chapters, however, the basic principle is the same.

The rough green inventory simulation was performed by cycling through production days. Sawmill production causes the inventory to increase, while some material is pulled for kiln drying. For example, consider the simulation shown in Table 3.1. The simulation is based on an operation the contains 2 products in rough green inventory, Both products are sawn each day, but only one 3000 bd. ft. charge is dried per day when the inventory level of one product is greater than or equal to 3000 board feet (bd. ft.) On average the sawmill in the Table 3.1 simulation produces approximately 1000 board feet of 1 x 4 lumber each day, and 2000 board feet of 2 x 4's each day.

Inventory levels of each product listed in table 3.1 are the levels contained at the start of the production day, before a charge is pulled to be kiln dried. As shown in the Table, the simulation starts with a total of 5000 bd. Ft., 3000 bd. ft. of 2 x 4's and 2000 bd. Ft. of 1 x 4's. Equation 4 was used to determine inventory levels as follows:

$$S_t = S_{t-1} + P_{t-1} – K_{t-1} \tag{4}$$

Where: S_{t-1} = Previous days Inventory of Product x before start of work day (bd. Ft.)

P_{t-1} = Previous days production of product x (bd. Ft.)

K_{t-1} = Previous day's quantity of Product x pulled for kiln if applicable (bd. Ft.)

$x = x_1, x_2, x_{3......}x_n$ individual products in product mix.

n = number of different size products

For example, Day 1 starts with 3000 2 x 4's before the work day begins (variable S in equation 4). The dry kiln pulls a charge of 2 x 4's that day as indicated in the kiln column. The charge is equivalent to 3000 bd. Ft.(Variable K). In addition, 2000 bd. Ft. of 2 x 4's are also produced on the sawmill (Variable P). When those values are entered into the equation, day two 2 x 4 inventory is equivalent to 2000 bd. Ft. at the beginning of the work day (See Table 3.1).

The same equation is applied to all the products. For example, the 1 x 4 inventory initially begins at 2000 board feet at the beginning of day one (S). Sawmill production on day one for 1 x 4's is 1000 bd. Ft (P). Since there is no 1 x 4 material dried in the kiln on day 1, K = 0. Thus, the starting inventory on day 2 for 1 x 4's is 3000 bd. Ft. as indicated in Table 3.1. The total inventory column in the table simply represents the sum of 1 x 4 and 2 x 4 inventory contained in rough green inventory at the beginning of each work day before a kiln charge is pulled.

Table 3.1. An example of rough green inventory simulation in excel. All numbers given in bd. ft.

	Starting Inventory, S_t		Kiln Pull, K_t		Products, P_t	
Day	X_1, 1 x 4	X_2, 2 x 4	X_1, 1x4	X_2, 2x4	X_1, 1x4	X_2, 2x4
1	2000	3000	0	3000	1000	2000
2	3000	2000	3000	0	1000	2000
3	1000	4000	0	3000	1000	2000
4	2000	3000	0	3000	1000	2000
5	3000	2000	3000	0	1000	2000

Rough green inventory simulations for the future state value streams were performed in the same manner, however, they typically contained 5 different products and that cycled through 100 production days. Also, dissimilar working times and cycle times of the dry kiln and sawmill required an inventory buffer. The dry kiln for some of the future state systems operates 7 days per week 18 hours per day, while the sawmill only produces lumber 5 days per week for an average of 8.8 hours per day. In those cases, the simulation included weekend days, and still used equation 4. Average total inventory values obtained in the simulations were used for lead time in inventory calculations for the future state value stream maps.

The simulations did not consider total volume variation of output by the sawmill, and each simulation assumed that the sawmill produced exactly to takt time (See Equation 5). Between product production volume variation was countered through the model's push scheme, where lower volume products were processed once their inventory levels were equal to or greater than 70,000 bd. Ft. Thus, as long as the mill was producing to takt time, it did not matter if the sawmill was producing 30 percent 2 x 4's or 2 percent 2 x 4's on a volume basis (explained further in Section 5.9).

Takt time calculation is also an important component of future state value stream mapping. Takt time is used to coordinate the speed of production with the pace of sales.

Takt time provides a reference for the rate at which a process should operate (Rother and Shook, 2003). Takt time was calculated as follows:

$$\text{Takt time} = \frac{\text{Available working time per day (minutes)}}{\text{Customer demand per day (MBF)}} \qquad (5)$$

In addition to the development of future state value stream maps, recommendations were made according to time-based manufacturing assessment in objective 1. These recommendations included improvements for preventive maintenance, shop-floor employee involvement, reengineering setups, and quality.

More frequent planer changeover is a requirement for the future state value streams. All of the future state models developed require processing different products more frequently, and a current assessment of planer changeover practices is provided in Section 4.14. Recommendations for planer changeover improvements that are based on the current state assessment are provided in Section 5.17.

3.3 Methodology for Evaluating Sawmill Inventory Capital Requirement

One major reason manufacturers want to limit work in process and finished goods inventory is due to the capital requirement of inventory. Capital invested in inventory cannot be recovered until the product is sold. Lumber manufacturers have capital invested in inventory located at various storage points. Consider the operation displayed in Figure 3.1. The process flow is typical of sawmills that dry and plane lumber. There are 4 different points where lumber manufacturers hold inventory: the log yard, green lumber yard, cooling area and the finished goods area. The investment in these inventory levels vary on the basis of product completion. Products located in finished goods inventory have been completely value-added, while raw material located in the log yard is at the initial stage of the process with no value added. Likewise, the capital investment in the inventory is going to vary based on the level of product completion.

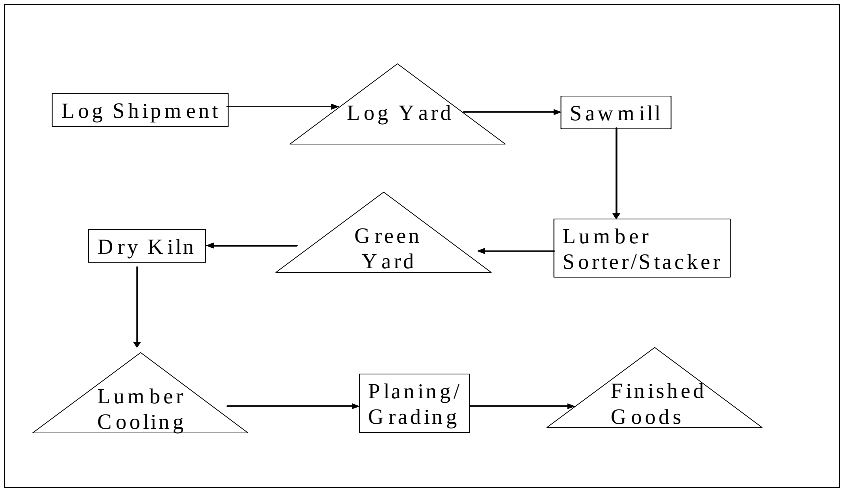


Figure 3.1. Typical process flow of a sawmill with a drying and planing operation. Triangles represent areas of inventory.

The method used for calculating the capital inventory requirement is shown in Figure 3.2. Capital is invested in inventory in the form of direct material, direct labor, and overhead costs. The model given in Figure 3.2 displays the costs applied when inventory is held between different stages of the production process. For example, to determine the capital requirement of inventory at the log yard the sum of the direct material, direct labor and log yard overhead costs must be calculated. Direct material costs include log costs. Direct labor includes the costs of paying an employee to load and unload logs from the log yard. Overhead could include costs such as insurance, taxes, etc. Total capital inventory requirements are determined through summation of the log yard, air dry, cooling, and finished goods capital investment.

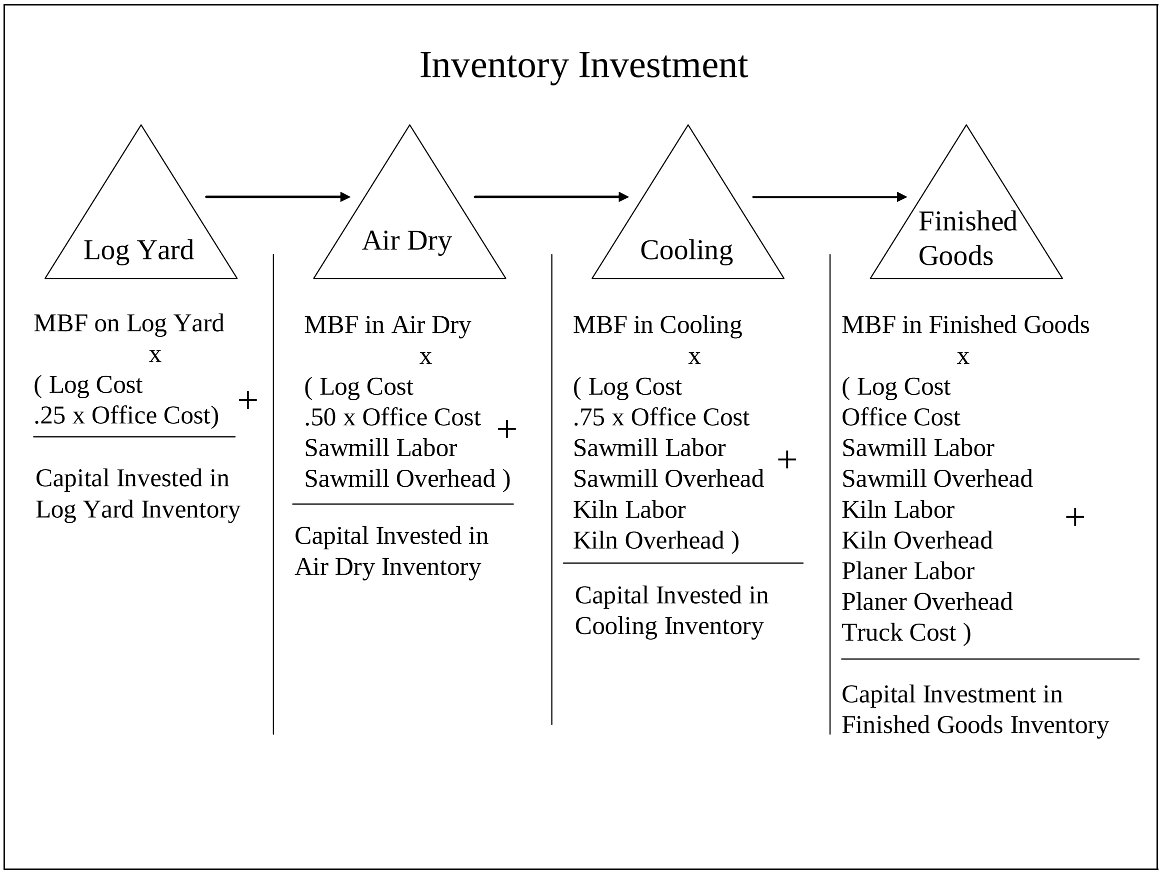


Figure 3.2. Method used to calculate capital requirement for inventory at various inventory points in the SYP manufacturing process.

One noticeable characteristic of the model in Figure 3.2 is that it is additive. For example the capital inventory requirement in finished goods inventory includes the capital invested at all the previous stages in the production process (for that particular finished goods inventory). Thus, the capital invested in inventory increases the closer the inventory becomes to being a completed product.

All costs listed in Figure 3.2 were obtained from mill management in the form of cost per thousand board feet (See cost description). Costs labeled as operation costs included both direct and indirect costs. Costs for this research project were separated in the same manner used by the manufacturer, and information required to separate direct and indirect costs was unavailable. The costs were multiplied by the corresponding inventory level to determine the investment held in inventory. This information was previously determined when developing the value stream maps. As mentioned previously, the current state inventory levels are based on six months of inventory data.

Cost Description:

Direct Material (Log Cost): The cost of purchasing logs

Sawmill Labor: Labor costs required to load logs and process into dimension lumber. Also includes labor required to stack lumber and load it onto the air dry yard.

Sawmill Operation: Includes energy cost required to operate sawmill, equipment costs, maintenance costs, building costs, insurance and taxes.

Kiln Labor: Labor costs associated with drying lumber, loading and unloading kiln

Kiln Operation: Energy cost, equipment cost including building, maintenance costs, taxes, insurance.

Planer Labor: Labor required to load planer, grade lumber, stack lumber and transfer it to finished goods

Planer Operation: Energy cost, equipment cost, maintenance cost, building cost of planer mill, taxes, insurance.

Office Cost: Includes salary requirement of management and sales staff, general administrative costs such as taxes, licensing and dues.

Truck Cost: The cost maintaining and operating trucks used for shipping finished lumber.

In addition to the current state capital inventory requirement, future state capital inventory requirements were also determined. Inventory levels determined during the development of the future state value streams were used to determine the future state capital inventory requirement through the use of the model shown in Figure 3.2. The future state capital inventory requirement model used the same costs per MBF as the current state model. These costs are given in Chapter 7.

The capital requirement of inventory can be directly related to lead time. If lead time is greater, the amount of inventory increases along with capital requirement. The opposite occurs when lead time is reduced. The capital requirement of the mill was observed under current state conditions, and then compared to the capital inventory requirement of the different future state value streams. The total capital inventory requirement provided a basis of financial comparison between the different value streams. This evaluation is presented in Table 7.1. The illustration of this relationship was necessary to show the benefit of lead time reduction.

4. Current Manufacturing Practices at the Southern Yellow Pine Sawmill

4.1 Introduction:

This chapter introduces the current state manufacturing process for a southern yellow pine (SYP) sawmill case study. A current state value stream map for the SYP sawmill was developed. Various manufacturing constraints and their impact on customer service were observed and discussed. An investigation of the current use of time-based manufacturing practices is included. This chapter provides the data and information necessary to improve the production process and create the future state value stream map.

4.2 SYP Manufacturer Data Set:

As mentioned in section 3.1, current state value stream mapping begins by gathering a data set. Information from the data set was used in the creation of the current state value stream map. Data contained in the data set is expanded upon throughout this chapter. The data collected for the operation is as follows:

Production Process

- The manufacturer produces 1 x 4, 2 x 4, 1 x 6, 5/4 x 4, and 5/4 x 6 in various grades and lengths. Products are sawn from a log, stacked, air dried and kiln dried, surfaced on four sides and then shipped to the customer.
- Changeover is required at the planer mill when switching between different width and thickness dimensions. Changeover takes approximately 45 minutes.
- Logs are supplied by various logging companies several times per day.

Customer Requirements

- There are approximately 40 different customers that order lumber specifically by size and grade. Customers order on average 464 MBF per week.

- A shipment is typically equivalent to a full truckload that is approximately 20 MBF.
- Shipments to customers occur approximately 5 times per day.

Work Time

- The mill operates 21 days per month according to six months of production data (March – August 2005).
- The planer mill and sawmill operate 8.8 hours per day, one shift per day.
- There is a 30 minute lunch break each day for each operation.

Production Control Data

- The sawmill depends on an optimized headrig for production decisions. The planer and kiln are scheduled by mill management staff based on inventory levels and market prices.
- The mill salesperson often solicits orders from customers. Orders are received through phone, as well as email.
- The length of the scheduling period varies with the amount of material available. Scheduling is done at both the kiln and planermill based on market conditions and work in process inventory

Process 1: The Sawmill

- 10 operators required
- Cycle Time = 5.24 minutes per thousand board feet (MBF)
- Changeover – N/A
- 89% Uptime

Process 2: The stacker

- 2 Employees required
- Cycle time = 3.0 minutes per MBF. Operates when material is available.
- Changeover – N/A
- 99% Uptime

Process 3: The Dry Kiln

- 1 Employee required
- Cycle time = 18 hours per 70 MBF or 15 minutes per MBF
- 2 hours required to load and unload kiln
- 96% Uptime
- 2 hour changeover time

Process 4: The Planermill

- 12 Employees required
- Cycle time 4.9 minutes per MBF
- Changeover = 45 minutes
- 97% Uptime

4.3 Current State Value Stream Map:

A current state value stream map is shown in Figure 4.1. This value stream map is based on information contained in the data set, and each component of the value stream map is thoroughly explained throughout this chapter. In addition, an explanation of value stream mapping symbols used in Figure 4.1 is given in Appendix A. Data for the value stream map were gathered from the beginning of March 2005 until August 2005. The data included inventory levels and sales volume (both in board feet), which were recorded monthly (See Appendix B and Table 4.1). Inventory levels were converted to lead times by the method outlined in section 3.1. Other value stream map information such as scheduling, etc. was determined from interviews with the mill management staff.

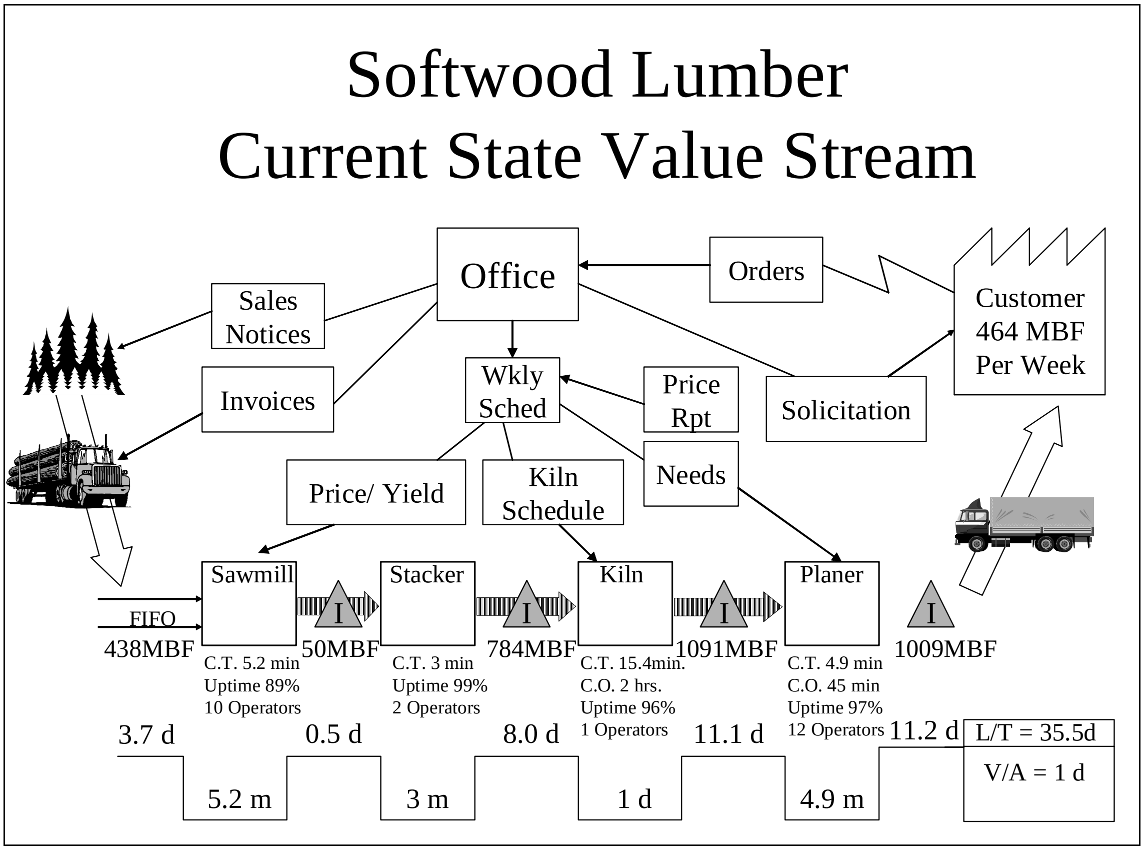


Figure 4.1. A value stream map of the SYP sawmill production process. Lead time and inventory levels were based on data gathered March-August 2005.

4.4 Lumber Company Value Stream Products and the Customers:

All of the products produced by the sawmill are subjected to the same production flow shown in Figure 4.1. The following product mix is manufactured in 8’, 10’, 12’, 14’, and 16’ lengths:

1 x 4, and 1 x 6	Grades: D and Better, D with stain, #2, and Low Grade
5/4 x 4, and 5/4 x 6	Grades: Premium, STD, Low Grade
2 x 4	Grades: #1, #2, #3 and #4

The following products are available in 6’ lengths:

1 x 4, and 1 x 6	Grades: #2 and Low Grade
5/4 x 4	Grades: Low Grade

- 5/4 x 6 Grades: Premium and Low Grade
- 2 x 4 Grades: #2 and Low Grade

The lumber manufactured is dried to 19 percent moisture content.Green lumber is occasionally sold, indicating that there is a small 2nd value stream that bypasses the kiln and planer. This value stream will not be considered for this research project.

The lumber manufacturer has approximately 40 customers. 26 percent of the lumber produced is sold to lumber treaters who treat the wood with preservative chemicals. Thirty-two percent of lumber produced is sold to crate, pallet or truss manufacturers, while the remaining 42 percent is sold to wholesalers. Since the SYP sawmill's production is dictated by price, yield, and avoiding planer changeover (which must occur to switch between certain products), the sales staff is often forced to solicit their products to buyers. If the production system produced according to customer order, such solicitation would be unnecessary. While customers do submit orders to the main office, these orders are most likely filled by the large safety stock held as finished goods inventory. The lumber producer spends the first half of the month filling contract orders. Contracts are typically the same each month (500MBF of 5/4 x 6 lumber) according to the sales manager. The SYP manufacturer typically needs two weeks notice to fill orders from customers.

Demand information was gathered from March – August 2005. The average volume demanded by customers per month was 2,048 MBF, with a standard deviation of 485 MBF. Demand is shown graphically in Figure 4.2. Anecdotal evidence suggests that that demand is seasonal, and determining the impact seasonality of this demand would require several years of monthly data for accurate analysis.

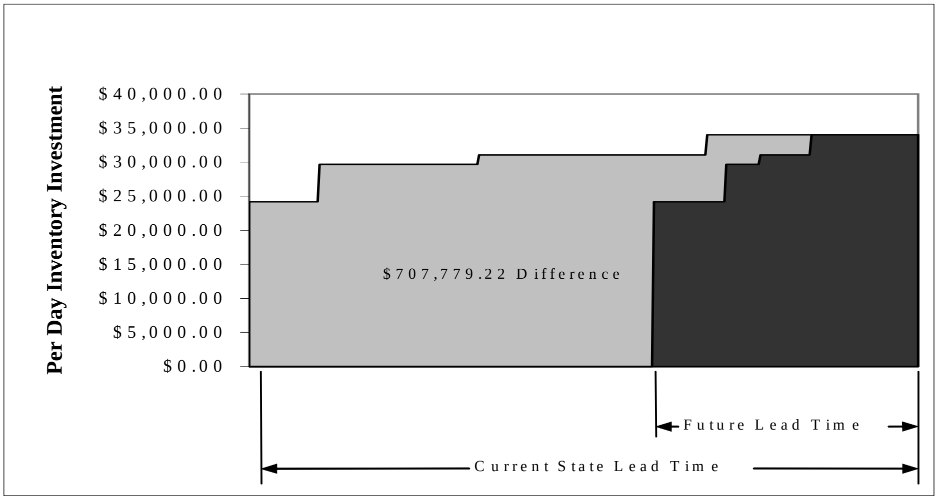


Figure 4.2. Monthly customer volume demand from March – August 2005.

4.5 Production Processes:

As seen in Figure 4.1, the value-added lumber manufacturing processes consists of sawing, stacking, kiln drying, and planing operations. Logs entering the sawing operation are debarked by a cambio ring debarker. The logs are then sent to the primary log breakdown system, which consists of a computerized carriage head rig and a computerized Mac Top Dog machine. The two primary breakdown systems create cants that are processed by the Ligna 10" x 60" thin kerf guided gang. Boards are transferred to a Hi-Tech optimized edger system if necessary. Lumber then passes through a Hi-Tech optimized trimmer system prior to being sorted in a 50 bin sorter. When lumber leaves the sorter it is stacked for air-drying by a Hi-Tech stacker.

According to mill management, the average sawmill yield is 82.5% of product from a log. The average yield is calculated on a weight basis, where lumber output is given an average weight based on dimension and is not physically weighed. Five months of production data were collected to determine a percentage wise breakdown of products produced by the sawmill. This data is shown below in table 4.1. As shown in the table, 5/4 x 6 products comprise the bulk of products produced by the sawmill, followed by 2 x 4, 1 x 6, 1 x 4 and 5/4 x 4 lumber.

Table 4.1. Average per product production of the SYP sawmill.

	Sawmill Production				
	1 x 4	**5/4 x 4**	**2 x 4**	**1 x 6**	**5/4 x 6**
AVG	7.2%	4.4%	9.4%	7.6%	71.3%
ST DEV	0.6%	1.7%	3.1%	1.4%	3.3%

After lumber is stacked, the next value-added process is kiln drying. The drying operation typically runs 24 hours a day 7 days per week. The dry kiln is an Irvington Moore computerized double track steam heated conventional kiln with a capacity of 100,000 board feet charge. Kiln drying time varies according to lumber size and moisture content. Lumber that has remained on the air-dry yard for a long period of time may be dried in as little as 10 hours but can take up to 18 hours. Lumber is dried to approximately 19 percent moisture content, but appears to be a very inexact science. Mill management indicated that the upper area of the dry kiln does not dry material as well as the lower portion. Material dried in the upper part is typically returned to the air dry yard to “finish drying”, hopefully to a moisture content of 19 percent.

After kiln drying, lumber is cooled in a cooling shed. The lumber is cooled to avoid defects in the planing operation. According to mill management, the lumber needs to cool for at least two days. The next value-added activity is lumber planing. Before the lumber is planed, a hemco tilt hoist breaks down the lumber packs. A 10 knife Yates American Planer then planes material. Planed lumber is conveyed into the grading area where SPIB certified workers grade the material. A Lucidyne Grade Mark Reader interprets the grading marks. The grader reader is electronically connected with the Hemco trimmer PLC and the Claussen grade stamper. Each piece of lumber is then conveyed to 25 bin Hi-Tech computerized sorter segregates each piece by size and grade. A Hi-Tech package maker and Signode package squeezer then package the lumber for final shipment.

4.6 Inventory:

Calculation for lead time in log, air dry, cooling, and finished goods inventory was performed by the method described in Equations 2 and 3 in section 3.1. Inventory levels were provided by the manufacturer over a six month span and the average values for each inventory is displayed underneath their respective inventory triangles in Figure 4.1. Inventory data is located in appendix B, while inventory fluctuations are shown in Figure 4.3.

As shown in Figure 4.1, inventory starts in the form of logs before the sawmill. Log inventory operates on a FIFO basis, where material is dated and material that has been on the yard the longest is processed first. According to the mill manager, log yard inventory typically ranges from 200 MBF to 1000 MBF. However, according to 6 months of inventory data, on average, there is 438 MBF on the log yard. The inventory on the log yard ranged from 140MBF to 857MBF (See Figure 4.3). This large inventory is due to uncertainties and inconsistencies log supply, where wet weather often makes logging impossible, and dry weather creates a sharp increase in log supply often resulting in oversupply.

The sawmill’s log supply is controlled by orders placed by the main office. Log procurement seems to be independent from customer demand due to the unpredictability of log supply and stumpage prices. According to management, saw logs are purchased based on knot size and frequency, straightness and log size. However, logs are not purchased by log grade or quality determination but rather, by weight. The sawmill does not appear to relate lumber grade output to the type of logs they purchase. If they were to be able to anticipate lumber products produced based on log attributes, they could possibly sort and adjust their log input more precisely to produce lumber products to better match that demanded by their customers.

In addition to the log inventory before the sawmill, there is work in process inventory at the drop sorter (located between the sawmill and the stacker). This inventory is necessary to allow sufficient product buildup needed to create a stack of lumber to be staged for drying on the green yard. The lumber inventory on the green yard, however, was observed to be 784MBF board feet according to the six-month average. This figure includes the average amount contained in the lumber stacker (50 MBF). The green yard inventory seems excessive considering that customers demand averages 464 MBF per week. According to investigation, the lumber remains on the green yard for an average of 8 business days. Planer production suggests that some low demand products remain on the green yard for a considerably longer period of time (see Section 4.10). Lumber remaining on the green yard for an excessive period of time may be susceptible to blue stain and high moisture content variation.

In addition to large inventory levels on the green yard and log yard, the value stream maintains a large inventory stock in the lumber cooling and finished goods area. Lumber spends an average of 11.1 days in the cooling area and 11.2 days in the finished goods area. Excessive finished goods inventory is an indication that production is not adequately matching the demand. Ideally, the sawmill should be able to ship their finished goods shortly after they are run through the planer.

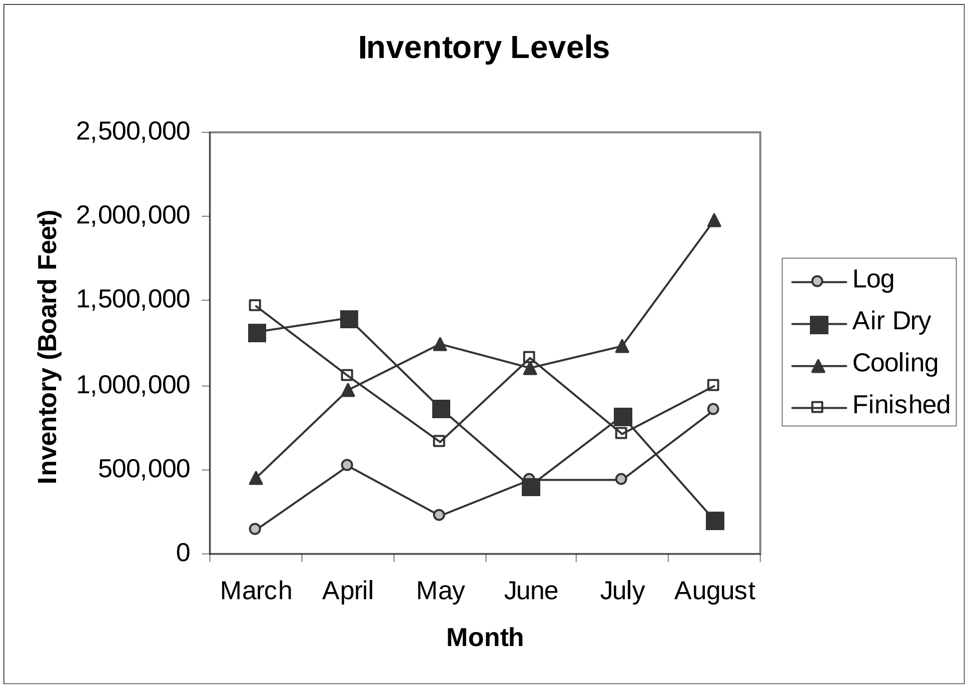


Figure 4.3. Inventory level fluctuations for the SYP lumber producer.

4.7 Value Stream Map Timeline:

The timeline at the bottom of Figure 4.1 shows the long lead time encountered in the southern yellow pine sawmill. This lead time was calculated on a monthly basis and averaged 35.5 business days on average and ranged from 28.9 to 43.8 days between March and August 2005. Lead time includes the time elapsed when the logs first arrive to when the lumber from those logs is delivered to the customer. The processing time for the lumber, however is 18.3 hours. The processing time is a measure of the total time spent adding value to the product. Kiln drying is considered a value added activity, however, the total value added time is shown as one day because a majority of the drying will typically occur when the sawmill and planer are not in operation (outside of normal operating hours). According to this information, value is being added to the lumber approximately 3% of the time when the southern yellow pine sawmill is in operation (See Figure 4.4). While air drying can typically be considered as a value added operation, there is not an effort to manage the air dry yard to obtain specific moisture contents or to minimize staining.

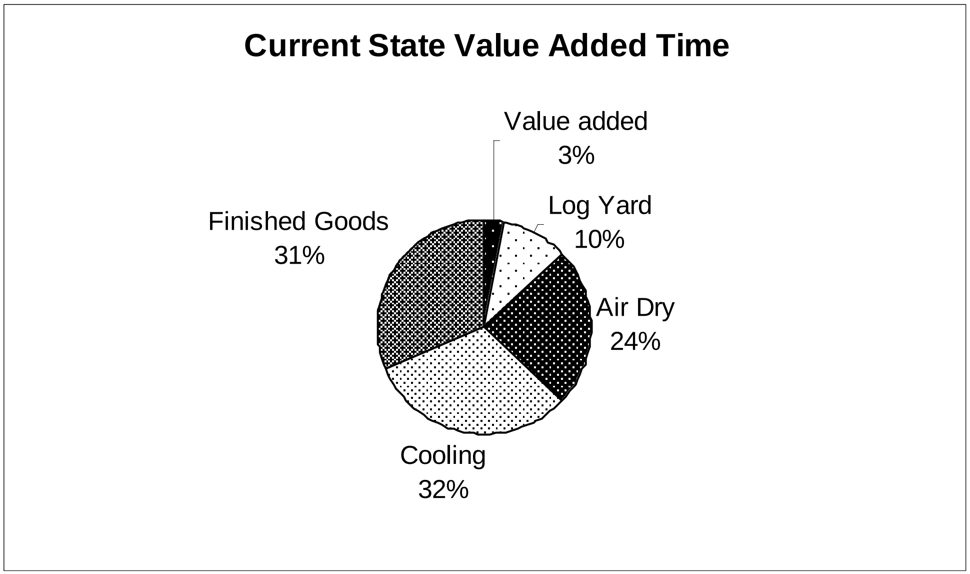


Figure 4.4. Graphical display of value added and non-value added time at the SYP sawmill.

Inability to quickly service customers (long lead times) drastically hinders the ability of the manufacturer to capitalize on short term market opportunities. Price changes in the softwood market occur on a weekly basis, yet the lumber producer requires considerably longer to produce a piece of lumber from start to finish. This necessitates forecasting, which is a very inexact science at best in the softwood lumber industry.

4.8 Production Scheduling:

As illustrated by the value stream map, production scheduling at the southern yellow pine manufacturer is essentially a push system that simultaneously schedules at three different points (kiln, planer and sawmill). Scheduling production at several processing points is undesirable because it tends to disconnect process flow and create more inventory and consequently more work for the production management staff to coordinate production schedules. According to the production staff, managers must constantly examine downstream production as well as consider work in process inventory at the various processing points and then make subsequent modifications to the scheduling system resolving real demand with what is currently in the system.

4.9 Sawmill Scheduling:

Scheduling in the sawmill is primarily based on prices obtained from Random Lengths pricing reports. In addition, there is speculation by the mill manager on which products will increase in price. Both the speculation and pricing factors are entered into the log scanning system, which determines how the logs will be processed. In addition to pricing, yield is also a major factor in sawing decisions. While the computer sawing program ensures the sawing of high priced lumber, it has no connection with real customer demand. Thus, there may not necessarily be a buyer for this high priced lumber.

Hypothetically, even if the manufacturer is aware of current demand and pricing, they may not benefit financially. Production decisions considered financially optimal at the time of sawing might become a financial loss by the time processing is complete. This is due to long lead time that averages 35.5 business days.

4.10 Kiln and Planer Scheduling:

Kiln scheduling is linked to the scheduling of the planer. The size of lumber dried in the kiln must be consistent with the products processed at the planer mill. While the manufacturer attempts to synchronize kiln and planer operations, there is still a large amount of buffer inventory between both processing areas. In general, the mill management staff does not plane a particular product until enough inventory is present in the cooling area to run the planer for at least 1 week.

The infrequency of planer mill changeover, and large kiln batching requirements appear to be the major source of the southern yellow pine lumber value stream's long lead times. There are various difficulties associated with changeover (See Section 4.11). According to mill management, changing over the planer typically takes 45 minutes. In addition, when the planer is changed to process a different lumber size, it results in lumber packs that are less than the required load sizes typically sold to customers. These partial packs are often difficult to sell at market price.

Since changeover is such a difficult obstacle for the mill, they typically process the same material for extended periods of time. It is common for the same lumber size to be planed for two consecutive weeks or more. The consequences of infrequent planer mill changeover and kiln batching requirements on production are shown in Figure 4.5. For example, 5/4 x 4 lumber was processed only 3 times over a six month period. Products other than 5/4 x 6 are typically processed infrequently. This indicates that the only product consistently available to customers is 5/4 x 6 lumber.

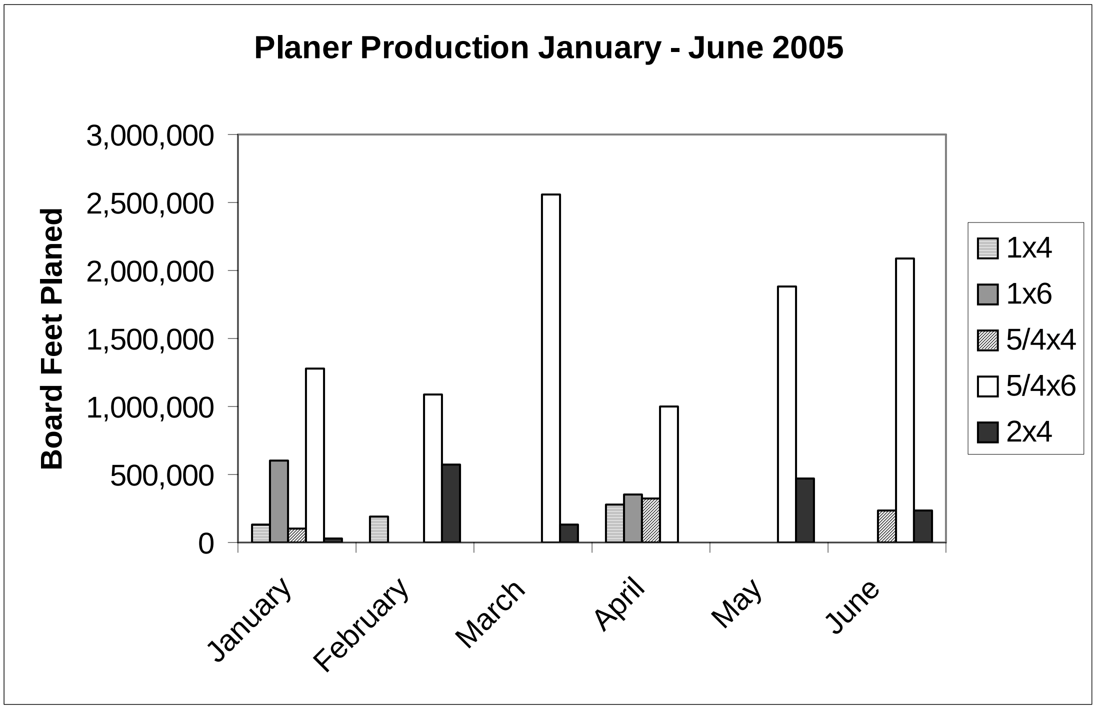


Figure 4.5. Production data for the southern yellow pine planer mill.

4.11 Yield Constraints:

Log variability appears to influence the sawmill's lumber production. According to mill management, 5/4 x 6 lumber is typically the most profitable product to produce, however, yield maximization requires that different lumber products are manufactured (ex. 1 x 4). In addition to differing lumber dimensions due to log yield, lumber grades are variable as well. The average grade yields for different lumber products are shown in Table 4.2. The planer mill averages a 94.7% yield on all products, thus the sawmill must saw more lumber than customers demand due to yield loss. Yield loss cannot be attributed to one particular factor. Yield loss may occur to actually increase the value obtained from a board, since graders attempt to trim boards to maximize the selling price of the lumber. Yield loss can also occur if the trimmer removes unwanted defects.

Table 4.2. Average yields for various lumber grades. Yields are based on monthly data from Mar. – Aug. 2005. Average summations do not add up to 100% due to yield losses.

	5/4 x 6		5/4 X 4	
Grade	**AVG**	**STD DEV**	**AVG**	**STD DEV**
Premium	25%	5%	30%	7%
Standard	43%	6%	25%	3%
Low Grade	20%	8%	35%	10%
Cutbacks	6%	3%	5%	2%

	1 x 4		1 x 6	
Grade	**AVG**	**STD DEV**	**AVG**	**STD DEV**
D and Better	29%	6%	19%	9%
D (stain)	5%	6%	4%	5%
#2	40%	4%	45%	4%
Low Grade	16%	2%	0%	0%
#3 and #4	NA	NA	21%	5%
Cutbacks	5%	2%	5%	2%

	2 x 4	
Grade	**AVG**	**STD DEV**
No. 1	14%	5%
No. 2	41%	14%
No. 3	14%	20%
No. 4	21%	11%
Cutbacks	4%	2%

4.12 Current Use of Time-Based Manufacturing Practices:

Interviews with mill management staff provided the assessment of time-based manufacturing practices at the SYP sawmill. The investigation included elements in discussed in Section 2.7 (Koufteros et al., 1998). Although it is listed as a time-based manufacturing practice, pull production was omitted from the assessment since their current system relies on pushing material through the manufacturing process. Recommendations for improvement for time-based manufacturing practices are given in section 5.16 – 5.20.

4.13 Shop Floor Employee Involvement:

Involving shop floor employees in problem solving facilitates lead time reduction. Input from shop floor employees is vital for reengineering setups, cellular manufacturing, quality improvement, and preventive maintenance. Therefore, employee input is key in creating a culture needed for continuous improvement, which lead to the implementation of pull production (Koufteros et al., 1998).

Mill management suggests that there is a low level of shop floor employee involvement in decision making. While employees were involved in making some decisions such as quality monitoring, maintenance, and suggestions for process improvement, the mill manager indicated that some employees were generally not skilled enough to handle greater responsibility required for decision making. The mill manager also indicated that some operators were very capable of handling decision making responsibilities and were observant of quality and maintenance issues. The sales manager and mill manager stated that language barriers were not an obstacle of shop floor employee involvement.

4.14 Reengineering Setups:

Machine set-up is sometimes the largest obstacle of reducing lead time (Monden, 1993). The only process where SYP mill has to changeover for different products is the planer mill. Planer change over requires emptying bins containing lumber as well as adjusting the planer settings for a different product. Changeover time depends on the lumber size being planed. Changeover takes approximately 45 minutes according to mill management staff, although the planer changeover observed for this project was completed in approximately 2.5 hours. Planer changeover is often done at the end of a shift, and requires a temporary work stoppage.

Planer changeover starts by shutting off the planer for knife changing. When the planer is turned off, the sorting line still continues by processing pre-planed material from partial lumber packs. Partial packs that cannot be sold bypass the planer and go through to grading station and into the drop sorter. While partial packs are being sorted, the planer mill manager changes the knives and settings on the planer.

In order to change the planer knives, the planer head is pulled out and dust is blown off with compressed air. Hoses are readily available overhead eliminating excessive foot travel. The knives are then removed from the planer with a wrench. Each knife is held in the planer head with bolts, and removing and replacing the knives on the bottom and top head is the most time consuming task for changing the planer. When a changeover was observed, the employee changing knives was frequently traveling from the planer to a cabinet to obtain the necessary tools. In addition, these tools were scattered throughout the cabinet with little organization. The mill manager indicated that it is not possible to completely remove and replace the head (instead of changing blades individually) to reduce changeover time. After the knives are changed, width and thickness setting adjustments are made.

After the planer sorting line processes lumber from partial packs, they must empty at least 10 of the 25 sorting bins located downstream from the planer. This process is the bottleneck of changeover according to the planer mill workforce and takes approximately 45 minutes. The conveyor layout requires the complete stacking of partial lumber that will be unstacked, sorted, and stacked again, indicating that time stacking partial packs is non-value added. While non-value added activities are very undesirable, the conveyor system does not allow partial pack lumber to bypass the stacking system.

After at least 10 sorter bins are cleared, the planer can begin processing the new product. The remaining partial bins are cleared while the planer begins processing the new lumber dimension.

4.15 Cellular Manufacturing:

Manufacturing cells are present in both the sawmill and planer mill where one piece continuous flow occurs. In the sawmill, the debarker, headsaw, gang saw, edger, and trimmer, as well as their operators are connected more or less through single-piece continuous flow (i.e. little or no product buildup between sawmill machine operations). Cellular manufacturing in the planer mill occurs between the planer, two graders, and the sorter. Boards come through the planer and are conveyed to the grading station where two graders stand side by side and grade lumber that is then conveyed to a drop sorter. The cellular processes mentioned above seem to provide little or no room for improvement in terms of creating and maintaining continuous flow.

4.16 Product Quality:

Time-base manufacturing principles indicate that quality should be constantly reinforced throughout the process. Defects that occur in the process should be noticed at that particular process (Monden, 1993). In the SYP sawmill, the sawmill manager, dry kiln operator, planer mill manager, and the loader operator in the finished goods area enforce quality. The sawmill manager enforces quality by periodically walking around to different machine centers and visually inspecting the output. The sawmill manager also measures boards with calipers for width variations. In addition, one sawmill employee located at the outfeed of the gang saw visually inspects the lumber for thickness variation. Quality monitoring in the dry kiln and planer mill is performed in the same manner, visual inspections by the kiln operator, or planer mill manager. The planer mill manager also measures boards roughly 5 to 10 times per day with a caliper.

The finished goods loader operator enforces quality through a visual inspection and has a quality checklist. The checklist standardizes quality measures at the end of the production process. The checklist contains the following items:

- No short lumber in pack
- No fork lift damage
- Verify grade and dimension to shipping order
- Total load matches order
- No wane on edge pieces
- Free of dust, debris, and bird droppings
- No twisted or slanted packaging bands
- Properly tightened packaging bands
- Bands 14”-18” from ends
- Number bands appropriate for lumber pack length
- Corner protectors present
- Moisture content meets customer specifications

Standardization of quality is not present upstream of the finished goods area. One premise of time-based manufacturing is that quality monitoring should occur at the source. Thus defects created during the production process should be observed and repaired at the same area where they are created with focus on elimination or minimizing causes of defects at the source.

4.17 Preventive Maintenance:

Preventive maintenance requires that operators develop a sense of ownership with equipment. This implies that the operators understand the causes of equipment performance as well as its repair (Bockerstette and Shell, 1993). According to management, the equipment operators are involved in preventive maintenance. Maintenance activities are governed by a preventive maintenance schedule. The sawmill and planer mill manager have access to these schedules and they communicate with employees when to perform the preventive activities. The schedules are based on historical equipment failures. Preventive maintenance activities include, but are not limited to lubricating fittings, changing blades and knives, cleaning optimizing sensors.

The frequency of maintenance related downtime in the sawmill and planermill is approximately 1 hour and 20 minutes per day respectively. Sawmill related downtime includes clean up time as well as chain repair. According to the sawmill manager the chain responsible for conveying boards separates approximately once per day. In addition, pieces of wood can lodge in between gangsaw blades and must be removed to continue proper operation. Planer related downtime includes time to change knives as well as clean up. In addition to routine maintenance, the mill management staff also attempts to minimize downtime by keeping parts in stock in a maintenance area.

Maintenance logs in the sawmill are frequently updated and monitored. If the headsaw stops production for more than 30 seconds, a dialog box on the sawing computer requires the operator to enter the cause of downtime. Sawmill management staff periodically reviews these downtime logs. Since the headsaw must stop when other machine centers are lagging, the headsaw log is used as a comprehensive way to monitor maintenance related downtime. The planermill does not attempt to closely monitor maintenance related downtime as done at the headsaw.

While the lumber manufacturer has an organized preventive maintenance schedule, maintenance tools are very unorganized. Tools needed for maintenance are scattered throughout cabinets, and they do not appear to have designated storage areas. In addition, maintenance activities appear to warrant excessive foot travel to obtain the maintenance tools further compounding downtime due to delays in maintenance. Also, no real root cause analysis methods are used to identify causes of downtime and fixes to eliminate causes (i.e., TPM)

4.18 Dependable Suppliers:

Dependable suppliers are necessary to effectively implement pull production (Monden, 1993). Unreliable log supply appears to be a production obstacle at the SYP sawmill. Weather conditions dictate the productivity of loggers, so the log supply tends to fluctuate with the weather. During wet weather, log supplies can become short. Conversely, prolonged periods of good weather can lead to over supply. An oversupplied log yard can cause grade loss as the ends of the logs become excessively dry.

4.19 Current State Improvement Opportunities:

According to the assessment provided in Sections 4.1 – 4.18, there are various opportunities for lead time improvement at the southern yellow pine manufacturing operation. These improvements include but are not limited to increasing the frequency of planer changeover, drying different products more frequently, synchronizing scheduling techniques to more accurately respond to market conditions. There is also opportunity improving time-based manufacturing practices. These improvements are discussed in Chapters 5, 6, and 7.

5. Future State Value Stream Maps and Time-based Manufacturing Recommendations

5.1 Introduction:

This chapter includes two future state value stream maps for the southern yellow pine lumber manufacturer under case study. The value streams developed in this chapter do not require additional investment to implement. The value streams represent opportunities to reorganize existing operations as well as identify technologies that need to be improved. The future state value streams were designed to better synchronize kiln and planer production with production of the sawmill. This required kiln drying and planing different products more frequently than the current state. Both future states represent a shortened lead time from the current state value stream map. Future state design is based on the six months of production and sales data collected from the mill as well as on interview information obtained from management staff. In addition to the future state maps, there is also a discussion on how future state leads to time-based manufacturing improvements based on the framework outlined by Koufteros et. al (1998).

5.2 Future State Value Stream Mapping

The goal of the future state value stream maps was to smooth and level production flow while implementing the shortest lead time, at the lowest cost. Current state practices such as infrequent planer changeover and the 70MBF batch drying requirement led to erratic production and long lead times (discussed in Chapter 4). Most notably, batch drying creates the need to process products 70 MBF at a time, while infrequent planer changeover results in processing certain products once every few months. The future state designs in this chapter attempt to reduce the impact of these constraints by changing over the planer more frequently, create a smoother dry kiln scheduling system and leveling production as much as possible. Leveling production provides a more consistent output of products to the customer and helps to lower overall inventory levels.

The future state value stream maps represent an improved process with reduced inventory. In addition, the future state value streams have a lower lead time, increased frequency of planer changeover, more efficient scheduling, matching production volume to demand, and very low or no implementation investment. While the future state value stream maps for the SYP lumber producer represent an improved manufacturing state, there are various production constraints that still limit response to customer order. There are several key manufacturing improvements that must be made to implement and sustain the future state. Such improvements are discussed in section 5.17.

The future state maps for the southern yellow pine sawmill are shown in Figures 5.1 and 5.2. The future state map shown in Figure 5.1 allows drying multiple lumber widths for a given thickness in the same kiln charge. Figure 5.2 dries each width and thickness separately. All of the Future state value stream maps will still enable the manufacturer to fill their monthly contracts of 500 MBF of 5/4 x 6 lumber per month.

Drying multiple widths in one kiln charge allows the lumber manufacturer to greatly reduce their lead time as well as batch size for different products. While these attributes are desirable, there may be moisture content variation issues associated with drying multiple widths in a single charge. There is evidence to suggest that drying times differ with lumber width and that drying two widths together may result in moisture content variations between the two dimensions. In contrast, products that take a long time to accumulate to 70 MBF (i.e. 1 x 4 and 1 x 6) may dry out significantly on the air dry yard which could lead to even greater variation than kiln drying multiple widths together (Culpepper, 2000).

As mentioned in the previous chapter, the SYP sawmill currently mixes widths in their drying operation. However, lumber that has not reached the target moisture content is put back on the air dry yard after kiln drying. The future state value stream drying multiple widths requires that all lumber dried in the kiln is not put back on the air dry yard, but moved to the cooling area instead. To implement the most desirable future state, the mill should experiment with multiple width drying to determine if moisture content variation will be outside of their quality specifications. Thus, two future states were given to allow the option of whether or not to dry multiple widths together. Specific details of the future state value streams are discussed throughout this chapter.

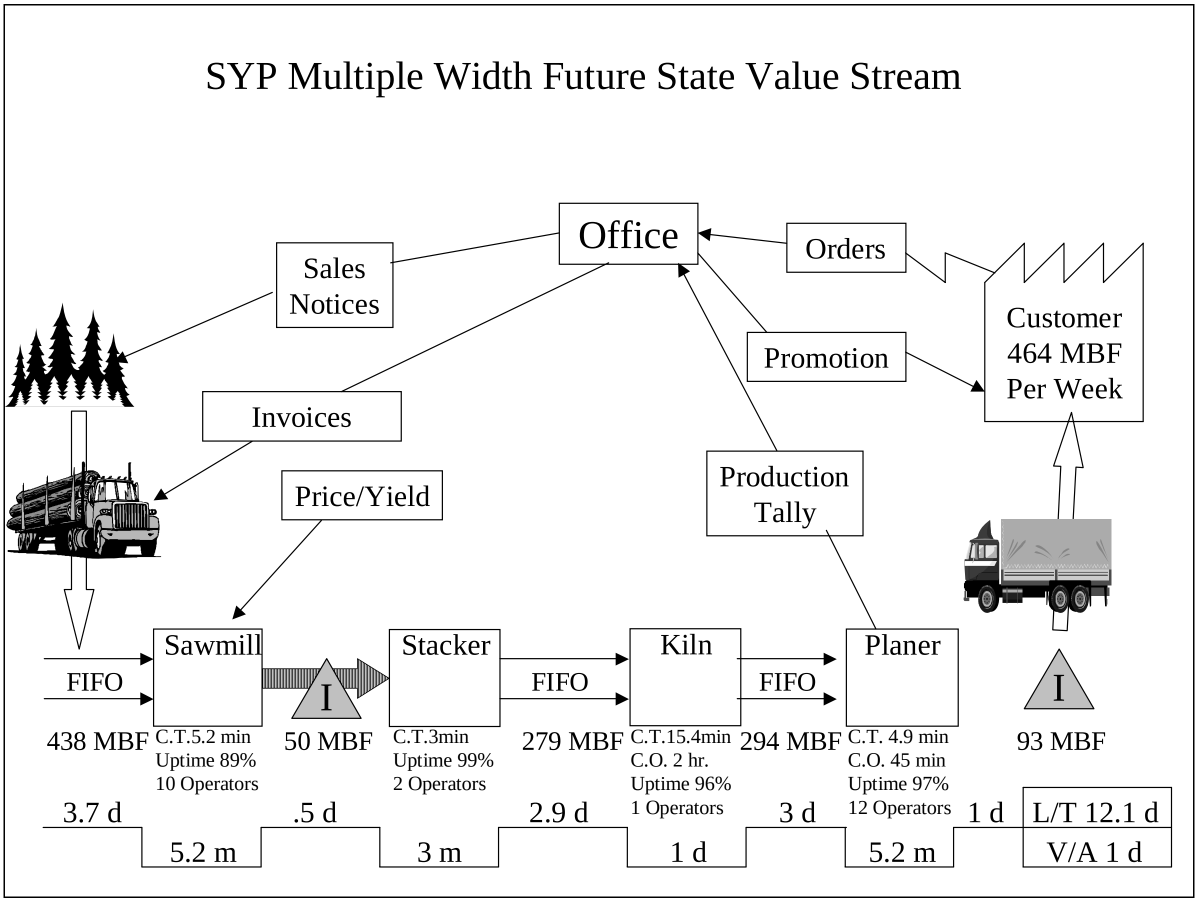


Figure 5.1. Multiple width drying future state value stream map for the SYP lumber manufacturer. The map was based on average customer demand from March-August 2005.

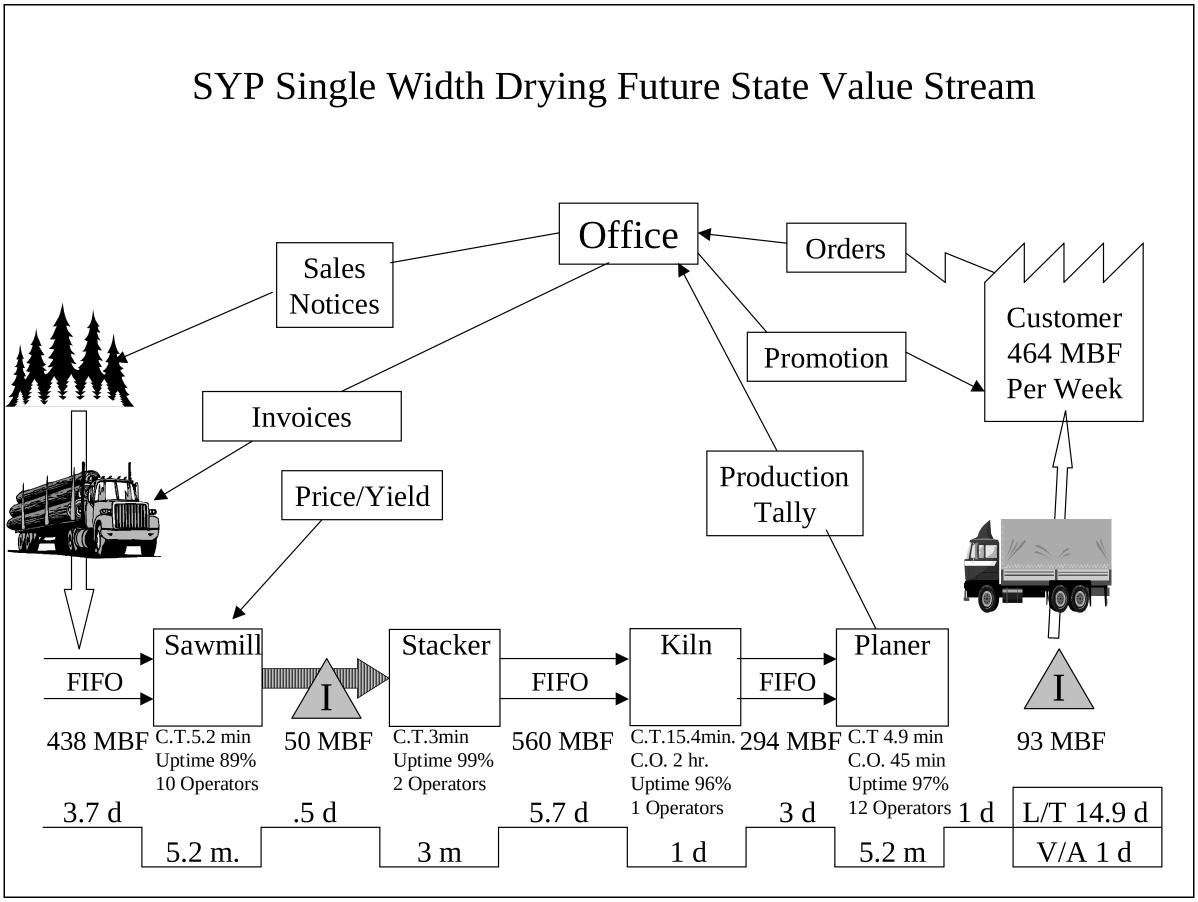


Figure 5.2. Single width drying future state value stream map for the SYP lumber manufacturer. The map was based on average customer demand from March-August 2005.

5.3 The Customer:

As shown in the value stream map in Figure 5.1 and 5.2, the average customer demand for the SYP lumber producer is 464 thousand board feet per week (MBF). The demand was obtained through the current state assessment given in the previous chapter. Filling customer demand of 464 MBF per week actually requires the manufacturer to saw 490 MBF since the average planer mill yield is 94.7% based on 6 months of yield data.

A takt time for the sawmill and planer mill was determined by the method outlined in Section 3.2. Producing to takt time allows the manufacturer to synchronize product volume with customer demand. The takt time for both the sawmill, stacker and planer mill is 5.2 minutes per MBF. This takt time is based on 40 hours of work time per week. Currently, the manufacturer operates 8.8 hours per week, however, 40 hours of work time was used in the takt time calculation to avoid overtime. As shown in both value stream maps, the sawmill cycle time is equivalent to the takt time. This does not allow room for unexpected downtime, and there should be focused efforts on limiting machine downtime.

As mentioned in the previous chapter, there are 119 different products manufactured (combination of different thickness, width, length and grade). Since the manufacturer's sawing decisions are driven by price and yield, they cannot accurately fill product orders through production at the head saw. Sawing lumber to customer order would require an extensive change to the current headrig optimization system. Thus, active market solicitation will still be required to sale lumber to customers. While solicitation will still be a requirement, the future state map contains a more predictable and consistent production system that will enable the sales staff to better anticipate production timing of different products in a much shorter time horizon.

5.4 Log Yard Inventory:

Log yard inventory for both future states is the same as it was for the current state value stream map (3.7 days assuming 82.5% yield). Keeping the same inventory is due to the lack of control the lumber company has over log supply. In the six months of inventory data collected, the log yard inventory varied from 1.5 to 9.5 business days. Mill management staff has continually voiced their frustrations related to inconsistency and large fluctuations in log supply. Logging regulations and weather conditions both contribute to log supply fluctuations and the lumber manufacturer claims inability to reduce fluctuations in their incoming log supply. While the lumber manufacturer cannot control log supply, they have not run out of logs in the last two years, indicating that the supply situation is not in desperate need of repair. However, the cost associated with office activities to deal with uncertainty and variation are certainly a major concern.

5.5 The Sawmill and Stacker:

Similarly to the current state value stream, the sawmill will continue to break down logs based on price and yield (in the same manner presented in Table 4.1). The future state production systems rely on consistency in the sawmill, so it may be necessary to improve current maintenance programs to make sure the mill produces steadily. This is especially true since sawmill cycle time and takt time are equal. If the sawmill does incur unnecessary downtime, their will be a one day inventory buffer located in the rough green yard in case the sawmill has to halt production for serious maintenance problems.

The stacker and inventory located upstream of the stacker will operate in the same manner as in the current state. The sorter will contain approximately 50 MBF of lumber and will have a lead time of .5 days. Batching at the stacker is still necessary for staging lumber for the drying process and represents an unavoidable batching constraint. Material is still pushed from the sawmill to the stacker because the sawmill still remains the decision point for which products are produced and due to log yield constraints, there is uncertainty on which products will yield out.

5.6 Air Dry Inventory and the Dry Kiln:

Rough green inventory between the stacker and dry kiln has been greatly reduced in the future state value streams. This reduction is achieved by processing different products more frequently in processes downstream from the sawmill. Rough green inventory was determined according to a load-leveling scheme devised for the dry kiln, as well as dry kiln batching constraints.

The dry kiln typically dries 70 MBF of lumber per batch. These batches are dried for approximately 18 hours. Because the cycle time of the sawmill is faster than that of the dry kiln, the dry kiln must operate 7 days per week. Since sawmill production is 490 MBF per week, the kiln must dry 7 loads per week. The future state kiln schedule dries one 70 MBF load per day. By the end of the work week, the sawmill builds up a surplus of rough green inventory to feed the dry kiln through the weekend.

Products of equal thickness are dried together in the future state map pictured in Figure 5.1. There are three different thicknesses produced by the lumber manufacturer (5/4”, 2”, and 1”). Thus kiln batches can be separated into the following:

A. 5/4” x 6” and 5/4” x 4”
B. 2” x 4”
C. 1” x 4” and 1” x 6”

According to past production data (See Table 4.1), it takes 4.83 days of sawmill production to produce a kiln charge of 1” thick lumber, and 7.6 days to produce enough lumber for a kiln charge of 2” thick lumber. 5/4” thick lumber charges are produced every .9 days (Table 5.1). The figures mentioned above are derived according to sawmill production of 490 MBF per day and a kiln charge requirement of 70 MBF. To reduce rough green inventory, 2” and 1” thick lumber is processed as soon as enough material is produced to fill the 70 MBF kiln requirement. 5/4” material is dried for the remainder of the kiln charges, and is often used to keep the dry kiln operational during the weekend.

Table 5.1. The amount of time required to produce enough material for a 70,000 bd. ft. kiln charge. Based on historical sawmill production data.

	Per Day Future State Sawmill Production		
Thickness (in.)	1	2	5/4
Daily Production	14504	9212	74186
Days to fill Charge	4.83	7.60	0.94

The future state value stream map in Figure 5.2 does not dry equal thicknesses together. Thus, the rough green inventory in Figure 5.2 is greater than that of Figure 5.1. The amount of time required to produce enough material for a kiln charge in the single width drying operation is shown below in Table 5.2. Table 5.2 is based on the current state sawmill production averages displayed in Table 4.1, and a daily sawmill production of 490 MBF.

Table 5.2. The amount of time required to produce enough material for a 70,000 bd. ft. kiln charge. Based on historical sawmill production data.

	Per Day Future State Sawmill Production				
Product	1 x 4	5/4 x 4	2 x 4	1 x 6	5/4 x 6
Daily Production	7056	4312	9212	7448	69874
Days to fill Charge	9.92	16.23	7.60	9.40	1.00

5.7 Air Dry Inventory Simulation For Multiple Width Drying:

A simulation was performed in Microsoft excel to determine rough green inventory and its fluctuations for both future state value stream maps. All of the rough green inventory simulations for this research project were performed according to the method described in Section 3.2. Lumber located in the stacker, approximately 50 MBF, was not included in the rough green inventory simulations because it was not yet stacked for kiln drying. The simulation cycled through production by day and included weekend days where the dry kiln was operational and the sawmill was not. The excel simulation for multiple width drying displayed three different inventories according to the three different product thicknesses (See Figure 5.3). The rough green inventories increased according to a 5-month sawmill production average. The 5/4" thick inventory increased by 74,186 feet per workday, while the 1" and 2" thick inventory increased 14,504 and 9,310 board feet respectively. When a kiln charge of a certain thickness was pulled for the rough green inventory, that particular inventory would be reduced by 70,000 board feet (See Appendix E). A kiln charge was pulled for 1" and 2" thick products whenever their inventory was over 70 MBF (enough material to fill one kiln charge), while 5/4" thick material was processed the remainder of the time. As shown in the table, inventory fluctuations consistently cycled from 209,998 board feet to 349,998 board feet. This represents a cycle time of 2.1 to 3.6 days, which is substantially lower than the current state cycle time of over 8 days. For simplicity, an average cycle time of 2.9 days is represented on the future state map. The inventory level fluctuates due to the different operating times of the kiln and sawmill.

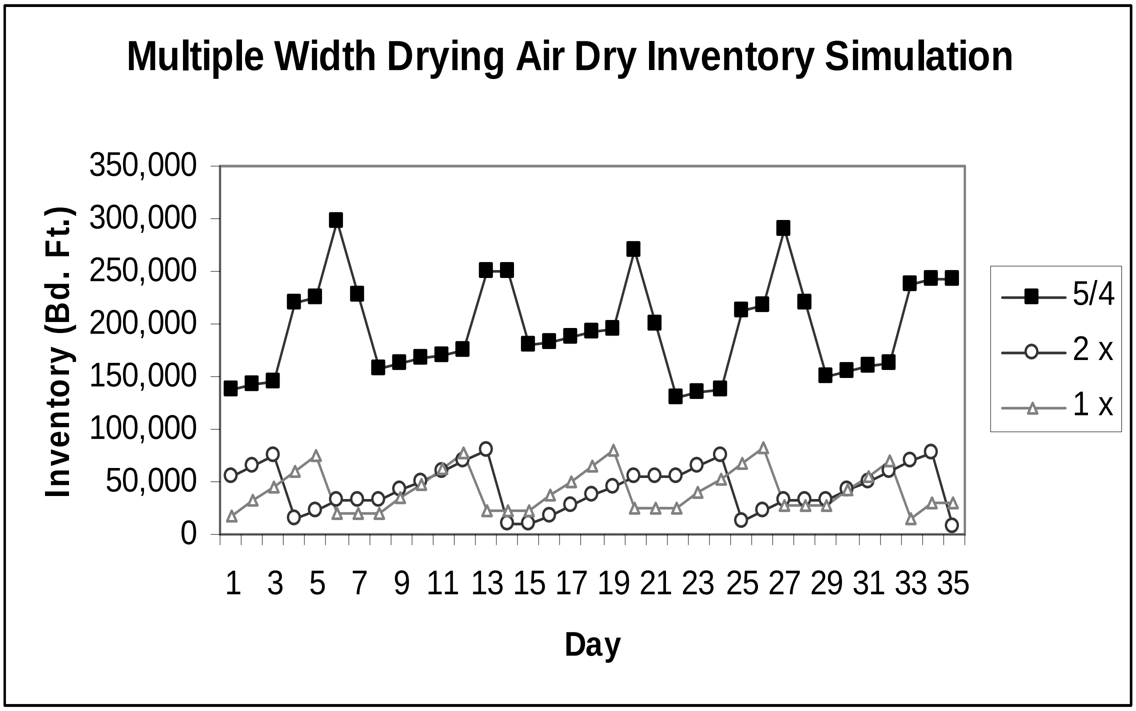


Figure 5.3. Graphical display of inventory fluctuations according to the rough green inventory simulation performed in Excel.

The 209,998 board feet minimum inventory represents the amount of inventory required to feed the kiln during the weekend as well as allow the processing of material in the event that the sawmill should shutdown on the first day of the work week. This minimum inventory represents a worst case scenario where there is not enough inventory to dry a complete charge of 1 x or 2 x dimension lumber (69,999 board feet per each). However, there is still enough 5/4 dimension lumber to fill the kiln for one day. Should the sawmill continue to be shut down, then lumber of other dimension can still be processed in the kiln though the loads are not at maximum capacity. It is uncertain whether or not this safety stock of inventory would ever be needed, or if it is sufficient. Ideally, optimal safety stock could be calculated based on historical sawmill downtime records.

5.8 Air Dry Inventory Simulation For Single Width and Thickness Drying:

The rough green inventory simulation for the future state shown in Figure 5.2 operates in a similar manner to the simulation for the value stream map in Figure 5.1. The rough green inventory simulation is shown graphically in Figure 5.4 and a table of the simulation is provided in Appendix F. This system requires the processing of 1 x 4, 1 x 6, 5/4 x 4, and 2 x 4 products when 70 MBF have accumulated on the air dry yard. 5/4 x 6 products are processed when there is not enough material to process other lumber sizes. The inventory amount was based on a situation where 1 x 4, 1 x 6, 5/4 x 4, and 2 x 4 have inventories of 69,999 each, and there must be enough 5/4 x 6 material to feed the kiln during 3 non-production days. This created a minimum total inventory of approximately 490 MBF. By the end of the work week, total inventory levels would rise to 630 MBF. The maximum and minimum total inventory levels reflect a cycle time of 5 and 6.43 days respectively. For the purposes of the value stream map, the average cycle time of 5.7 days was used in Figure 5.2.

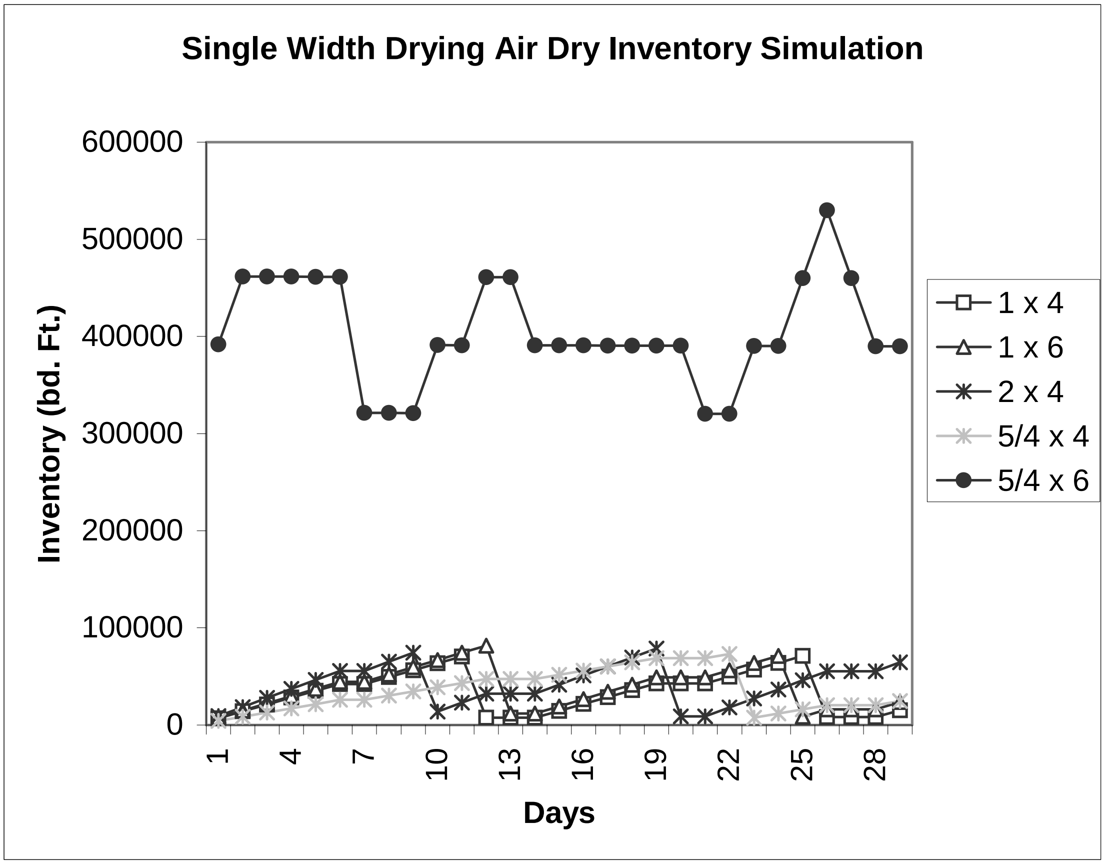


Figure 5.4. Air Dry inventory simulation for the value stream map shown in Figure 5.2.

5.9 Product Mix Variation:

Both the multiple width, and single width drying system depend on synchronizing production exactly with takt time. However, the system will allow variation in the product mix, as long as sawmill and dry kiln weekly production are equal (490,000 bd. ft. per week). For example, suppose that sawmill increased the production of 2 x 4 lumber by 10% and decreased the production of 5/4 x 6 lumber by 10 percent. The proposed product mix is shown below in Table 5.3.

Table 5.3. Production of the sawmill based on hypothetical product mix variation.

	Sawmill Production				
	1 x 4	5/4 x 4	2 x 4	1 x 6	5/4 x 6
bd. Ft./ Day	7056	4312	19099	7448	60104
Percentage	7.2%	4.4%	19.4%	7.6%	61.3%

Table 5.3 shows sawmill production based on takt time of 98MBF per day. A simulation was performed in the same manner as outlined in Section 5.8, however, the production output of Table 5.3 was used to show the impact of a variation in product mix from the historical averages. The results of the simulation are shown graphically in Figure 5.5 The total inventory in the simulation ranged from 429,796 at the beginning of the week to 569,796 at the end of the last production day of the workweek.

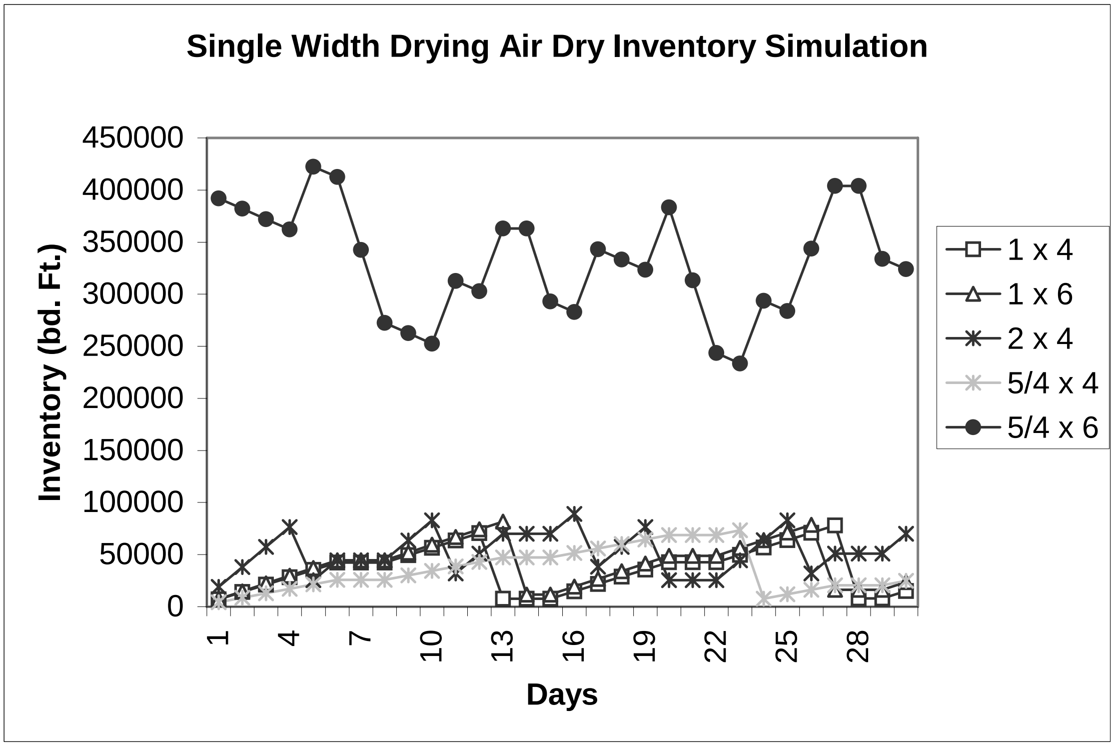


Figure 5.5. Single width drying air dry inventory simulation where sawmill product mix output varied from the historical data collected.

Since the proposed future states systems can accommodate product mix variation from the sawmill when takt time is maintained, this can be a valuable control for the sawmill to alter the product mix to meet demand. For example, under the simulation shown in Figure 5.5, 2 x 4 lumber could be processed every 3.7 working days on average. This is substantially lower than the 7.6 days under the system modeled in section 5.8.

Thus, if the manufacturer can alter the headrig optimization system to increase the output of certain products, they can reduce their lead time for that certain product. One disadvantage to such alterations is that yield may subsequently decrease, and the lead time for other product(s) will increase.

5.10 Cooling Inventory:

In contrast to the current state value stream, there is a FIFO lane located between the kiln and planer mill. FIFO simply means first in first out, thus as charges are removed from the kiln they are planed according to which charges have been in the FIFO lane the longest. The rough green inventory discussed in the previous section also operates on the FIFO principle. One major advantage of FIFO systems is that they do not require scheduling.

As shown in Figures 5.1 and 5.2, there is an inventory of 3 days in the FIFO lane. The inventory level actually fluctuates from 2 to 4 days due to the dissimilar operating times of the kiln and planer, but the average is used for the purposes of the value stream map. This inventory is needed to allow sufficient cooling time for the lumber, and to equalize the differing operational times between the planer mill and kiln. The mill management staff stated that their lumber requires approximately 2 days of cooling to avoid planing defects.

5.11 The Planermill:

As mentioned in the previous section, material at the planer mill is processed according to a FIFO lane. Since both future state value stream maps rely on processing different products more frequently, the planer mill must be able to changeover quickly to surface different lumber products and keep up with takt time of 5.2 minutes per thousand board feet. Reengineering planer changeover is described in reengineering set-ups section of this chapter.

5.12 Finished Goods Inventory:

Finished goods inventory is approximately 1 day. This value is based on the time needed for the sales staff to solicit the products produced by the planer mill. Variation finished goods lead time is discussed further in section 7.6. Ideally, the sales staff could solicit material in advance based on average grade yield at the planer mill. An investigation of planer production data indicated that grade yield is highly variable and difficult to anticipate. Table 5.4 shows the variation of grade yield at the planer mill. The variation is based on two standard deviations from the mean for 6 months of planer production data for each grade produced (Table 4.2 contains means and standard deviations for each product). The kiln charge column in the table represents the range of material yielded from a 70 MBF kiln charge.

Considering that a truckload of lumber is typically 20 MBF, some lumber grade and dimension combinations will not be able to fill an entire truck when one 70 MBF kiln charge is processed. Table 5.5 shows the production days required to fill a 20 MBF truckload of each grade, width and thickness under the single width drying future state. The table was derived from data contained in table 4.2 and the variation in Table 5.4.

As shown in Table 5.5, it may take a long time to accumulate a truckload of certain grades, the sales staff will need to find customers who will buy mixed grades in a truckload of lumber to maintain a low finished goods inventory. Since the lumber manufacturer future state will lead to the competitive advantage of processing of different products more frequently, perhaps the sales manager could make agreements with customer to buy certain products ahead of time even with the possibility of product yield variation. The implications of variation in finished goods lead time is discussed further in Section 7.6.

Table 5.4. Confidence interval for planer mill grade yield. Based on 6 months of planer production data.

	5/4x6 (78 Observations)		5/4x4 (9 Observations)	
Grade	**95% Interval**	**Kiln Charge bd. Ft.**	**95% Interval**	**Kiln Charge bd. Ft.**
Premium	14 - 35%	10,045 - 24,707	14 - 42%	10,011 - 29,586
B Grade	0 - 5%	0 - 3,841	0%	0 - 0
Standard	30 - 56%	20,796 - 38,914	18 - 32%	12,838 - 22,395
Low Grade	4 - 36%	2,666 - 25,479	12 - 52%	8,526 - 36,282
Cut Backs	0 – 12 %	0 – 8,400	1 - 9%	700 – 6,300

	1x4 (10 Observations)		1x6 (12 Observations)	
Grade	**95% Interval**	**Kiln Charge bd. Ft.**	**95% Interval**	**Kiln Charge bd. Ft.**
D and Better	18 - 40%	12,263 - 27,671	2 - 36%	1,041 - 24,860
D (stain)	0 - 17%	0 - 12,021	0 - 13%	0 - 9,134
#2	31 - 48%	21,590 - 33,778	38 - 52%	26,274 - 36,615
Low Grade	11 - 21%	8,019 - 14,992	0%	0%
#3 and #4	NA	NA	11 - 30%	7,787 - 20,919
Cut Backs	1 – 9%	700 – 6,300	1 - 9%	700 – 6,300

	2 x 4 (12 Observations)	
Grade	**95% Interval**	**Kiln Charge bd. Ft.**
No. 1	5 - 24%	3,456 - 16,678
No. 2	14 - 69%	9,540 - 47,965
No. 3	0 - 53%	0 - 37,409
No. 4	0 - 42%	0 - 29,602
Cut Backs	0 - 8%	0 – 5,600

The ability of the sales staff to predict planer mill yield could be improved through the understanding and reduction of grade yield variation. There are four or five factors that likely contribute to grade yield variation; log variability, log breakdown pattern, inconsistent and poor drying practices, and mechanical degrade. If the lumber manufacturer can understand and influence the impact of these variables, they can improve their customer service by improving the consistency of product output.

Table 5.5. Production days required to accumulate a truckload of each grade and size combination. Minimum and maximum are based on the 95% yield variation presented in Table 5.4.

	5/4x6		5/4x4	
Grade	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Premium	1.0	2.0	16.2	32.5
B Grade	6.0	inf.	0.0	0.0
Standard	1.0	1.0	16.2	32.5
Low Grade	1.0	8.0	16.2	49.0
Cut Backs	2.0	5.0	16.2	inf.

	1x4		1x6	
Grade	**Minimum**	**Maximum**	**Minimum**	**Maximum**
D and Better	9.9	19.8	9.4	188.0
D (stain)	19.8	inf.	28.2	inf.
#2	9.9	9.9	9.4	9.4
Low Grade	19.8	29.8	inf.	inf.
#3 and #4	NA	NA	9.4	28.2
Cut Backs	19.8	49.6	18.8	37.6

	2 x 4	
Grade	**Minimum**	**Maximum**
No. 1	15.2	45.6
No. 2	7.6	22.8
No. 3	7.6	inf.
No. 4	7.6	inf.
Cut Backs	15.2	121.6

5.13 Information Flow:

The future state value stream map represents an improved and simplified flow of information. The current state map required scheduling at both the planer and kiln, while the new system schedules strictly at the sawmill. The new scheduling system has been modified in approach as well. Under the current scheduling system, management schedules based on how much inventory is present to provide a long run of product at the planer mill, while also considering some customer needs at both the planer mill and kiln. The future state system simply processes certain products once their rough green inventory rises above 70,000 board feet (with the exception of 5/4” thick material), on a FIFO basis. Since the FIFO system is less complex, management has the opportunity to reduce the time spent managing their rough green inventory. In addition, the resulting product output will become more predictable, and quality will increase due to more predictable moisture content variation.

5.14 Total Lead Time:

As shown in Figure 5.1, the lead time for the future state value stream map is approximately 12.1 days. The lead time for the value stream map shown in Figure 5.2 is 14.9 days. This is significantly lower than the current state lead time of 35.5 days. While the lead time is lower, it is still longer than the elapsed time between market pricing reports. Thus, the price of some products in production could change before the customer purchases them. However, the impact of price changes are likely to be less drastic than that encountered in the current state, and the system more responsive to these changes. As mentioned in the current state assessment chapter, some products have a lead time that is much longer than the 35.5 day average lead time. Under the multiple width future state system, the planer processes all products every 7.64 working days minimum. The single width value stream processes all products every 16.24 working days minimum (See Section 5.6). The financial implications of the various lead times are discussed in Chapter 6.

5.15 Value Added Time:

A graphical display for value added time in both future states is displayed in Figures 5.6 and 5.7. Figure 5.6 represents the value added time of the manufacturing system that dries multiple widths. Figure 5.7 represents the manufacturing system with single width drying. For both future states, the value added time is greater than the current state which added value to material approximately 3 percent of the time (See Figure 4.4). Increasing the percentage of value added time means that the material is moving through the production operation more quickly, thus the manufacturer has increased the rate of return on the investment required to produce an individual product. The impact of this faster velocity will be studied in detail in Chapter 7.

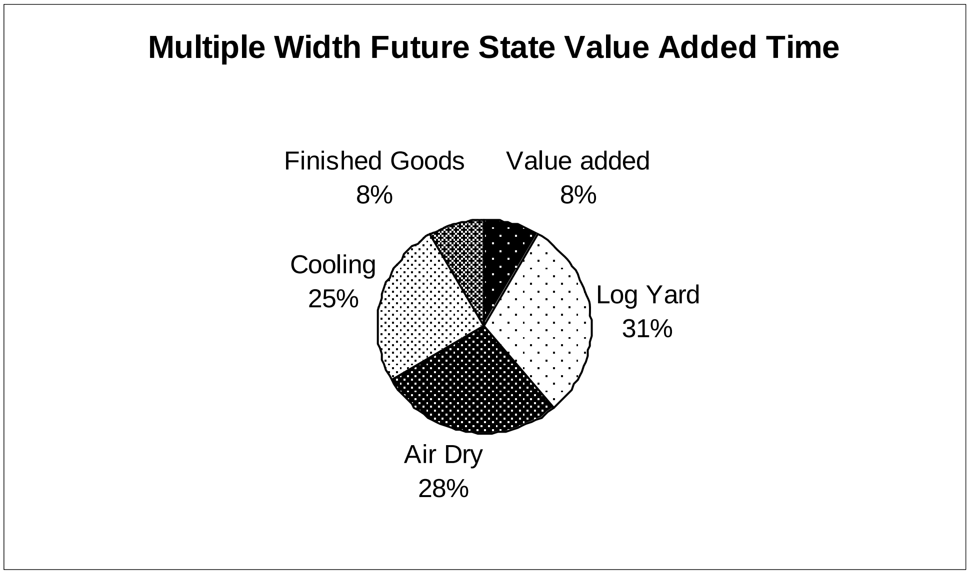


Figure 5.6. Value added time for the future state that dries multiple widths in the dry kiln.

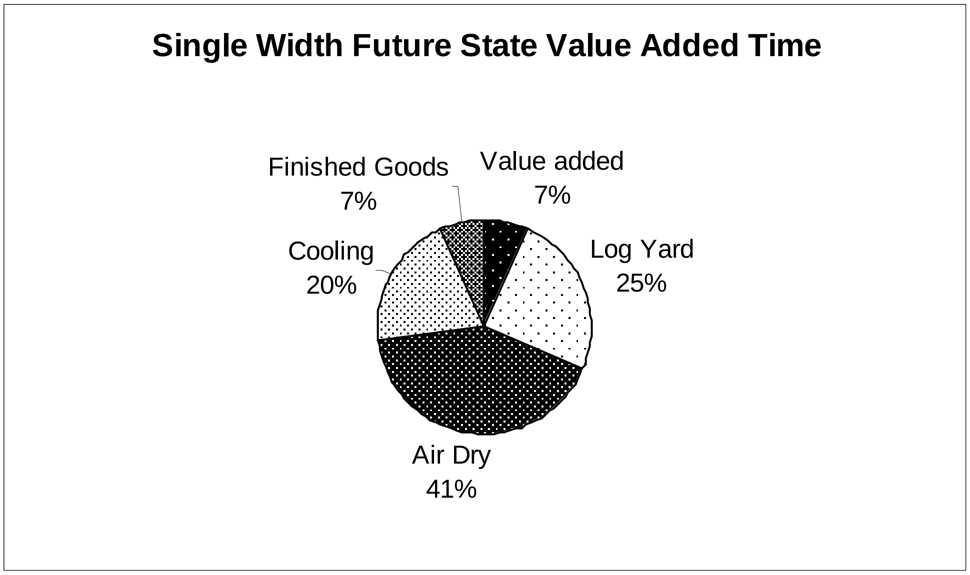


Figure 5.7. Value added time for the future state manufacturing system that dries single widths.

5.16 Time-based Manufacturing Practices for the Future State:

Improvements for the lumber manufacturer according to time-based manufacturing practices are outlined in the remaining sections. Suggestions for improvement were based on current state observation and feedback from mill employees.

There are some time-based manufacturing practices that do not have improvement recommendations. Cellular manufacturing does not contain recommendation for improvement due to the fact that processing constraints prohibit the formation of additional cells, and existing cells already contain continuous flow and are relatively efficient. There is also no recommendation for improving the supply of raw material. The mill management staff has clearly stated that this is an area over which there is no immediate control (see section 5.4). Smoothing log supply requires an in depth supply-chain investigation.

5.17 Reengineering Setups:

A current assessment of planer changeover practices was provided in Section 4.14. In summary, planer changeover consists of two major activities:

1) Switching planer knives and making adjustments

2) Emptying drop sorter bins for the next product size

Emptying drop sorter bins is the bottleneck in the changeover process and takes approximately 45 minutes. This constraint is difficult to overcome since material must be stacked due to the conveyor system. Future state improvement related to the drop sorter bins should focus on:

1) Modifying the conveyor system so that partial material can be removed before it reaches the stacker. This would most likely reduce the time it takes to unload bins.

2) Sale of all partial packs of lumber, thus eliminating double handling and stacking of material. Partial packs typically re-enter the drop sorter at the beginning of a changeover (see section 4.14).

Implementing the improvements listed above could possibly make knife changing and planer adjustment the bottleneck of the entire changeover process. Changing planer knives and making machine adjustments would then become an extremely important changeover improvement area. As mentioned in section 4.14, the planer knife changing adjustment process was poorly organized. Improvements for the future state should focus on improving organization by:

1) Making tools readily available and easy to find.

2) Eliminating unnecessary travel between the planer and tool cabinet by assembling a rolling tool cart.

Implementing all of the planer changeover improvements would reduce changeover time, increasing the ease of switching between products, thus increasing the flexibility of the planing system.

5.18 Shop-floor Employee Involvement:

A current assessment of shop floor employee involvement was provided in Section 4.13. The current assessment indicated that there is a low level of shop floor employee involvement in problem solving. One way the mill can improve involvement is to simply ask employee input on processing related decisions. In addition, the mill management staff should demand employee participation in both quality improvements and maintenance reorganization (discussed in the next two sections).

5.19 Preventive Maintenance:

Effective and reliable equipment is a key component of achieving and maintaining short product lead times. The current assessment of preventive maintenance provided in Section 4.17 indicated that maintenance activities were scheduled effectively though they were poorly organized. Poor organization made tools difficult to find, and often required excessive travel to obtain tools. Maintenance areas should be arranged and organized so that necessary tools are easily found, unnecessary tools are removed, and excessive travel is eliminated. This could be accomplished by using rolling tool carts, or placing maintenance stations closer to machine centers. Maintenance reorganization projects should require the input and planning of shop-floor employees as well as mill management.

5.20 Quality Improvement:

Investigation of quality monitoring indicated a need for monitoring “quality at the source” (See section 4.16). Efforts should be made to promote more frequent quality checks and spread quality responsibility from managers to all shop-floor employees. Currently, strict quality monitoring is present after the planing operation, where it is typically too late to link quality errors to certain steps in the manufacturing process. A quality loss detected after the planing operation could have occurred several weeks prior. Quality monitoring could also be enhanced with visual quality charts at the source of quality errors.

6. Future State Value Streams Requiring Additional Investment

6.1 Introduction

Chapter five contained two future states that represented a significant reduction in inventory and lead time without additional investment. While the future state maps represented an improved manufacturing system, they were subject to large batch drying constraints, and were not directly linked to customer needs. This chapter contains two future state value stream scenarios that attempt to improve system responsiveness, as well as reduce current batch drying constraints. Both future state systems do require investing in additional manufacturing equipment. One future state value stream presented in this chapter involves the use of pull production. Due to various constraints of the lumber manufacturing process, effective utilization of pull production is currently not feasible, and the value stream was developed to highlight these constraints. Unless otherwise specified, the future state value streams presented in this chapter operate in the same manner as the value streams presented in the previous chapter.

6.2 Future State Value Stream with Additional Dry Kiln

A future state value stream map containing an additional dry kiln is shown in Figure 6.1. The map is based on the consumer demand and sawmill production data used in the previous chapters. The future state system does not dry multiple widths together, however, multiple width drying could reduce lead time and inventory even further

The additional kiln is used to process all material other than 5/4 x 6. According to previous analysis, on average, the mill produces 28,096 board feet per day of material that is not 5/4 x 6. Thus, the capacity of the additional kiln is 28,096 board feet per charge, and 5 charges are dried per week. The other kiln, is dedicated to processing 5/4 x

6 material and processes 5 charges a week of 69,903 board feet. On average, the sawmill produces 69,903 board feet per day of 5/4 x 6 material.

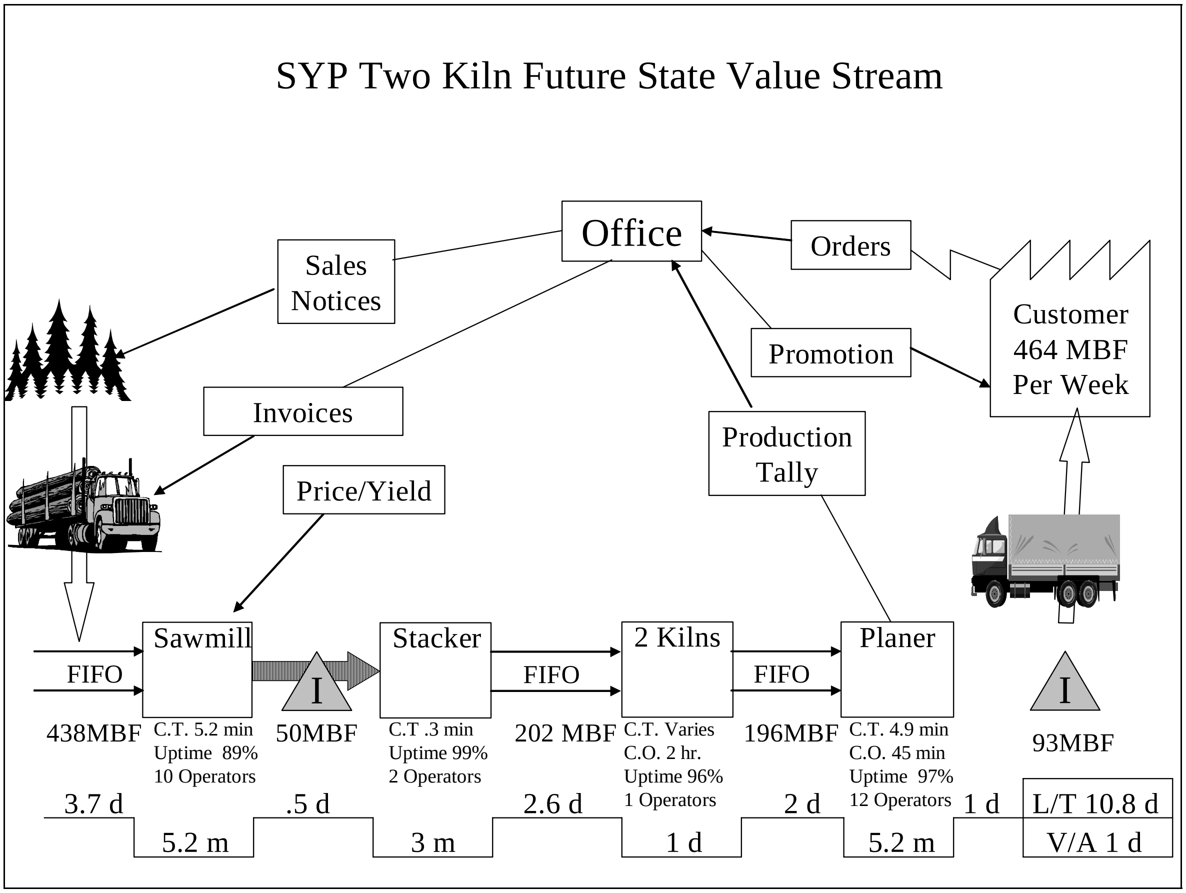


Figure 6.1. Future state value stream map for the SYP sawmill. This value stream map contains two kilns.

As shown in Figure 6.1, the lead time for the two kiln system is approximately 10.8 days. This represents a decrease in lead time when compared with the future state maps presented previously in Chapter 5. The inventory is reduced due to the decreased size of drying batches for material other that 5/4 x 6. The additional kiln dries 1 x 4, 1 x 6, 2 x 4, or 5/4 x 4 once their respective rough green inventory level is greater than or equal to 28,096 bd. Ft. Since the batch size is decreased for these products, there is a subsequent drop in inventory, reducing the time material spends in rough green inventory. A rough green inventory simulation is shown below in Figure 6.2.

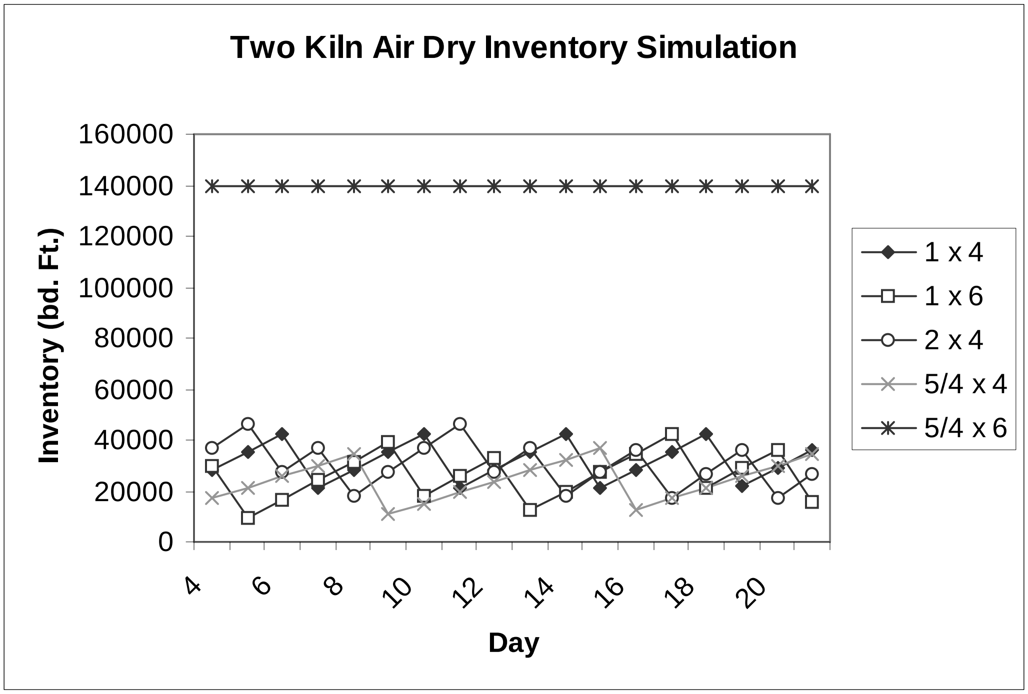


Figure 6.2. Rough green inventory simulation for future state value stream map containing 2 kilns. Inventory provided in board feet.

The total rough green inventory for the future state value stream is 252,192 board feet (See Appendix G). The inventory total is based on a simulation in excel performed in a similar manner to the simulation described in section 5.9. The simulation contains two kilns. Kiln one processed strictly 5/4 x 6 material (69,603 bd.ft. per day), and the second kiln processed 28,096 board feet from 1 x 4, 1 x 6, 2 x 4, or 5/4 x 4 whenever the inventory level was greater than or equal to 28,096 board feet. If multiple lumber sizes had an inventory greater than 28,096 board feet, the product with the highest inventory was processed. 5/4 x 6 material levels did not fluctuate since the kiln would dry one days worth of sawmill production (69,903 board feet). An extra day of 5/4 x 6 inventory was held to compensate for sawmill yield variation and downtime if present. One major advantage of the two kiln future state system is that it requires the kilns to run 5 days per week, eliminating the need for inventory buildup over the weekend.

The air-dry inventory simulation for the 2 kiln push system does not model product mix variation. If product mix varies from the mix presented in Table 4.1 (but takt time is still the same), then one kiln may be operated for more than the typical 5 charges per week to accommodate this variation. For example, suppose that in one week there is more 5/4 x 6 lumber produced than can fit in 5 kiln charges (greater than 350MBF). The excess lumber could be dried on the weekend since the future state value stream does not require utilizing the kilns during the weekend. The future state system does still require that exactly 98MBF per day is produced by the sawmill.

There are a few advantages to the two kiln future state production system. The greatest advantage is the reduced rough green inventory and subsequent reduction of lead time. The reduction of lead time improves the responsiveness of the SYP lumber producer. In addition, the two kiln system improves the synchronization between the sawmill, kiln and planer mill, since the kiln is operated 5 days per week.

While the two kiln future state system has many advantages, the system is still incapable of responding directly to customer demand (in terms of controlling the production of a certain grade). In addition, a greater strain is placed on the planer mill to reduce changeover even more since most products are now processed in smaller batches than 70MBF. One alternative to the changeover requirement is to add an additional planing system that can be quickly switched from product to product. The existing planer mill could be dedicated solely to the production of 5/4 x 6 lumber, while the additional planer could process all remaining products.

The two kiln future state value stream has the highest percentage of value added time of all the future states (See Figure 6.3). Value is added to the product approximately

9 percent of the time it is at the lumber manufacturer. In addition, material spends the longest period of time in its least value-added state (the log yard). This is desirable because it represents the area of least investment.

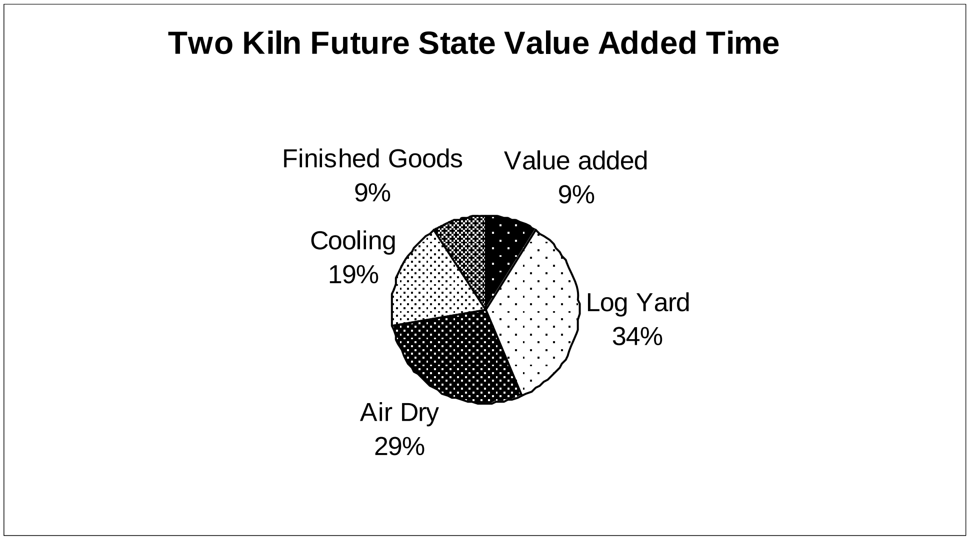


Figure 6.3. The percentage of value added time of the two kiln future state value stream.

6.3 Mixed Pull Future State Value Stream

The value stream map shown in Figure 6.1 represents a future state with improved responsiveness, and decreased inventory. One major downfall to the system, however, is its failure to produce directly to customer order. A hypothetical mixed pull system was developed to combat this problem and provide a direct link with customer demand for 5/4 x 6 lumber. 5/4 x 6 lumber was chosen for pull production because it makes up the greatest percentage of sales for the SYP lumber producer on both a volume and price basis.

Unfortunately, current lumber manufacturing constraints limit the feasibility of a pull production system. The constraints are as follows:

1. Log variation

2. Need to presort by grade and dimension before drying
3. Necessity to dry without grade loss
4. Drying time
5. Cooling time.

These constraints are explained through the future state value stream. Both value stream maps in figures 6.4 and 6.5 show the mixed pull system. The value stream map in Figure 6.4 applies to 1 x 4, 1 x 6, 2 x 4, and 5/4 x 4 products, while the value stream map in Figure 6.5 applies to 5/4 x 6 materials. The mixed pull system is based on the same dry kiln scheduling principles shown in Figure 6.1. There are two kilns used for the mix pull system, and charges are processed when enough material accumulates for a product to fill a charge. The main difference between the mixed pull system and the future state shown in Figure 6.1 is the presence of a finished goods supermarket for 5/4 x 6 material.

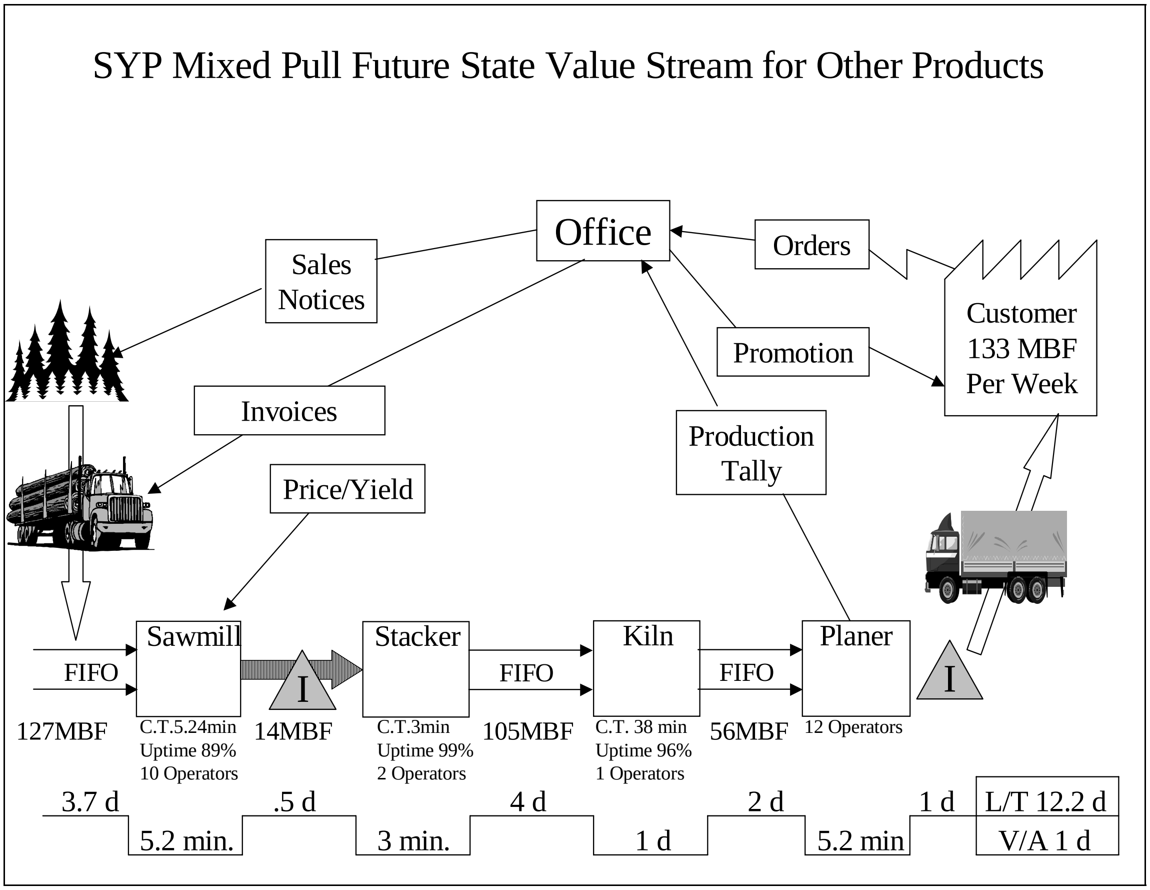


Figure 6.4. Mixed pull future state value stream map for products other than 5/4 x 6.

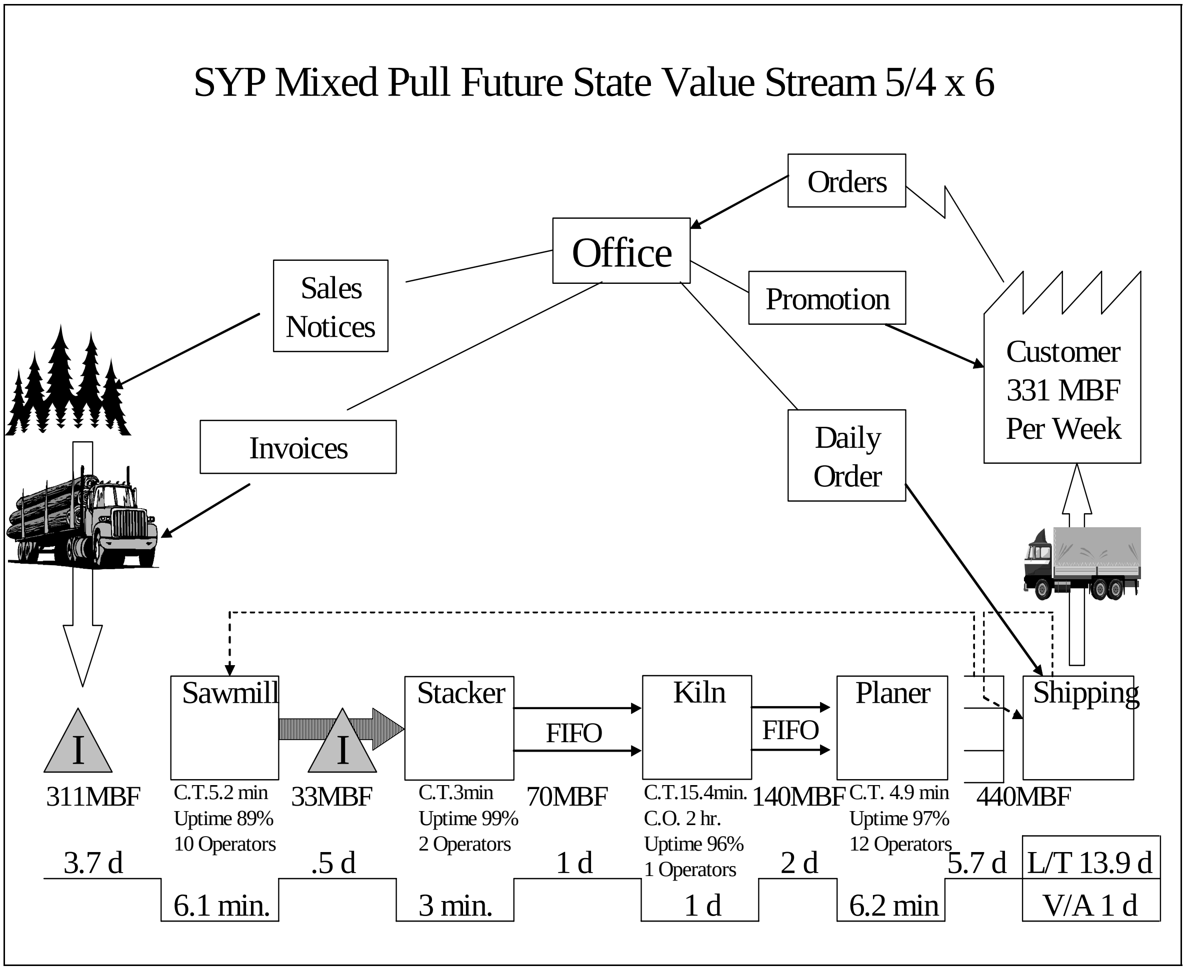


Figure 6.5. Mixed pull future state value stream map for 5/4 x 6 lumber.

The system displayed in Figures 6.4 and 6.5 requires greater change to implement than the other future state value streams. The mixed pull system processes 5/4 x 6 products only when the customer demands them. Customers submit orders for a specific 5/4 x 6 length and grade that is sent to the shipping department. The finished goods supermarket downstream from the planer fills the orders. The supermarkets contain a truckload of each 5/4 x 6 grade and length combination (400 MBF total). When the shipping department pulls the order from the supermarket, and a signal is sent from the supermarket to the sawmill to produce material to replenish what was withdrawn from the supermarket. The log breakdown system must be able to precisely determine what 5/4 x 6 grade and length products that a log will yield prior to sawing so that the proper logs are selected to replenish the supermarket. After 5/4 x 6 lumber is claimed from a log, the remainder of the log will be processed into other products (1 x 4, 1x 6, 2 x 4, and 5/4 x 4) based on price and yield. Products other than 5/4 x 6 could potentially be sawn to order if the breakdown system was capable of coordinating all the orders while simultaneously maximizing log yield. While such a system would precisely meet customer demand, it could greatly reduce log yield.

After the lumber is removed from the log, it must then be graded directly after the sawing operation. The 5/4 x 6 material must be presorted by grade and length so that it can be staged for drying. This would require the addition of a grading station, as well as additional drop sorter bins to accommodate all the product mix combinations.

After the lumber order is sorted by grade and dimension for drying, it must be dried without grade loss. Otherwise, the manufacturer must overproduce the quantity of lumber demanded. After kiln drying, the lumber must still cool for 2 days to avoid planing defect. Thus, 4.5 days are required from the time the order is received and sent to the sawmill to when the lumber arrives at the supermarket. Thus, the rapid response capability typically associated with supermarkets is not realized by the lumber manufacturer. Response could be improved if drying technologies were implemented to reduce drying and cooling times.

While pull production has been effectively utilized in various industries, its effectiveness at the SYP lumber manufacturer would be very limited. The major disadvantage is the change required to successfully implement mixed pull. There must be continuous modifications to headrig optimization system, and 5/4 x 6 material must be graded and sorted after it leaves the sawmill. In addition, there must be very little or no grade loss after the material is presorted at the sawmill. Grade loss will reduce the ability of the sawmill to precisely fill orders for 5/4 x 6 lumber. Drying and cooling times required for SYP lumber must also somehow be reduced and continuous flow targeted to reduce order response time.

Table 6.1. Comparison of inventory and lead times for all value streams. Inventories are provided in MBF, while lead times are given in days.

	Value Stream				
	Current State	Mult. Width Drying	Single Width Drying	2 Kiln	Mixed Pull
Log Inventory	438	438	438	438	438
Log Lead Time	3.7	3.7	3.7	3.7	3.7
Stacker Inventory	50	50	50	50	47
Stacker Lead Time	0.5	0.5	0.5	0.5	0.5
Air Dry Inventory	784	279	560	202	175
Air Dry Lead Time	8.0	2.9	5.7	2.6	1.9
Cooling Inventory	1091	294	294	196	196
Cooling Lead Time	11.1	3.0	3.0	2.0	2.0
Finished Goods Inventory	1009	93	93	93	467
Finished Goods Lead Time	11.2	1.0	1.0	1.0	5.0
Total Inventory	3372	1154	1435	979	1323
Total Lead Time	35.5	12.1	14.9	10.8	13.1

6.4 Evaluation of Customer Responsiveness for all Future States:

A comparison of all the different value streams is provided in Table 6.1. All of the future state value streams presented in Chapters 5 and 6 represent improved customer responsiveness. While the mixed pull value stream is the only system that produces some products to customer specifications, all future state value streams process different products more frequently. Since products are processed more frequently, customers can benefit by the increased availability of certain products. For example, current assessment indicated that non-5/4 x 6 lumber was processed sporadically (See section 4.9). If a customer demanded 1 x 4, 5/4 x 4, 1 x 6, or 2 x 4 lumber, the current system could require a potential wait of 2 to 3 months for these particular products. The future states reduce the wait to a maximum of 16.23 days working days. Thus, even though some future state designs do not process directly to customer order, they still improve customer service by providing a more consistent and reliable output of products.

6.5 Implications for the Future Design of Sawmills:

To provide the highest level of customer service in a pull production system, lumber manufacturers must be able to accurately know what will be obtained from a log and alter their log mix according to what the customer needs. In addition, headrig optimization systems consider individual customer orders and be able to coordinate them effectively to utilize kiln capacity while simultaneously maximizing yield. Material must be sorted according to customer specification directly downstream of the sawmill, and degrade must be avoided to prevent the need for overproduction. Drying and cooling times must also be reduced. Implementing such a system is most likely expensive, and profitability is dependent upon willingness of the customer to pay for short response times that cater specifically to their needs.

In addition to technological innovation, pull systems would be enhanced if customers altered the manner in which they buy lumber. Purchasing lumber more frequently and in smaller quantities would enable the lumber manufacturer to reduce supermarket size, thus their inventory would be lower. Customers may not demand certain lumber grades currently produced and perhaps some grades could be combined to reduce the number of grades held in supermarkets. If the manufacturer were to implement pull production, determining exactly what the customer needs and wants would become increasingly important.

7. Capital Invested in Inventory

7.1 Introduction

Inventory in sawmills requires a capital investment. This investment varies with the level of completion of the inventory. For example, finished goods inventory has undergone more processing than log inventory, thus more capital has been invested in the finished goods inventory. This capital investment cannot be recovered until the product is sold. Such capital investment represents one of the consequences associated with carrying inventory.

A method for evaluating the capital inventory requirement was discussed in Methods Section 3.3. This method was devised for the lumber manufacturer based on traditional accounting practices to allocate direct labor, direct material, and overhead costs. The capital requirement of inventory for the SYP sawmill was evaluated for both the current and future states, and is described in the following sections of this chapter. Evaluation of the current state capital inventory requirement was based on 6 months of inventory data. Each value stream was evaluated according to the method described in Section 3.3.

7.2 Current Accounting Practices at the SYP Sawmill

The sawmill under investigation allocates direct labor and overhead costs to the sawmill, kiln, and planer mill. Direct material costs for the manufacturer are simply log costs. In addition, the sawmill also incurs a shipping cost and an office cost. Table 7.1 lists all of the costs mentioned above as cost per thousand board feet. The manager of the lumber manufacturing operation provided all of the costing information.

Table 7.1. Cost per thousand board feet for the southern yellow pine lumber manufacturer.

March-July	**Cost per MBF**
Log Cost	$251.53
Sawmill Labor	$27.80
Sawmill Operation	$31.45
Kiln Labor	$3.60
Kiln Operation	$11.32
Planer Labor	$17.85
Planer Operation	$13.42
Office Cost	$35.93
Truck Cost	$0.93

7.3 Current State Inventory Capital Requirement

The six months of inventory data collected from the southern yellow pine lumber manufacturer (located in Appendix B) was used to calculate the capital inventory requirement. The average inventory levels of log, air dry, cooling and finished goods inventory (Displayed in Figure 4.1) were applied to the calculation method described in Section 3.3. Lumber in the stacker was included in the air-dry inventory. The results of the calculation are displayed below in Table 7.2.

Table 7.2. Capital inventory requirement based on six months of inventory from the southern yellow pine lumber manufacturer.

	Capital Investment				
Inventory	Log	Air Dry	Cooling	Finished	Total
Average	$114,104.30	$266,829.50	$388,625.68	$370,203.15	**$1,139,762.63**
Std. Dev.	$65,372.77	$151,569.48	$166,443.59	$109,998.25	$137,415.38
Total Inventory (MBF)	438	834	1,161	1,009	3,443

As seen in table 7.2, the average capital inventory requirement for the lumber manufacturer was $1,139,762.63 with a standard deviation of $137,415.38. The greatest average investment in inventory was in cooling yard inventory, while the lowest investment was in log yard inventory.

7.4 Future State Inventory Capital Requirement

Future state inventory levels developed in chapters 5 and 6 were used for the future state capital inventory requirement calculation. The capital inventory requirement for both future states is displayed in table 7.3. Table 7.3 includes the calculation for both single dimension drying operations and the drying operation that process multiple widths in a single charge.

Table 7.3. Future state capital inventory requirement for the multiple width and single width drying operations.

	Single Width Drying		Multiple Width Drying	
	Inventory (MBF)	Capital	Inventory (MBF)	Capital
Log Yard	438	$114,104.48	438	$114,104.48
Air Dry	609	$194,735.56	328	$104,882.10
Cooling	368	$123,163.16	368	$123,163.16
Finished	93	$34,120.07	93	$34,120.07
Total	1508	$466,123.07	1227	$376,269.81

As displayed in Table 7.3, the total capital inventory requirement for the single and multiple width drying operations is $466,123.07 and $376,269.81 respectively. Thus, the capital requirement of these future states is less than 50 percent of the current state capital requirement. A graphical comparison of the capital requirement difference is shown below in Figures 7.1 and 7.2.

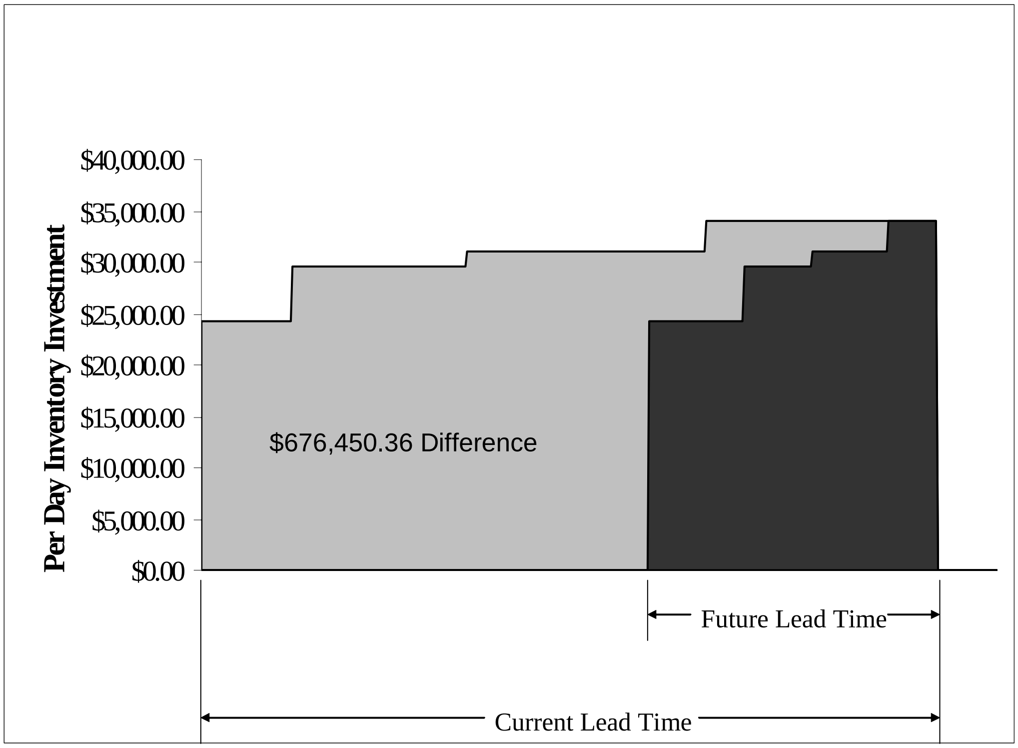


Figure 7.1. Capital inventory requirement comparison for the multiple width drying operation and the current state value stream.

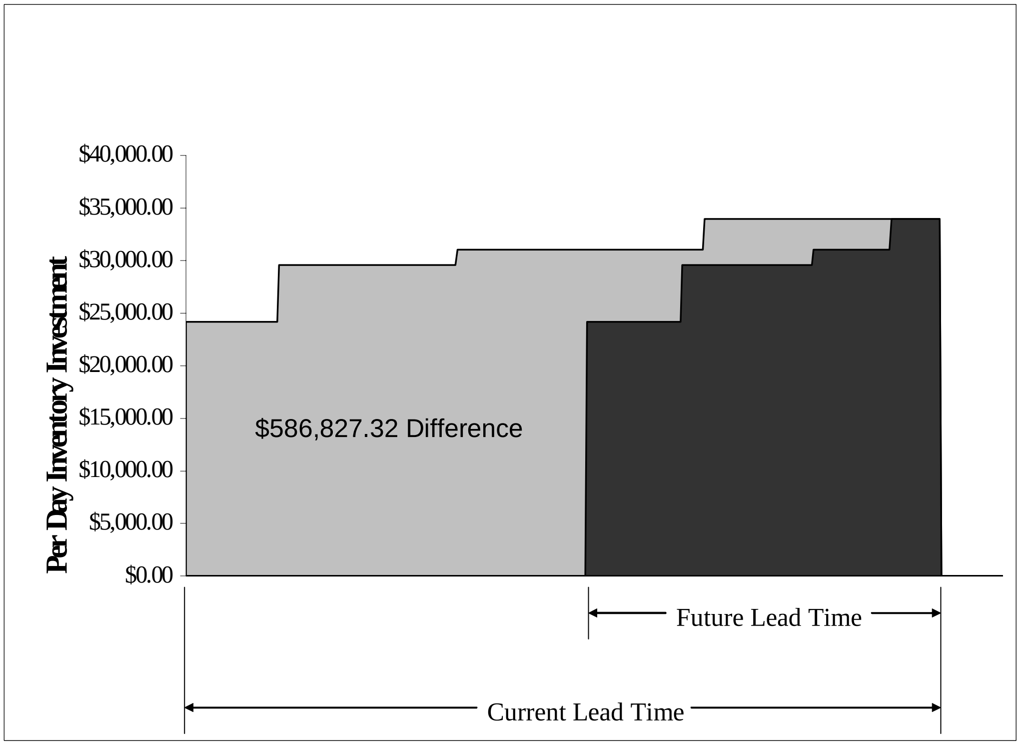


Figure 7.2. Capital inventory requirement comparison for the single width drying operation and the current state value stream.

In both graphical comparisons (Figures 7.1 and 7.2), the sum of the gray and black areas represents the total average current state capital inventory requirement. The black area represents the capital requirement for the future state, while the gray area is the capital difference between the two manufacturing systems. In order to show possible opportunity cost, an annual discount rate of 5 percent was applied to the differences between current and future states. For the multiple with drying operation, the five percent discount is $33,822.52, while the single width drying operation had an opportunity cost of $29,341.37.

7.5 Capital Requirement for the Future States Requiring Additional Investment

The capital inventory requirement for the two kiln future state and the mixed pull future state was evaluated and compared with the current state capital inventory requirement. As shown in Table 7.4., the capital inventory requirement for the two kiln future state is $294,402.47. This is lower than the capital inventory requirement for both future states not requiring additional investment to implement. The capital inventory requirement for the mixed pull system is also shown in Table 7.4. As seen in the table, the total capital inventory requirement for the mixed pull system is $431,938.41.

Table 7.4. Capital inventory requirement comparison of two kiln future state and mixed pull future state value stream.

	Two Kiln Push		Mixed Pull	
	Inv (MBF)	Capital	Inv (MBF)	Capital
Log Yard	438	$114,104.48	438	$114,104.48
Air Dry	252	$80,580.15	252	$80,580.15
Cooling	196	$65,597.77	196	$65,597.77
Finished	93	$34,120.07	468	$171,701.01
Total	979	$294,402.47	1354	$431,983.41

The capital inventory requirements of the future states requiring additional investment are compared with the current state capital requirement in Figure 7.3 and 7.4.

The capital inventory requirement of the two kiln push system was $845,360.16 less than the current state. The capital requirement of the mixed pull system was $707,779.22 less than the current state. Applying a 5 percent discount rate to the two kiln and mixed pull system yielded a value of $42,268.01 and $35,388.96 respectively.

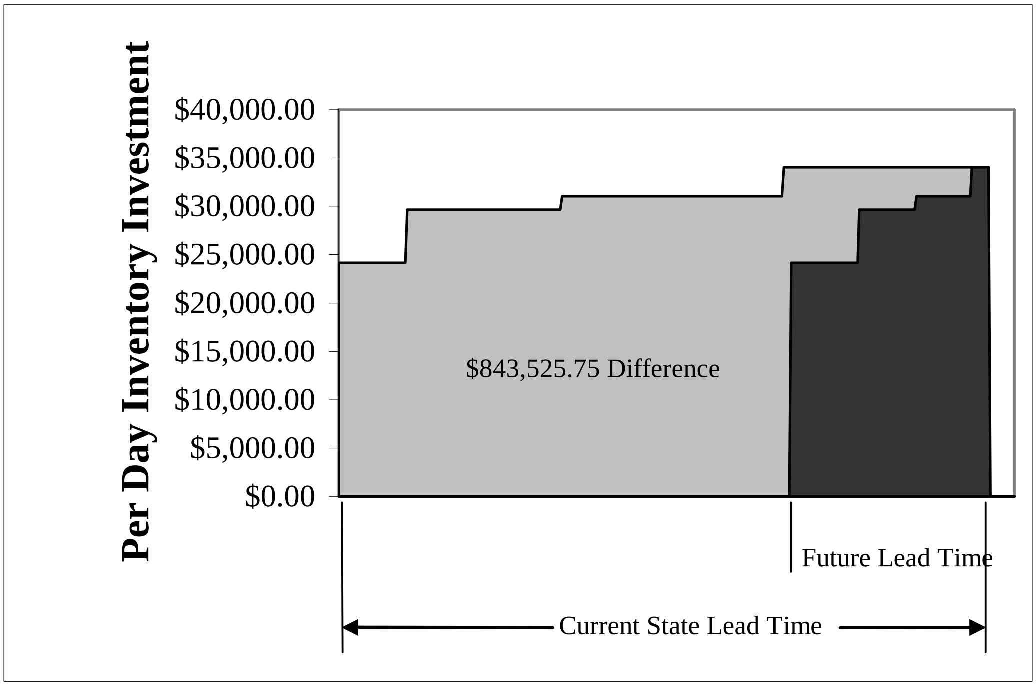


Figure 7.3. Capital inventory requirement comparison for the two kiln push system and the current state value stream.

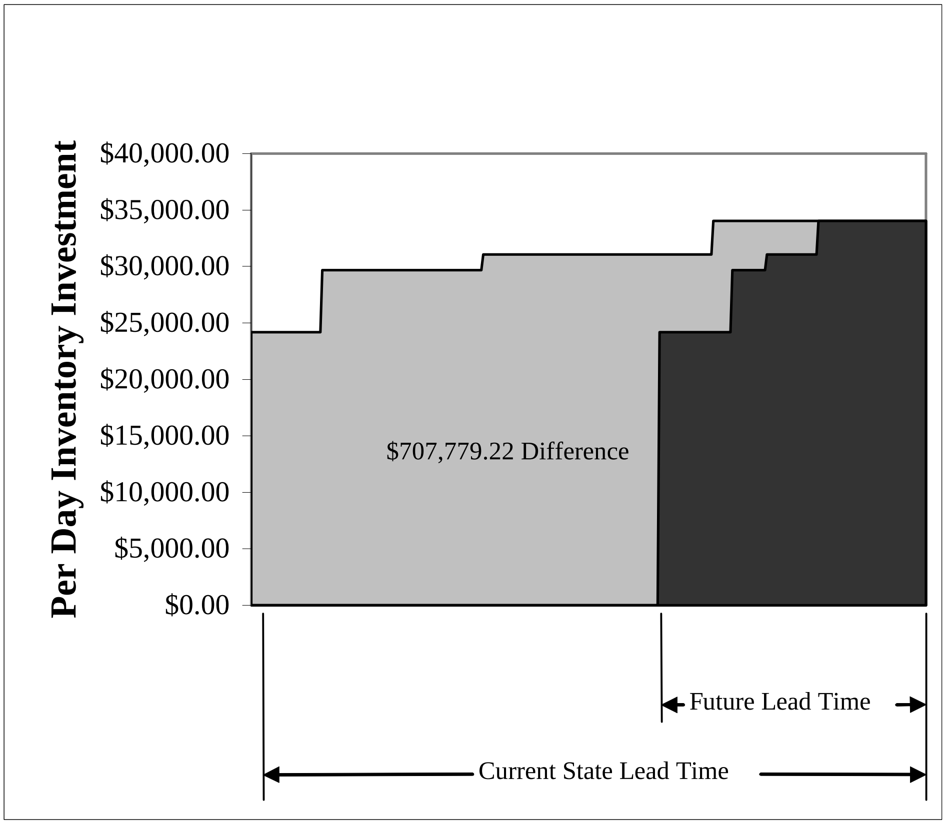


Figure 7.4. Capital inventory requirement comparison for the mixed pull system and the current state value stream.

7.6 Variation of Finished Goods Inventory

As mentioned in Section 5.11, the future state value streams assume that the sales staff will be able to solicit material effectively and sell the lumber within a day after it is planed. Table 7.5 shows the capital inventory requirements of each future state, with a finished goods inventory level of 1,009 MBF. This inventory level is based on the current state value stream, and would occur if the sales staff was unable to increase how quickly they sale lumber after it has been planed. As shown in Table 7.5, there is still a notable difference between the future states and current state capital inventory requirement. The difference indicates that there will be an improvement in financial performance, even if the sales staff is unable to reduce the time lumber spends in finished goods inventory.

Table 7.5. Capital inventory requirement of various value streams with all systems having 1009MBF in finished goods.

Value Stream	Total Capital Inventory Requirement (MBF)	Total Capital Inventory Requirement	Difference from Current State
Current State	3442	$1,139,537.23	
Multiple Width Future State	2143	$712,334.18	($427,203.05)
Single Width Future State	2424	$802,187.44	($337,349.79)
Two Kiln Future State	1895	$630,466.84	($509,070.39)

7.7 Inventory Turnover

The inventory turnover of each value stream is presented below in Table 7.5. Typical inventory turnover calculation is discussed in Section 2.20. The inventory turnover calculation in Table 7.6 assumed yearly sales of 23,664 MBF. The yearly sales volume is based on 464MBF(current and future state demand) produced weekly for 51 weeks in a year. Inventory turnover was calculated by dividing annual sales volume by the total inventory of the value stream. As shown in the table, the two kiln future state value stream had the highest level of inventory turns at 24.2, while the current state value stream had the lowest level of inventory turns at 6.9. As mentioned in Section 2.20, higher inventory turns indicate a better cash flow and are more desirable from a manufacturing standpoint.

Table 7.6. Inventory turnover for the SYP lumber manufacturer. Calculation based on yearly sales of 23,664MBF.

Inventory Turnover		
Value Stream	**Total Inventory**	**Inventory Turns**
Current State	3443	6.9
Multiple Width Future State	1227	19.3
Single Width Future State	1508	15.7
Two Kiln Future State	979	24.2
Mixed Pull Future State	1354	17.4

7.8 Inventory Management Strategy

All of the future state systems rely on moving material as quickly as possible through the value stream and ultimately to final sale. The value streams are based on the assumption that the product mix produced by the headrig optimization system should be moved as quickly as possible through the system to achieve the greatest economic benefit. Some lumber manufacturers may hold material if they feel the market prices will increase. There is risk associated with this strategy, and significantly increases capital requirement costs required for this holding strategy may outweigh the benefit of holding inventory to take advantage of price increases. In addition, holding inventory for one product that has a rising price may eventually impede the flow of a product whose price is simultaneously decreasing.

A distribution of price changes is shown in Figure 7.5. The price changes are based on Random Lengths data from Feb.1999 – Dec. 2004 (Random Lengths, 2004). The distribution models price changes per MBF that occur for an 8-week product lead time. As shown in the graph, maintaining an 8-week lead time for No. 1 - 2 x 4 lumber would result in financial gain about 50 percent of the time, however financial loss would also be commonly incurred the other 50 percent. If the lumber manufacturer were able to accurately predict price increases, they may be able to benefit financially. The cost of holding inventory may, however, substantially reduce the perceived benefit of price increases. Future research efforts could focus on the economic consequences of holding inventory to capitalize on lumber price changes.

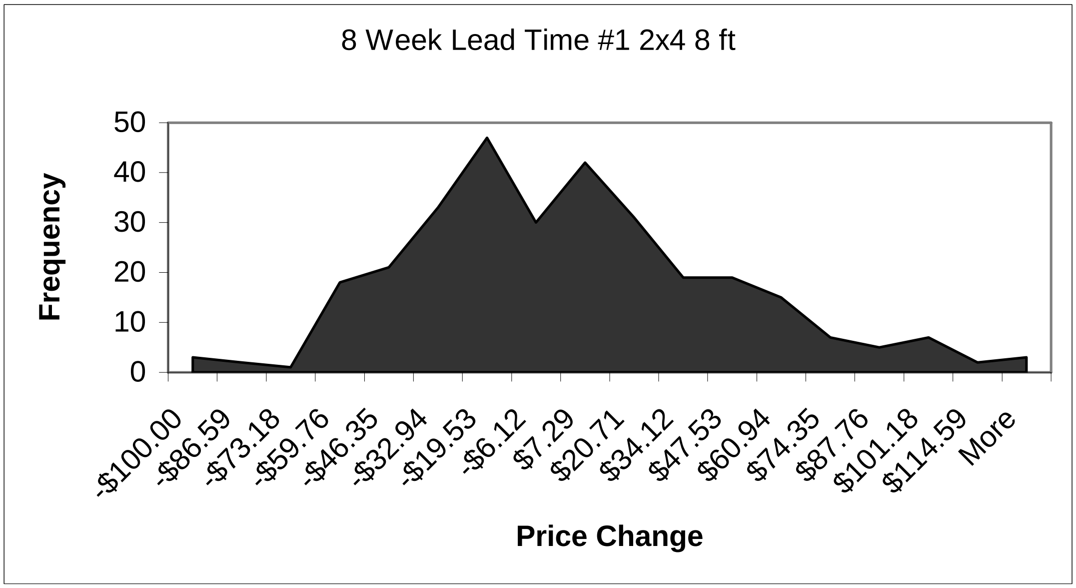


Figure 7.5. Price changes for an 8 week lead time based on 5 years of Random Lengths data.

7.9 Capital Inventory Calculations

The previously described capital inventory requirement valuations may provide a conservative estimate. There are certain elements that the basic financial calculation does not cover. For example, the space saved by reducing inventory is not entered into the calculation. Also, excessive material handling and other excessive operations that may be required to handle large inventories under the current system is not considered. More importantly, there is no calculation for the increased flexibility of the future state systems that process products more frequently than the current state system. Tax and insurance cost reductions that could be realized from reduced future state inventories are also not entered into the capital inventory requirement calculation.

7.10 Summary:

The difference between current and future state capital inventory requirements ranged from $586,827.32 to $845,360.16. This represents a potential opportunity for the lumber manufacturer to decrease capital investment through implementation of a future state value stream. Decreasing capital required by the system will enable the manufacturer to turn their inventory quicker, respond quickly to customer deman, invest their money elsewhere, and increase the ability of the business to diversify their operations and/or investments.

8. Conclusion

Softwood lumber manufacturers can benefit by improving their response to market price changes through reducing their lead time. Lead time reduction can be facilitated through value stream mapping. Lead time reduction in softwood lumber manufacturing operations can be accomplished by synchronizing both kiln drying and planing operations with sawmill production, and through the reduction of kiln batch sizes. In addition to improving response to market prices, processing different products more frequently improves the manufacturer's abilities to reduce cost while increasing customer service.

One method for manufacturers to improve their responsiveness to a particular customer order is to implement pull production. While pull production has been utilized effectively in various industries, current constraints render its positive attributes in the softwood sawmill limited at best. Various alterations must be made to softwood sawmill production systems before they can effectively implement pull production

This research project demonstrated how tools such as value stream mapping and time-based manufacturing practices can provide a valuable opportunity to reduce lead time and subsequently the capital invested in inventory. Inventory reduction is especially beneficial to softwood lumber manufacturers where lumber inventory is subject to degrade, insurance, taxes, excessive handling, and market price decreases.

One of the benefits of this research project is that the methodology could be applicable to both hardwood and softwood lumber manufacturers. Lead times can be evaluated and future states designed by leveling production and reducing inventory as much as possible while still providing sufficient customer service. Although hardwood lumber manufacturing drying cycle times may differ drastically from softwood manufacturers, kiln batch reduction can still be a successful method to reduce lead times. In addition, the methodology for evaluating capital held in inventory can be utilized to assess the benefits of future state implementation. Emphasis on improving lead times could ultimately increase the competitive advantages of lumber manufacturers in the United States.

8.1 Summary of Findings Related to Specific Objectives

The purpose of this research project was to perform an in depth analysis of lead time of an individual southern yellow pine sawmill. Specifically, the project determined lead time and capital inventory reduction opportunities. The specific study objectives were:

1) To perform a current state value stream evaluation of the southern yellow pine manufacturing system.

2) To design a future state value stream with reduced lead time and increased efficiency.

3) To evaluate the capital inventory requirement of the current and future state value streams.

Objective 1:

The first objective involved a current state manufacturing evaluation of the southern yellow pine lumber manufacturer. The evaluation was performed through value stream mapping, as well as observations of six time-based manufacturing principles. Six months of inventory and sales data were gathered to create the value stream map. In addition, input from mill management and staff was also used in the creation of the current state value stream map.

The current state manufacturing assessment calculated an average lead time of 35.5 days, and a value added time of 18.3 hours. Customer demand was 464 MBF per week over the six-month period, and the sawmill was required to saw more lumber than demanded due to yield constraints. Sawing decisions were based on price and yield (not customer demand), and mill management developed production scheduling for the kiln and planer mill independent of what was produced at the sawmill. Some low volume products were processed infrequently due to the time required for planer changeover, and kiln batching requirements of 70MBF.

In addition to a value stream mapping evaluation, the production system was evaluated for shop-floor employee involvement in problem solving, quality, dependable suppliers, reengineering setups, and preventive maintenance. Observations of the time based manufacturing practices were based on input from mill management staff and employees. A summary of the assessment is given in the following list:

- Shop-floor employee involvement: The assessment indicated that there is a need for increased shop-floor employee involvement, especially in quality.
- Dependable suppliers: Log supplier dependability is in need of improvement, however it appears beyond the control of the lumber manufacturer.
- Reengineering setups: Planer changeover takes approximately 45 and offers potential for improvement. However, emptying sorting bins is a currently unavoidable constraint to reducing changeover time.

- Quality: Some employees are not involved in monitoring product quality, even though they are directly involved in the manufacturing process.
- Preventive maintenance: While the SYP producer has an aggressive maintenance program with operator involvement, maintenance tools are not organized or properly located.

Objective 2:

Several future state value streams were developed for objective 2. All of the future state value streams reduced inventory by processing different products more frequently, and sometimes through reduction of kiln batch sizes. The value streams were separated into those requiring investment to implement, and those not requiring investment. Two future state value stream maps were developed for each category, and recommendations for improvements in time-based manufacturing practices were also given.

Future state value streams not requiring additional investment were created based on current demand. Both future states relied on a FIFO scheduling system at the kiln, while the sawmill continued to produce based on price and yield. One production system dried each width and thickness dimension separately and had a lead time of 14.9 days. The other system mixed widths in the dry kiln (but not thickness), and had a lead time of 12.1 days. Both production systems promise much lower than the current state lead time of 35.5 days. While the value streams did not produce to customer order, altering the sawmill product mix output can decrease the lead time for certain products.

Two additional future state value streams were developed for the SYP lumber producer, but they required investment in equipment. One future state system was a mixed pull system that may currently not be feasible due to log variation, need for reduction of drying time, reduction of cooling time, presorting material before the dry kiln and little or no drying grade loss. Both future state maps required the purchase of a dry kiln with approximately 28 MBF capacity where products other than 5/4 x 6 were processed. One future state value stream map was a mixed pull system, and was developed to highlight the obstacles currently impeding the implementation of pull production in the softwood sawing industry.

Future state time-based manufacturing recommendations were also developed, they are summarized as follows:

- Quality – Need to spread quality responsibility from managers to hourly employees.
- Reengineering Setups – Need to decrease non-value added time during changeover by eliminating double processing. This may require a modification to the conveyor system.
- Preventive Maintenance – Need for improved organization in maintenance areas.
- Shop-floor employee involvement – More effort should be made to involve hourly employees in decision making related to process improvements, maintenance organization projects, and quality monitoring.

Objective 3:

Evaluation of capital required for inventory was based on the accounting system currently used by the SYP lumber manufacturer. The assessment allocated overhead and labor costs to products based on the level of completion. The capital requirement of future states was compared to the current state capital inventory requirement. The current state capital inventory requirement was based on 6 months of inventory and sales data, as well as costs supplied by the lumber manufacturer.

According to the six month inventory average, there was $1,139,762.63 invested in inventory under the current state system. The future state systems have the following capital inventory investment:

- Single width drying - $466,123.07
- Multiple width drying - $376,269.81
- 2 kiln (investment required) - $294,402.47
- Mixed pull (investment required) - $431,983.41

The difference between current and future state inventory capital requirement presents a major opportunity for the lumber manufacturer. Through future state implementation, the manufacturer can benefit from available cash and pursue other investments.

8.2 Limitations to Study and Future Research

There are several limitations to this research project. One limitation is that the study specifically assessed one single mill, and the results gathered may not reflect the remainder of the southern yellow pine lumber manufacturing industry. However, the methods employed in this research project could be effectively be used in other lumber manufacturing operations. Additionally, the assessment did not attempt to investigate the entire supply chain, specifically the log suppliers, lumber processors and distributors, as well as the final customer. Finally, the future state production systems designed in the previous chapters were based on average customer demand, and seasonal variation may result in fluctuations in inventory levels. Estimation of season induced demand variation would require gathering additional sales data far beyond the six months gathered for this project.

Future research related to SYP lumber manufacturing could address some of the previously mentioned limitations of this study. There is a need for a research investigation of the entire SYP supply chain from the forest to the final consumer. Such research could include how log suppliers can develop a better system that can overcome weather constraints and the ability of lumber grades to adequately match the needs and wants of customers.

In addition, there needs to be a deeper investigation of the constraints associated with implementing pull production in a sawing, drying and planing operation. Due to grade yield unpredictability, lumber sorting, drying, and cooling practices, it is currently very difficult to implement a supermarket pull system in softwood lumber manufacturing. Such research could focus specifically on enabling manufacturers to implement pull manufacturing in an economically feasible manner.

8.3 Final Thoughts

The SYP lumber manufacturer has a great opportunity to reduce their lead time and inventory capital requirement, while simultaneously improving customer service, and providing a more reliable and steady output of various products. The mill could realize these improvements through future state implementation. Future state implementation would require:

1) Selecting a particular future state to implement according to kiln drying practices and quality implications (See Section 5.2).

2) Reducing all inventories to future state levels with the exception of the stacker and log inventory (may require temporarily shutting down some processes)
3) Creating visual controls for the air dry FIFO system so that kiln operators will easily know which material to process.
4) Conducting various Kaizen events to improve time-based manufacturing practices, especially planer mill changeover (See Sections 5.16 - 5.20).
5) Working with customers to minimize finished goods inventory (See Section 5.12).
6) Increase understanding and control of log mix and grade yield variation to become more responsive to customer demand (See Section 5.12).

Successful future state implementation would require major cultural commitment to change and lead time reduction. Support must be present from hourly wage employees as well as mill management and ownership. Mill management and staff must adopt a continuous improvement philosophy to deter stagnation and to propel the organization toward increasingly shorter lead times and improved customer service. Such commitment would likely build and maintain a successful competitive advantage for the softwood lumber manufacturer.

References:

Adams, E.L. 1984. DESIM: A system for designing and simulating hardwood sawmill systems. General Tech. Rept. NE-89. USDA Forest Serv., Forest Prod. Lab., Madison, WI.

Ainsworth, Penne and Dan Deines. 2002. Introduction to Accounting: An Intergrated Approach. McGraw-Hill: New York.

Aune, P.A. 1974. System simulation – A technique for sawmill productivity analysis and designs. Forestry Chronicle 50 (2):66-69.

Banks, Jerry, et. al. 2001. Discrete-Event System Simulation. Third Edition. Prentice Hall, Upper Saddle River, NJ.

Blackburn, J. 1991 Time-Based Competition: The next battleground in American manufacturing. Business One Irwin, Homewood, IL.

Bockerstette, Josheph A. and Richard Shell. 1993. Time Based Manufacturing. McGraw-Hill, Norcross, GA.

Bolander, Steven F. and Sam Taylor. 2000. Scheduling Techniques: A Comparison of Logic. Production and Inventory Management Journal. First Quarter 2000; 41, pages 1-5.

Bower, J.L. and T.M. Hout. 1988. Fast-cycle capability for competitive power. Harvard Business Review. Vol. 66, No. 6, pages 110-118.

Cavinato, Joseph. 1988. What Does Your Inventory Really Cost?. Distribution. March, pages 68-72.

Crandall, Richard E. and Timothy Burwell. 1993. The effect of work-in-progress inventory levels on throughput and lead times. Production and Inventory Management Journal. Vol.34, Iss. 1, pages 6-7.

Culpepper, Larry. 2000. Softwood Drying: Enhancing Kiln Operations. Miller Freeman, San Francisco, CA.

Daugherty, Patricia J. and Paul Pittman. 1995. Utilization of time-based strategies: Creating distribution flexibility/responsiveness. International Journal of Operations & Production Management. Vol. 15, Iss. 2; pages 54-61.

Dunn, Michael, et al. 2003. Homebuilder attitudes and preferences regarding southern yellow pine. Forest Products Journal. Vol. 53, Iss. 4, pages 36-42.

Hall, R.J. and D.B. Jewett. 1988. A simulator for the design, analysis, and management of sawmills. Presented at: Forest Prod. Res. Society 42nd Annual Meeting. Forest Prod. Soc., Madison, WI.

Haygreen and Bowyer. 1996. Forest Products and Wood Science. Iowa State University Press, Ames, IA.

Holemo, Frederick J. 1971. Inventory Management: The tool and need in lumber production. Forest Products Journal. Vol.21, No.1, pages 12 – 16.

Hyer, Nancy, and Karen A. Brown. 1999. The discipline of real cells. Journal of Operations Management. Volume 17, Issue 5, pages 557-574.

Kempthorne, K.H. 1978. Whole mill simulation of small log sawmills with head sawyers. In: Proc. Winter Simulation Conf. 2:684-692.

Koufteros et al. 1998. Developing measures of time-based manufacturing. Journal of Operations Management. Volume 16, pages 21-24.

Kline, D.E., D.W. Cumbo and R. Lovern. 2003. VFPA 2003: Summer Conference Lean Manufacturing: Doing More with Less. VFPA Newsletter, July/August. 2003.

Law and Kelton. 1991. Simulation Modeling and Analysis. Second Edition. McGraw-Hill, Inc., New York.

Lean Enterprise Institute. 2 November 2005. Inventory Turn Charts. < http://www.lean. org /Community/Registered/InventoryCharts.cfm>.

Lewandrowski, Jan K., Michael K. Wohlgenant and Thomas J. Grennes. 1994. Finished Products Inventories and Price Expectations in the Softwood Lumber Industry. Amer. J. Agr. Econ. Vol. 76, No. 1, pages 83 – 93.

Mwamakimbullah, Reuben J. 2004. Reduction of Green Lumber Inventory before Wood Dry-kilns Using Kiln-charge Size: An Application of Discrete Event Simulation. Proceedings of the 2004 Summer Computer Simulation Conference.

Maness, Thomas C. 1993. Adding value to commodity lumber through market timing controls. Forest Products Journal. Vol. 43, No. 7/8, pages 72-77.

McKeever, D.B. and Anderson, R.G. 1992. Timber products used to build U.S. single family houses in 1988. Forest Products Journal. Vol. 42, No. 4, pages 11-18.

McKillop, et al. 1980. Competition between wood products and substitute structural products: an econometric analysis. Forest Science. Washington, D.C., Society of American Foresters. (1) p. 134-148.

Monden, Y. 1993. Toyota Production System. Second Edition. Industrial Engineers and Management Press, Norcross, GA.

Noel D. Uri and Roy Boyd. 1990. Estimating the Regional Demand for Softwood Lumber in the United States. North Central Journal of Agricultural Economics. Vol 12, No. 1, pages 137-147.

O'Guin, Michael C. 1991. The Complete Guide to Activity Based Costing. Prentice-Hall. Englewood Cliffs, NJ.

Pennick, E.B., Jr. 1969. Monte Carlo simulation for production control. Forest Prod. J. 19(5): 10.

R.E. Taylor & Associates Ltd. 2002 Edition Wood Markets. International Wood Markets Research Inc., Vancouver, BC. 2002.

Reeb, James E. 2003. Simulating an Extra Grader in a Sawmill. Forest Products Journal. Vol. 53, No. 11/12, pages 81.

Rother, Mike and John Shook. 1999. Learning to See: Value Stream Mapping to Add Value and Eliminate Muda. The Lean Enterprise Institute, Brookline, MA.

S. Shingo. A revolution in manufacture: the SMED system, Productivity Inc., Stamford, CT. 1985.

Samaddar, Subhashish. 2001. The effect of setup time reduction on its variance. Omega. Vol. 29, Issue 3. pages 243-247.

Simpson, William T. 1991. Dry Kiln Operators Manual. USDA Forest Service. Forest Products Laboratory, Madison, Wisconsin.

Smalley, Art. 2004. Creating Level Pull: A lean production-system improvement guide for production-control, operations, and engineering professionals. The Lean Enterprise Institute, Brookline, MA.

Tu, Qiang, et al. 2001. The impact of time-based manufacturing practices on mass customization and value to the customer. Journal of Operations Management. Vol. 19, Issue 2, pages 201-217.

Wagner, F.G., Jr. and F.W. Taylor. 1983. SPSM – A southern pine sawmill model. Forest Prod. J. 33(4)37-43.

Wagner, et. al. 1989. MICRO-MSUSP: An interactive computer simulation program for modeling southern pine sawmills. In: Executive Summary of 44th Forest Prod. Research Society Annual Meeting. Forest Prod. Soc., Madison, WI.

Weil, N.A. 1998. Make the Most of Maintenance. Manufacturing Engineering. Vol. 120, Issue 5, Pages 118-124.

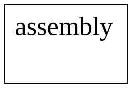
Wu, Qinglin, and W. Ramsay Smith. 1998. Effects of elevated and high-temperature schedules on warp in southern yellow pine lumber. Forest Products Journal. Vol. 48, Iss. 2, pages 52-57.

Yauch, Charlene A. and Harold J. Steudel. 2002. Cellular manufacturing for small businesses: key cultural factors that impact the conversion process. Journal of Operations Management. Vol. 20, Issue 5, pages 593-617.

Zhang, Daowei and Changyou Sun. 2001. U.S.-Canada Softwood Lumber Trade Disputes and Lumber Price Volatility. Forest Products Journal. Vol. 51, No. 4, pages 21-27.

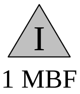
Appendix A: Value Stream Mapping Symbol Descriptions


Log Shipment



Process box


Push Arrow

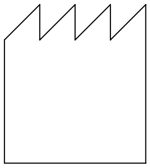


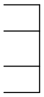
Inventory

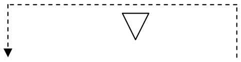

Lumber Shipment

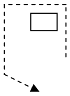
First-In-First-Out
Suquence Flow

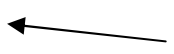

Forest

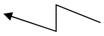

Customer


Supermarket


Production Kanban


Withdrawal
Kanban


Manual
Information
Flow


Electronic
Information
Flow

Appendix B:

	Inventory bf			
Month	Log	Air Dry	Cooling	Finished
March	140,599	1,311,111	448,416	1,468,289
April	522,267	1,395,966	966,100	1,055,660
May	228,377	866,554	1,241,419	659,588
June	440,000	406,823	1,096,630	1,165,623
July	440,000	821,825	1,231,765	709,789
August	856,753	204,490	1,982,733	995,357
Average	437,999	834,462	1,161,177	1,009,051
Std. Dev.	250,939	474,006	497,318	299,819

Appendix C:

Capital Investment					
Month	Log	Air Dry	Cooling	Finished	Total Capital
March	$36,627.80	$419,244.13	$150,076.99	$538,689.54	$1,144,638.46
April	$136,057.08	$446,377.58	$323,336.76	$387,303.18	$1,293,074.60
May	$59,495.06	$277,091.47	$415,481.21	$241,991.29	$994,059.05
June	$114,625.50	$130,086.74	$367,022.87	$427,646.68	$1,039,381.79
July	$114,625.50	$262,788.82	$412,250.19	$260,409.16	$1,050,073.67
August	$223,194.8659	$65,388.23	$663,586.04	$365,179.06	$1,317,348.20
Average	$114,104.30	$266,829.50	$388,625.68	$370,203.15	**$1,139,762.63**
Std. Dev.	$65,373	$151,569	$166,444	$109,998	$137,415

Appendix D:

Time Based Manufacturing Questions

Questions Related to Shop Floor Employee Involvement:

1. What input do employees have in decisions related to the production process?
2. Do you ever receive input from shop floor employees related to how to improve the production system?
3. Are there any language barriers that limit the input from shop floor employees?
4. What are your feelings on the ability of shop floor employees to make decisions?

Questions Related to Dependable Suppliers:

1. What is your ability to control the frequency, and quality of raw material shipments?
2. Are you satisfied with the current frequency and quality of shipments?
3. What are areas related to dependable supply that you would like to see improve?
4. What are the consequences associated with unreliable supply?

Questions Related to Preventive Maintenance:

1. Who is responsible for maintenance in general and for specific pieces of equipment?

2. Do you have a preventive maintenance schedule? If so what is it based on?
3. Are shop floor employees involved in the maintenance process? Do they have a sense of responsibility over their equipment and its output?
4. Do you tabulate the frequency of maintenance related downtime? If so what is the average frequency for each process, and how and when is it recorded?
5. When a piece of equipment fails what actions are taken and by whom?

Questions related to Quality Improvement:

1. Who is responsible for quality and where are they responsible?
2. Is there a consistent effort to monitor quality at the source?
3. What is your criteria for quality monitoring?
4. Are operators able to receive feedback of their machine’s quality?

Cellular Manufacturing:

Based on observations of continuous flow

Reengineering Setups:

1. What are the activities required to changeover the planer? Who is involved?
2. How long does it take to changeover?
3. What is the bottleneck of the changeover process?
4. Do you feel you could improve the speed of planer changeover?

Appendix E: Table for Multiple Width Drying Air Dry Inventory Simulation

Day	5/4 x	2 x 4	1 x	Charge	Inventory
8	137114	55860	17024	5/4 x	209998
9	141300	65170	31528	5/4 x	237998
10	145486	74480	46032	2 x 4	265998
11	219672	13790	60536	5/4 x	293998
12	223858	23100	75040	1 x	321998
13	298044	32410	19544	5/4 x	349998
14	228044	32410	19544	5/4 x	279998
15	158044	32410	19544	5/4 x	209998
16	162230	41720	34048	5/4 x	237998
17	166416	51030	48552	5/4 x	265998
18	170602	60340	63056	5/4 x	293998
19	174788	69650	77560	1 x	321998
20	248974	78960	22064	2 x 4	349998
21	248974	8960	22064	5/4 x	279998

Appendix F: Example Table for Single Width Drying Air Dry Inventory Simulation

Day	1 x 4	1 x 6	2 x 4	5/4 x 4	5/4 x 6	Charge	Inventory
8	42313	44615	55791	25859	321417	5/4x6	489996
9	49365	52051	65090	30169	321320	5/4 x 6	517996
10	56418	59487	74388	34479	321224	2 x 4	545996
11	63470	66923	13687	38789	391127	5/4x6	573996
12	70522	74358	22986	43099	391031	1 x 4	601996
13	7574	81794	32284	47409	460934	1x6	629996
14	7574	11794	32284	47409	460934	5/4x6	559996
15	7574	11794	32284	47409	390934	5/4x6	489996
16	14627	19230	41583	51719	390838	5/4x6	517996
17	21679	26666	50881	56028	390741	5/4x6	545996
18	28731	34102	60180	60338	390645	5/4x6	573996
19	35783	41538	69478	64648	390548	5/4x6	601996
20	42835	48974	78777	68958	390452	2 x 4	629996
21	42835	48974	8777	68958	390452	5/4 x 6	559996

Appendix G: Example Table for 2 kiln push air dry inventory Simulation

Day	1 x 4	1 x 6	2 x 4	5/4 x 4	5/4 x 6	Kiln 1	Kiln 2	Inventory
4	28209	29743	37194	17240	139807	5/4x6	1x6	252193
5	35261	9083	46493	21549	139807	5/4x6	2x4	252193
6	42313	16518	27695	25859	139807	5/4x6	1x4	252193
7	21269	23954	36993	30169	139807	5/4x6	2x4	252192
8	28321	31390	18195	34479	139807	5/4x6	5/4x4	252192
9	35373	38826	27494	10692	139807	5/4x6	1x6	252192
10	42425	18165	36792	15002	139807	5/4x6	1x4	252192
11	21381	25601	46091	19312	139807	5/4x6	2x4	252192
12	28433	33037	27293	23622	139807	5/4x6	1x6	252192

Vita

Henry T. Leonard III, the son of Henry and Catherine Leonard was born in Radford, Virginia on February 23rd 1982. After graduating in 2000 from Brentsville District High School, Mr. Leonard went on to Virginia Polytechnic Institute and State University where he received a Bachelor of Science degree in Wood Science and Forest Products in 2004. Mr. Leonard continued his education at Virginia Polytechnic Institute and State University by earning a Master of Science degree in Forest Products in 2005. Mr. Leonard will begin work in the forest products industry as a Production Manager Trainee with Woodgrain Millwork in Marion, Virginia.