Pull Manufacturing System Design for Rough Mill Systems: A Case Study

Garrett Todd Norman

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Dr. D. Earl Kline, Chair

Dr. Brian H. Bond

Dr. Robert L. Smith

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ABSTRACT

Domestic secondary wood products manufacturers are losing their competitive edge in the global economy. Foreign competition is steadily gaining market-share due to decreased labor costs. While domestic operations can not compete with labor costs available to foreign manufacturers, they may be able to remain competitive through product lead time reduction and on-time delivery to the final customer. Pull based manufacturing is one technique to reduce lead time increase on-time delivery.

Value stream mapping was used in this project to evaluate a furniture rough mill located in Virginia to assess the current state, as well as develop 2 future state value streams. The current state evaluation found the system to be yield driven and production was based on a forecast. The lead time for internal nightstand components in the current state was found to be 15.1 hours. Using pull production and supermarket methodology in proposed future states, it was found that the lead time could be reduced to 7.5 hours. Lead times could be reduced by eliminating yield increasing non-value added activities currently in place which not only increase lead time, but also manufacturing waste as defined by lean manufacturing concepts. A cost analysis found that the labor and overhead costs associated with yield increasing activities in the current state outweighed the costs of a decreased yield measurement in the future state.

While this project was limited to one rough mill and one product family of a lesser valued wood species it represents what is possible for assisting secondary manufacturers to remain competitive. The once successful traditional yield driven rough mill does not guarantee internal customer satisfaction and in this project is not cost effective. Future research should focus on the implications of the furniture rough mill's inability to meet downstream demand to internal customers.

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1.1 Problem Statement

Traditional secondary wood products manufacturers are losing their competitiveness in the new global economy. The industry is responding by developing capacity and expertise in dealing with outsourcing to lower cost regions. Foreign manufacturers, specifically those in China and other Asian countries, have increased their share of the United States wood household furniture market to the point that they provide more than half of the furniture demanded in the United States (Bumgardner et al. 2004).

Secondary wood products manufacturing research has focused on locally optimizing high cost work centers such as drying and rough mill yield primarily because of the high percentage of total material product cost incurred in such operations. While simulation and optimization in previous research successfully helped maximize industry yield, it has been shown high yield emphasis results in large batch sizes, excessive re-work, high work-in-progress levels and increased production lead times (Willard 1970; Thomas and Buehlmann 2007). Increased lead times prevent the rough mill from meeting demand changes downstream effectively.

Schuler et al. (2002) noted that *companies must prepare for a shift from the old world of mass production to the new business world where variety and customization of products and services are the norm.* This shift can be seen in kitchen and bath companies as this segment of the industry has not lost significant business due to imports by quickly and more precisely responding to local customer need (Ray et al. 2006).

As seen in kitchen and bath companies, future competitiveness depends on system optimization by focusing on what will make secondary manufacturing more effective at meeting customer demand. Traditional yield based operations do not guarantee part requirements will be met efficiently to meet real customer demand in a timely manner. This study will focus on better connecting the lumber processing system (rough mill) to downstream customer processes (machining and assembly), as a first step to optimizing the entire system.

1.2 Research Objectives

The goal of this research was to study the overall cost effectiveness of achieving yield but not meeting actual demand in the rough mill. This research provides a method for furniture rough mills to become more responsive to downstream customer demand. The project involved a case study of a large sized furniture manufacturer's rough mill located in Virginia. It was hypothesized that many non-value added processes exist that increase production cost and reduce rough mill effectiveness at meeting demand. Many of these non-value added processes deal with overproduction, inappropriate processing, part transportation, and expediting parts in immediate demand. Techniques such as pull systems and supermarkets are discussed as a strategy to balance between cutting yield vs. precise yield of demanded parts. The specific research objectives were:

1) To perform a current state value stream evaluation of the rough mill manufacturing system.
2) To design an improved rough mill future state value stream that is responsive to downstream demand using pull system methodologies.
3) To demonstrate the cost effectiveness of the future state value stream using a furniture manufacturing case study.

1.3 Approach

This research focused on rough mill operations, particularly, how yield influences operations (Figure 1-1). It was hypothesized that many hidden costs are added in the yield optimization system. While these optimization systems were effective at one time, they may not be as effective today or not for certain product value streams. This study develops and demonstrates a methodology to understand the true cost effectiveness of the entire system.

While this study focuses on how yield influences operations, it is important to note that the objective of downstream furniture operations is to minimize unit cost of machining and assembly as well as the order backlog handling system. The downstream furniture operations objective adds cost that can be more significant than the rough's mill focus on yield. This study's methodology can be applied to future research to understand how downstream cost effectiveness adds into the system.

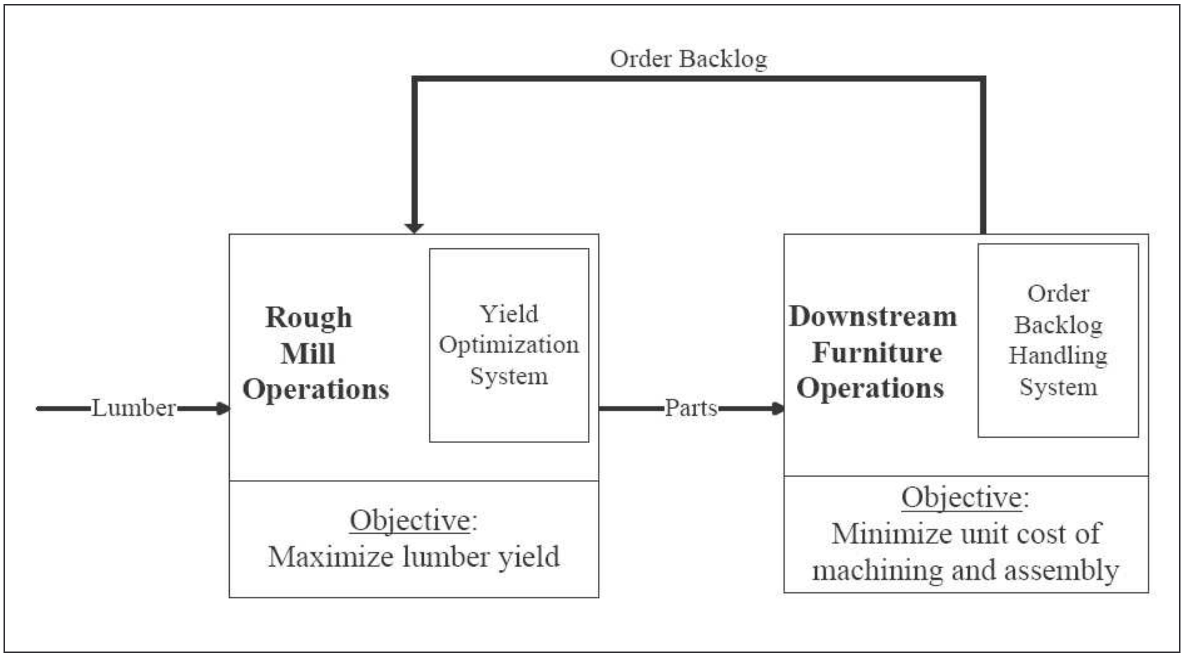


Figure 1-1 Approach

The objectives of each operation shown in Figure 1-1 are to minimize local costs, often times this approach does not accurately meet true demand needs on-time. In rough mill operations, maximizing yield is the way to minimize lumber costs therefore yield optimization systems are developed. This further removes the focus away from demand, plus adds system costs in non-value added activities that may negate yield benefits. Furniture assembly operations require the system to deal with order backlogs; this adds costs that can negate yield benefits. The rough mill schedule needs to be altered to make up for critical backlogs, this alteration further increases costs.

1.4 Limitations

This project was limited to the boundary of the rough mill of a furniture manufacturer. While this project may prove to be beneficial for the rough mill, the real opportunity is beyond the rough mill. The cost of not meeting demand in the studied operation was outside the scope of this project as all costs associated with backlog and reschedules were unavailable. However, it is an area that future research should focus on and should not be limited to just the rough mill.

The value streams were limited to internal nightstand components. This was done because the system is too complex to take on all value streams. The methods used focus on all issues in-depth for one component; this approach is also applicable for other component value streams. Similar opportunities are hypothesized and require additional future state development. Yield simulation was used in this project and can only be assumed to represent the study rough mill. While simulation is a working research tool, it cannot simulate exactly what a rough mill does.

2 Literature Review

2.1 Wooden Furniture Manufacturing Trends in the United States

A recent survey found that 61% of large home furnishings manufacturing executives agreed with the statement *that by the end of the decade, little will remain of domestic wood furniture and other similar wood products manufacturing in the United States* (Buehlmann et al. 2003). Figure 2-1, which represents the trend in imported wooden furniture from China to the United States, displays one of the reasons why the sampled executives believe this statement to be true (US Department of Commerce 2007).

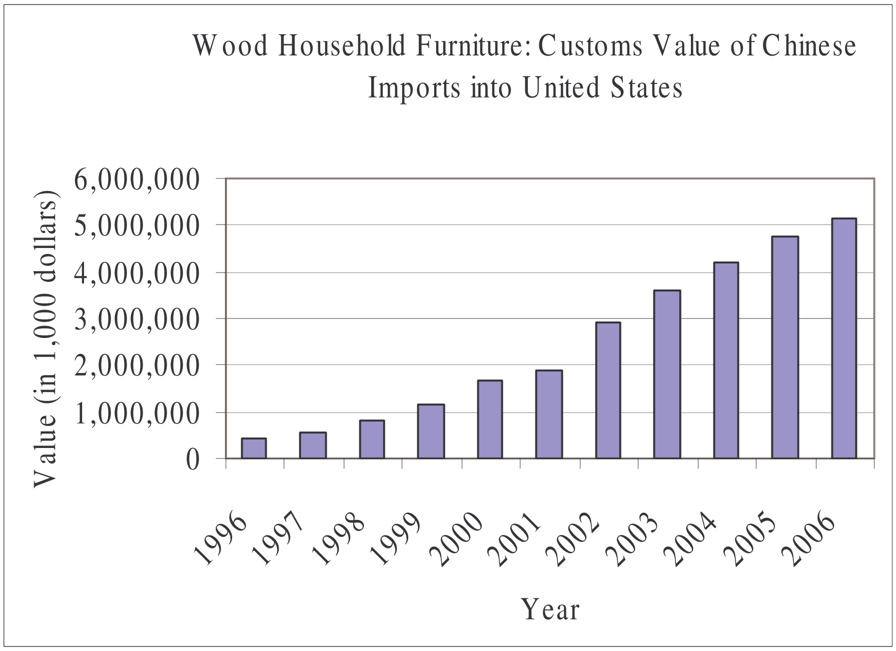


Figure 2-1 Wooden furniture imported from China from 1996 to 2006 (U.S.D.C 2007).

Chinese and other Asian countries have increased their market share in the United States largely in part to a lower selling price. Lower selling prices are directly related to these countries ability to produce the same product with much lower operational and labor costs (Cao et al. 2004). For these reasons, China and other Asian countries have *focused efforts on industries such as furniture, that are labor intensive and provide exporting potential* (Schuler and Buehlmann 2002). As such, many domestic manufacturers have moved their labor-intensive operations to Asian countries to stay price competitive. While the furniture industry has moved to importing products, members of the cabinet industry have found success in domestic production by improving their manufacturing processes (Merillat 2003).

2.2 Wooden Furniture Manufacturing Processes

As Schuler (et al. 2002) noted, furniture manufacturing is labor intensive. In a large furniture manufacturing facility in the United States several hundred people can be employed at the plant level. Figure 2-2 is an overview of the typical processing stages of manufacturing wooden furniture from start (lumber received) to finish (finished product stored in the warehouse) (Anonymous N.D.).

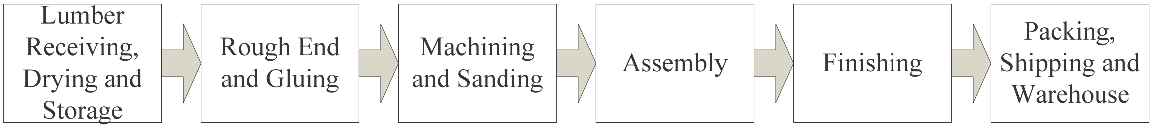


Figure 2-2 Manufacturing steps of wooden furniture

The purpose of the lumber receiving, drying and storage stage is to *receive, prepare and maintain an adequate inventory of appropriate quality lumber for the subsequent manufacturing processes* (Anonymous N.D.). Lumber is typically provided to furniture manufacturers from sawmills as rough green lumber (Skinner and Rogers 1968). Once green lumber has been received, it is unloaded, graded, sorted, stacked, air and kiln dried, and stored until needed. These steps are performed outside of the plant in what is typically known as the "lumber yard". The amount of time lumber is in the lumber yard depends on several variables; inventory levels, demand, species and thickness. Lumber could remain on the lumber yard for several months before it is further processed in the plant.

The lumber cutting order for a particular production run or time period is a listing of all needed parts for a particular suite or grouping of furniture pieces. It can contain several hundred combinations of part sizes and qualities, with quantities for each combination. The cutting order is broken down into a series of cutting bills (Gatchell 1987). *Cutting bills are essentially an aggregated list of parts to be cut in the rough end of a furniture manufacturing facility* (Buehlmann 1998). Once a cutting bill has been completed, the required amount of lumber needed to fulfill the specific cutting bill can be moved from the lumber yard to be processed.

Actual lumber processing for furniture manufacturing begins when dried lumber enters the rough end and gluing stages. Here, rectangular pieces of lumber are cut out of dried lumber provided by the lumber yard for use later as furniture components. In addition to cutting specific lumber pieces to fulfill cutting bills requirements, defects in the boards are often cut out of the boards. After pieces have been cut out of the boards they may go on to the gluing process (Anonymous N.D.). Gluing pieces together edgewise after they have been defected decreases the amount of lumber needed to be input into the system and increases the overall lumber yield. By gluing these pieces together, essentially a "defect-free" piece of lumber can be salvaged from what would have been waste.

Solid and glued pieces from the rough end proceed to be machined once the entire batch has been processed. The machining process is when lumber pieces take form; pieces are taken from a rough, blank state and processed into a planed, shaped state of the specified final dimension. To reach the final dimension and shape the following actions may or may not take place depending on the final part requirements: planing, moulding, shaping, cutting and tenoning (Anonymous N.D.). The rough end and gluing stage as well as some of the machining processes take place in an area of the furniture plant typically known as the "rough mill".

Sanding operations take place after pieces have left the rough mill. Sanding creates a smooth surface on the machined pieces faces and edges for the following finishing steps. For some pieces, such as those that have been moulded previously, sanding may not be required. Sanding represents the final manufacturing steps of furniture pieces, once pieces have been sanded they are ready to be assembled into furniture (Anonymous N.D.).

The assembly stage when is all the pieces required to construct the furniture come together to create the furniture piece. To do this the lumber pieces can be glued, screwed, stapled, and/or nailed together to make the furniture piece. After assembly, the furniture piece moves to be "finished". During the finishing process, coats of lacquer are applied to the exposed wood surfaces. Finishing not only provides an appealing coating but also provides the piece with the protection it needs to extend its lifespan (Anonymous N.D.). Once a piece of furniture has been fully assembled and finished and has passed quality inspection it is ready to be packed for shipping.

At this point the furniture is considered complete. The steps that remain involve packing the piece to ensure no damage occurs during transport and holding in a warehouse until it is demanded. The final step is shipping the packaged product to the final customer once an order is received. Furniture is made in anticipation of actual demand due to the traditionally long lead time of all manufacturing stages.

As can be seen, furniture manufacturing is typically very labor intensive and has evolved to be a rather complicated and extended process. Lumber must go through many stages of manufacturing, starting at the rough mill, to be ready for final assembly and shipping. These stages not only include the essential steps such as shaping, machining, assembly and finishing they also include many incidental steps such as transporting, stacking, unstacking, queuing, and warehousing that can add significantly to the cost of production.

2.3 The Rough Mill

2.3.1 The Rough Mill Defined

As previously mentioned, furniture and secondary wood products manufacturing starts with the breakdown of dried lumber in the rough mill (Cumbo et al. 2006). *The rough mill production process for dimension parts starts with the cut-up of lumber and other processes such as drying, grading, sorting, or skip planing of the lumber may precede this process* (Buehlmann 1998).

Lumber enters the rough mill from the lumber yard kiln dried and of random length and random width for the purpose of cutting the lumber to smaller pieces of specific demanded length and width while maximizing lumber yield. Since all finished furniture pieces require components of different dimension and quantity, depending on what product is currently being produced, the rough mill must dimension parts accordingly (Willard 1970).

Due to the nature of wood as a material and previous drying process, defects are present in most boards that enter the rough mill. Cutting defects out of the lumber as it enters the rough mill is as of equal importance as the previously mentioned cutting for dimension and quantity. Defects in the dimensioned pieces are generally considered unacceptable for the finished product, especially pieces that are on the exposed surface of the furniture piece (Willard 1970).

How parts are cut for dimension and defected depends on the type of cutting system present in the rough mill. *The two types of cutting systems employed in the rough mill are: crosscut-first and rip-first. The distinction between these two systems is the sequence in which the boards are cut to smaller pieces. Rip-first systems cut the incoming boards to long, narrow strips and then crosscut the strips to length in the second stage. Crosscut-first systems cut the parts to length first and then to width. Both systems contain process loops that allow to repeat the cutting sequence to salvage parts with defects. Salvaged parts may be glued together and remanufactured to increase yield and fill cutting bill requirements* (Buehlmann 1998). Edge-gluing pieces together is one of ways salvage parts are remanufactured (Figure 2-3) (Willard 1970).

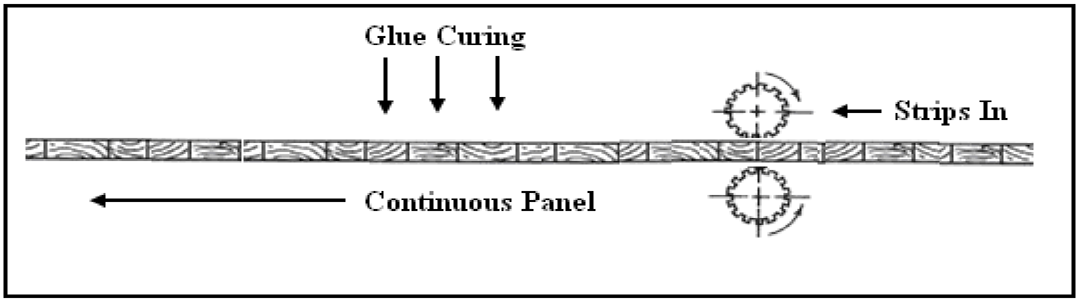


Figure 2-3 Continuous edge glue process example (Willard 1970)

The purpose of edge-gluing is to glue salvaged pieces from the previous cutting operation together on edge into a continuous panel. The salvaged pieces receive glue on both edges and are then fed edge to edge onto a continuous feed roll where the glue is cured creating a continuous panel (Figure 2-3). To obtain the desired panel length out of the continuous panel, a rip-saw is generally placed at the end of the gluer (Willard 1970).

Edge gluing is the result of the gang rip's inability to fulfill cutting bill requirements with solid pieces or the piece width requirement is wider than lumber entering the system. In the occurrence of not being able to fulfill a cutting bill with solid pieces from the gang-rip operation, random width pieces are edge glued together into a panel. Further remanufacturing such as re-ripping must occur at this point to obtain strips back out of the panels to fulfill cutting bill requirements. Once pieces have been obtained as either solid or glued panels further manufacturing such as moulding, re-ripping and sanding is required depending on the final destination of the piece.

2.3.2 Rough Mill Costs

As seen in Figure 2-4, material costs represent 50% of total costs in the rough mill (Mitchell et al. 2005). This determination has lead both researchers and the industry to focus efforts on reducing the costs associated with materials (lumber). While improvement efforts have focused on the reducing material costs, what is often overlooked is how some efforts effect other costs. For example, activities such as edge-gluing is a method used to decrease material costs, however, edge-gluing activities also increase labor, factory overhead costs and increase the amount of time required to process dimensioned pieces.

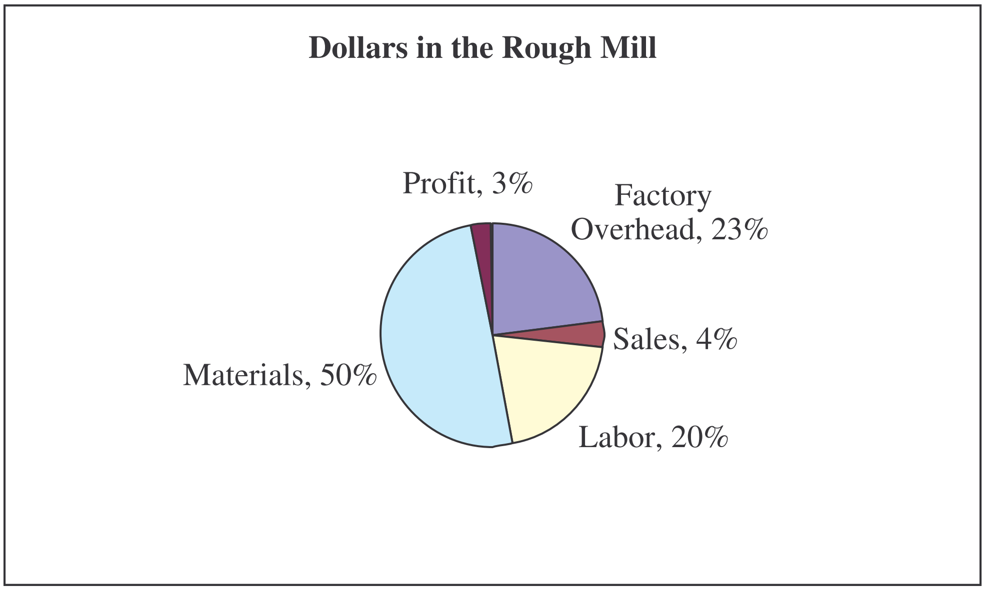


Figure 2-4 Where dollars go in rough mill manufacturing (Mitchell et. al 2005)

2.3.3 Performance Measures

With material being the primary cost of rough mill operations, it is understandable that secondary manufacturing companies containing rough mill operations consider their most important performance metrics as: *1.) Yield; 2.) Production output (tally/quota); 3.) Throughput (BF/labor hour); 4) labor costs (labor hours) and 5.) Quality* (Cumbo et al. 2006). Cumbo et al. (2006) surveyed the secondary wood manufacturing industry and found that that yield is considered to be the most important performance measure while the labor costs associated with meeting the yield metric is not considered to be one of the top 3 performance measures. Many yield recovery activities such as edge gluing have been put into place in the rough mill; however the labor and equipment costs associated with these activities are overlooked due to the importance manufacturers place on meeting the yield metric.

2.3.4 Yield

Lumber yield is the most commonly used measure of efficiency in the rough mill. It has been estimated that increasing rough mill yield by 1% there is a potential to save 2% of total production costs (Wengert and Lamb 1994; Kline et al. 1998). This is why yield has been used for a replacement for rough mill costs. Traditionally this was satisfactory but presently may not be appropriate. *Yield is defined as the ratio of (part) output surface area to (lumber) input surface area* (Buehlmann 1998). Mitchell et al. (2005) stated that in a business sense *percent rough mill yield is defined as the sum of the volume of wood parts that are needed to satisfy the cutting bill (this will include parts of all fixed lengths and widths, panels made up of random width parts, and specified overages) divided by the volume of dry lumber used* this can be expressed as:

% Yield = [Volume of Rough Parts and Panels (board feet) ÷ Volume of Rough, Dry Lumber (board feet)] X 100

Mitchell et al. (2005) noted that *lumber species, mix of lumber grades, lumber drying quality, lumber size, cutting bill sizes, part quality, operator experience, plant layout, machinery, processing sequence, and production scheduling can directly impact rough mill yield. All of these factors interact so that a slight change in any factor may have a large impact on yield—and hence on the profitability of the rough mill.*

2.3.5 Rough Mill Yield Simulation

Rough mill research and development has relied heavily on computer simulation to increase rough mill efficiency. Many computer simulation programs have been created to simulate various aspects of rough mills and to determine yield, labor, capital costs, and processing times (Giese and Danielson 1983; Brunner 1984; Thomas 1996). ROMI-RIP (Thomas 1996) is a rough mill simulation program designed for research use and was produced by the Northeastern Research Station's Forestry Sciences Laboratory. Thus far 3 versions of ROMI-RIP have been developed: ROMI-RIP (Thomas 1996), ROMI RIP 2.0 (Thomas 1999), and ROMI-3 (Weiss and Thomas 2005). Thomas and Buehlmann (2002) found that the ROMI RIP 2.0 program produced higher yield measurements than actual rough mills but determined it was a valid program for research use. The ROMI-RIP program has been used multiple times in rough mill research for varying applications (Buehlmann 1998; Hamner et al. 2002; Shepley 2002; Thomas and Brown 2003; Thomas and Buehlmann 2003; Thomas and Buehlmann 2007). Using the "The Databank for Kiln-Dried Red Oak" (Gatchell et al. 1998) as lumber input, researchers can observe the effects of lumber grade mixture, lumber length and width, cutting bill requirements, arbor type and solid or panel production.

2.3.6 Demand

Past research dedicated to improving rough mill operations has focused primarily on optimizing rough mill yield based on lumber grade and cutting requirements. While yield improvement research has been helpful in improving rough mill efficiency, such research has not considered the dynamic nature of downstream demand for parts produced in the rough mill and the impact of that changing demand on the rough mill (Cumbo et al. 2006). In other words, it is possible to achieve an overall high part yield, while the parts produced may or may not supply any real or immediate demand, which negatively affects manufacturing cost and flexibility downstream (Vickery et al. 1997).

2.3.7 Flexibility

Vickery et al. (1997) identified four dimensions of manufacturing strength in the furniture industry: *1.) Innovation; 2.) Delivery; 3.) Flexibility; and 4.) Value*. According to Vickery et al. (1997), flexibility is the strong point of all furniture manufacturers. Flexibility in manufacturing allows the system to rapidly respond to changes customer demand. While flexibility in furniture takes a backseat to innovation and delivery, Japanese manufacturers consider flexibility to be such a top priority they have developed a type of manufacturing labeled as pull system manufacturing that focuses on system flexibility. Furniture manufacturers have placed more emphasis on products reaching their final destination than being able to respond to customer's actual demand (Maskell 1991).

2.3.8 Over-Run (Overages)

To accommodate customer demand needs, traditional American manufacturing (including the furniture industry) have developed extensive inventory holding systems. These systems alleviate unforeseen changes in customer demand by holding large amounts of finished goods until demand is known. Inflexibility and large of amounts of finished goods inventory in the system has forced many systems to produce more than is actually demanded and vice versa. No system should produce more than is actually demanded if they hope to compete in today's competitive marketplace (Rother and Shook 2003).

Lot size determines the amount of dimensioned parts the rough mill must produce. A "lot" is the predicted customer demand for a piece of furniture. For example, if it is forecasted that 300 nightstands will be demanded in the future, the lot size would be 300. Once the lot size has been determined through forecasting, the number of parts required to complete that particular lot size is calculated. Many of the parts within the lot size vary in quantity and dimension. While only 300 tops may be required for the finished product, there may be 800 internal components required. During the entire furniture manufacturing process, a percentage of these parts may become defected and be considered unusable, to combat against possible shortages, the rough mill may produce material for 320 tops and 850 internal components. These extra parts are typically called "overages" (Willard 1970).

Translating Smalley's (2004) discussion on waste in terms of rough mill operations, overproduction in the rough mill leads to ineffective use of time and effort by producing parts that are not currently demand. By overproducing, money is tied up in the extra manpower, and in making, storing and handling of the overproduced parts. Carrying extra parts in the system makes the rough mill even more inflexible than it already is because these parts need to be stored, managed, and oftentimes moved and handled many times. While systems are overproducing parts, they often find themselves behind schedule and must expedite parts that are actually in demand.

2.3.9 Production Scheduling

Furniture pieces are scheduled for cutting and manufacture by "lots" or "cuttings". *In the 1960's, cuttings or lot sizes manufactured in multiple factories ranged from 250 to 500 pieces. The larger cuttings had been an important factor in enabling companies to hold prices within reason when labor and material costs increased. The increase in unit costs on the small cuttings resulted primarily from decreased labor efficiency; the output per labor hour was lower on the small cuttings as setup costs increased as a result of* *workers and machines shifted more often from one pattern to another* (Skinner and Rogers 1968).

This type of production can be labeled as mass production. Assuming that every thing produced is demanded and paid for, the mass production model says that the cheapest way to produce a good is doing it very fast and in high volumes. Mass production, while successful and cheapest according to traditional accounting practices does not take into costs such as overages, shortages and expediting (Rother and Shook 2003).

In interviewing one company in particular, Skinner et al. (1968) found that the cutting size was determined by the amount of plant storage available. Many furniture manufacturers today still operate under the mass production model in that large cutting sizes are produced and stored for use at a later time. The systems are considered to be mature and inflexible in the current state, resulting in high work-in-process (WIP) levels and long lead-times.

2.4 Production Control Systems

There are two different production control systems that manufacturing operate under: push and pull systems. In a push system, production is controlled using forecasts of believed customer demand. In this type of system, products are manufactured on the assumption that when the item has been completed it will be demanded by the customer. Pull systems work in the opposite manner of a push system in that products are not manufacturing until they have been demanded by the customer (Ono 1988).

2.4.1 Push Systems

Mass production systems such as the traditional furniture industry are push type systems. As mentioned, production is based on a forecast of believed customer demand. Using the forecast, the production process is scheduled for individual process within the manufacturing system, such as the rough mill. Depending on the type of forecast and manufacturing environment, the forecast can be range from weeks to months before the actual product is produced. If the forecast is correct this type of system works efficiently, however if the forecast is incorrect it can be very difficult to correct especially for systems that are inflexible such as the rough mill (Langer 2004).

Historically, furniture manufacturers have based operations on forecasted due dates. In typical push-method fashion, operations are scheduled upstream from the end operations forecasted due date. Software such as Material Requirements Planning (MRP) has been implemented in various manufacturing settings, including furniture, to determine the manufacturing schedule and inventory requirements (Bhoot 2004).

MRP is a very common production scheduling software tool used in push driven manufacturing systems used amongst many industries (Deleersnyder et al. 1989). When forecasts are accurate MRP proves to be a excellent tool, however when forecasting errors do exist the effectiveness of MRP decreases (Lee and Everett 1986). Forecasting errors, no matter what the size can have a tremendous consequence of cost effectiveness (De Bodt 1983). Knowing the consequences associated with forecasting errors, *production planners rely on various buffering mechanisms to respond to forecast errors, such as: freezing the schedule, maintaining safety stock, or overstating the planned lead time, all of which can be expensive* (Ho and Ireland 1993).

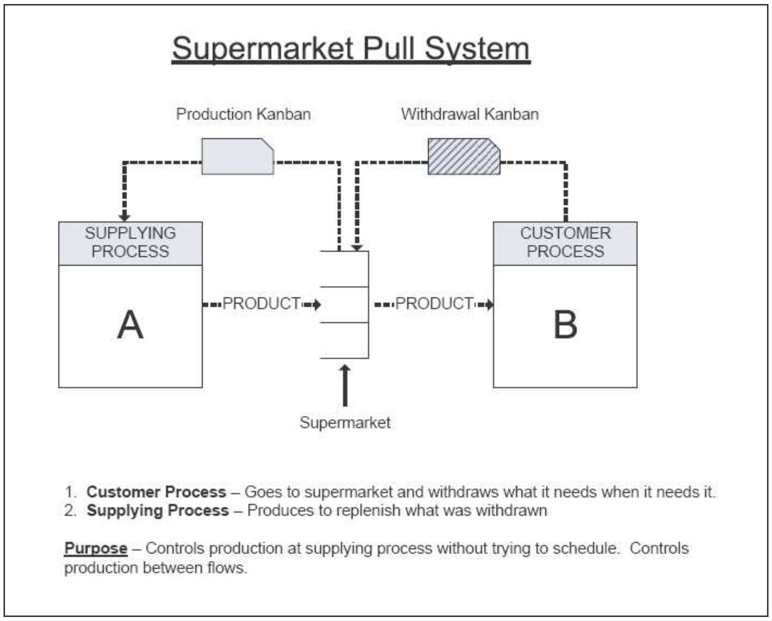
2.4.2 Pull manufacturing / Just-in-time

An alternative to push based manufacturing system is “pull” or “just-in-time” manufacturing. Schuler et al. (2001) and Vickery et al. (1997) suggested just-in-time manufacturing (pull systems) as a strategy for the existing domestic furniture industry to consider for increasing flexibility and reducing operational costs. While they fall under many different labels such as lean and continuous flow manufacturing, JIT systems in simplest terms are “pull” production systems. Japanese manufacturers such as Toyota have found great success using pull system methods (Singh and Brar 1992).

Pull production received its label because products are essentially pulled through the system starting from the final process upstream through the system. The final process withdraws material from the next upstream process as it is demanded. Producing to actual demand is where pull differs from push manufacturing where manufacturing is based on a forecast of demand. This type of withdrawal occurs at all steps in the system. Material is not produced until it is demanded downstream and only the amount demanded is produced (Ono 1988).

The success Toyota has found in using pull systems has lead to a recent focus from industry and academics. As mentioned the philosophy behind pull is to create a manufacturing system that produces the right amount of material at the right time (Singh and Brar 1992). This philosophy goes against the current mentality of overages and production based on capacity found in the rough mill. Ray et al. (2006) noted that while this type of manufacturing was developed for the automotive industry, it has been applied and successful in the wood products industry, specifically the cabinet industry.

Pull production aligns production and instruction with actual demand and eliminates the need to forecast. Pull systems allow downstream processes to control exactly what and how much is being produced. For pull systems to be successful, "supermarkets" are used throughout the system. When a downstream process needs a part, it will pull the part from the upstream processes supermarket. As material is pulled from the supermarket, the upstream process replenishes the exact quantity of parts withdrawn (Figure 2-5) (Rother and Shook 2003), as opposed to releasing materials downstream as in push systems based on a forecast.



1. **Customer Process** – Goes to supermarket and withdraws what it needs when it needs it.
2. **Supplying Process** – Produces to replenish what was withdrawn

Purpose – Controls production at supplying process without trying to schedule. Controls production between flows.

Figure 2-5 An example of a supermarket pull system (Rother and Shook 2003)

When using supermarkets, the supplying process assumes ownership of the supermarket it supplies and the supermarket is typically located in close proximity to its supplier. The close proximity allows the supplier to quickly identify the supermarket's inventory level. Withdrawals from the supermarket by customers are typically not made without notification to the supplier processes. In many supermarket based pull system, notifications come via “kanban” cards. Kanban cards are essentially signal which let the supplying process know exactly what was taken and the quantity taken. When the supplying process has received a kanban card the process knows exactly what to produce to replenish its supermarket (Rother and Shook 2003).

According to Smalley (2004) the four major purposes for kanban systems are:

1. *Prevent overproduction of material between production processes.*
2. *Provide specific production instructions between processes based upon replenishment principles. Kanban achieves standard instruction by governing both the timing of material movement and the quantity of material conveyed.*
3. *Serve as a visual control tool for production supervisors to determine whether production is ahead or behind schedule.*
4. *Establish a tool for continuous improvement. Each kanban represents a container of inventory in the value stream. Over time, this can lead to systematic reduction in inventory, reduced process variation, and ultimately a proportional decrease in lead time to the customer.*

2.4.3 Inventory Control

The result of improper inventory planning can be very costly and disruptive to any manufacturing system. Having too much undemanded inventory results in extra handling, storage and ties up monies. Too little inventory results in shortages and means expediting products through the system (Smalley 2004).

Proper inventory control begins with what is termed as “ABC” production analysis. ABC production analysis is an inventory planning technique used by many pull based companies to determine the amount of inventory that needs to be held. ABC analysis differentiates products based on order frequency. “A” items account for 60% of demand, “B” items the next 20% and “C” items the final 20% of demand. ABC analysis allows manufacturers to identify which items are ordered frequently (A items) and which items are in low demand or infrequent orders. ABC analysis is a good planning step to help determine which products to hold in finished goods and which to make-to-order. By determining which items are A, B, or C the manufacturer can determine which items need to held in the previously mentioned supermarkets. Table 2-1 Represents various strategies for finished goods holdings (Smalley 2004; Leonard 2005).

Table 2-1 Options for finished goods versus make-to-order (Smalley 2004)

Finished Goods Options	Pros	Cons
1. Hold all items (A's, B's, C's).	All items are ready for shipment.	Increased inventory and holding space.
2. Make to order all items	Lowest inventory levels.	Requires flexible system and short lead time.
3. Hold only C's, make to order A’s and B’s	Low inventory levels	Requires mixed production control and daily stability
4. Hold A’s and B’s products, make C's to order.	Moderate inventory	Requires mixed production control and visibility on C items

Upon determining a proper finished goods options (Table 2-1), the level of inventory goods to be held in finished goods can be calculated. According to Smalley (2004) inventory can be split into three different segments: cycle stock, buffer stock, and safety stock. Cycle stock covers normal customer demand while buffer stock covers against change in normal customer demand. Safety stock is in place as protection against quality issues and any downtime (Table 2-2). Smalley (2004) provides a simple equation to calculate finished good requirements (Table 2-2). As can be seen the summation of cycle, buffer and safety stock determines the proper finished goods inventory levels to be held.

Table 2-2 Finished goods calculation

	Finished-Goods Calculation	
	Average daily demand x Lead time to replenish (days)	Cycle Stock
+	Demand variation as % of Cycle stock	Buffer Stock
+	Safety factor as % of (Cycle stock + Buffer Stock)	Safety Stock
=		Finished-goods inventory

2.5 Value Stream Mapping

Rough mills are managed using push methodology and are typically yield driven. While improving yield improves overall output efficiency in the system it does not directly link production to actual upstream demand. Value stream mapping is a tool that helps provide the capability necessary to link production and upstream demand. A value stream depicts all value and non-value added actions required to manufacture a product from start to finish. There are two types of value stream maps: current state and future state. The fundamental steps to current state value stream mapping according to Rother and Shook (2003) are:

1.) Determining a product to map

2.) Determining selected product demand

3.) Product manufacturing process flow

4.) Work time

5.) Determining manufacturing process information

Current state maps depict the current manufacturing while the future state represents the improved state of the manufacturing process using pull and supermarket methodology which link production with demand (Rother and Shook 2003). The following measurements are in value stream mapping: cycle time (C/T), changeover time (C/O), lead time (LT), value-added time (VA) and machine uptime. Cycle time is the time it takes to process one product and changeover time is the time to switch from producing one product type to another. Lead time is the time it takes one piece to move all the way through a process or a value stream, from start to finish. Overall LT is determined by summing each individual lead time. Value added time, which is the time required to transform the product into something the customer is paying for (Rother and Shook 2003).

One of the benefits of value stream mapping is it helps to identify waste. Waste is any process that does not add value to the product, processing that the customer is not willing to pay for. Eliminating waste reduces waste and improves efficiency in the system (Rother and Shook 2003; Leonard 2005). For pull systems to be successful they must be flexible and responsive. To be flexible and responsive they must be free of production waste.

According to Ono (1988), there are seven types of waste in production:

1) *Overproduction*
2) *Waiting*
3) *Transportation*
4) *Inappropriate processing*
5) *Unnecessary inventory*
6) *Unnecessary Motion*
7) *Defects*

The goal of the value stream mapping process is to identify current manufacturing processes wastes for in the development of a future state pull-based value stream system. While there has been significant research and development in industrial systems to test and implement pull based manufacturing systems using value stream mapping techniques, there is no current evidence to suggest that these practices are being utilized in rough mill systems. Importance has been placed on lumber yield and material costs for manufacturer's sake while disregarding meeting customer demand.

3 Rough Mill Current State Evaluation

3.1 Introduction

As discussed in Chapter 1, the goal of this research is to study the cost effectiveness of the current state value stream. In addressing this, the first study objective as discussed in this chapter, describes and evaluates the current state value stream of a furniture manufacturer's rough mill located in Virginia. The value stream evaluation focused specifically on internal nightstand components. All processes currently performed in the rough mill to transform dried lumber into internal nightstand components are identified and discussed. The current state evaluation also identifies areas of improvement for consideration in the implementation of a future state pull based value stream.

3.2 Methods

The first objective involved a description and evaluation of the current state value stream of a rough mill at a furniture manufacturer in Virginia. This evaluation was based on information obtained from on-site observation, data provided by the manufacturer, and informal interviews with the company's rough mill management, industrial engineering department, and shop floor employees. The evaluation was performed using value stream mapping techniques outlined by Rother and Shook (2003).

One product type, internal nightstand components, was the focus of the current state value stream evaluation. One product type was chosen due to overall lead time variation between products as a result of varying kiln drying schedules and finished product type. Finished nightstands represent 12% of the manufacturer's total sales and their internal components are in constant demand, fairly uniform in dimension and species, and undergo constant routing.

The current state evaluation also identifies what Ono (1988) considers to be processing waste: overproduction, waiting, transportation, inappropriate processing, unnecessary inventory, unnecessary motion and defects (Table 3-1). Eliminating waste focuses efforts on the value creating activities that customer's desire and are willing to pay for, and results in improved processes – shorter lead times, fewer defects and errors and lower costs.

Table 3-1 shows what information was collected and the collection method for the current state evaluation and processing waste identification. Part yield and on-time delivery was also measured; these metrics are representative of current industry rough mill benchmarks as well as suggested pull system benchmarks. Using this information, current state analysis determined what limits the rough mill's flexibility and prohibits the rough mill from meeting downstream demand.

Table 3-1 Collection methods for determining current state value stream and waste

	Collection Method		
	From Manufacturer	Observation	Interview
Labor	**X**	**X**	
WIP		**X**	
Takt Time	**X**	**X**	
Lead Time	**X**	**X**	
Cycle Time		**X**	
Cutting Bills	**X**		
Yield Reports	**X**		
Route Sheets	**X**		
Downtime		**X**	**X**
Changeover Time	**X**	**X**	**X**
Work time	**X**	**X**	
Overages		**X**	**X**
Shortages		**X**	**X**
Product Flow	**X**	**X**	**X**
Transportation		**X**	
Motion		**X**	
Information Flow	**X**	**X**	
On-time Delivery	**X**	**X**	

3.3 Manufacturer Profile

The furniture manufacturer is considered to be a large organization that has been in business since the 1920's. It is currently a publicly traded company that operates 4 manufacturing facilities. However, this case study focused on the largest facility. According to plant management, the majority (75%) of production is performed domestically while the remaining products are imported. The majority of imported products are chairs and upholstered products; it was a business decision that these items (especially upholstered products) could be produced at a lower cost overseas.

Figure 3-1 displays all products the furniture manufacturer sold in 2006. This information was provided by the manufacturer and is based on sales volume. All products are sold directly to furniture retail stores and there is typically little or no direct contact with the final customer. In the current business model, any problem the final customer may encounter with the finished furniture piece is the immediate responsibility of the retail store. If the retail store believes the manufacturer is responsible for any customer problems, the manufacturer is contacted for restitution.

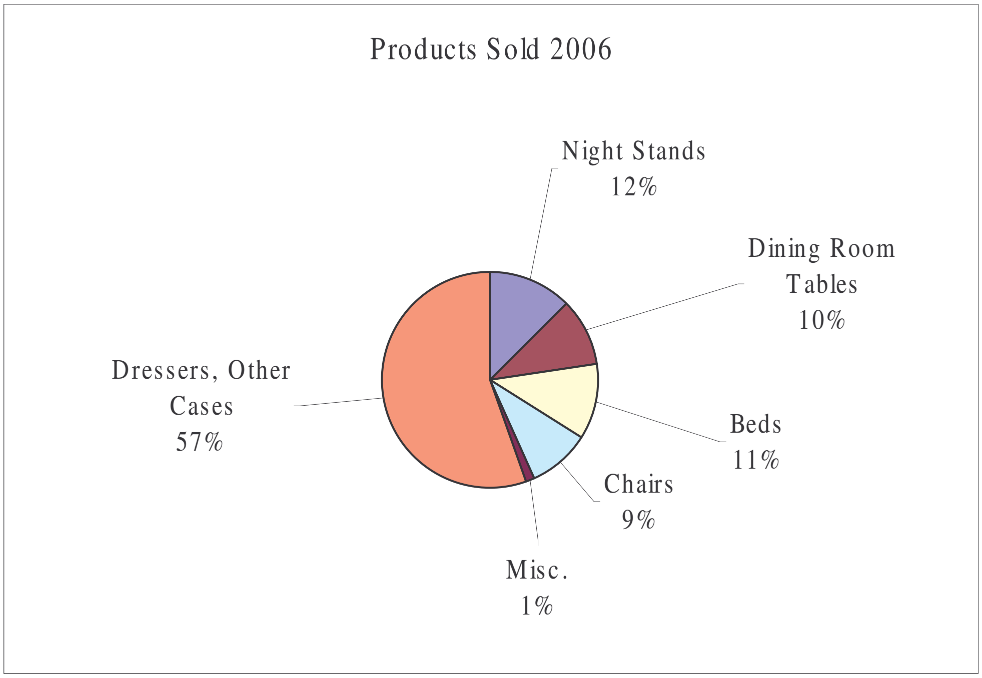


Figure 3-1 Products sold by manufacturer as a % of sales volume in 2006

3.4 Nightstands

As shown in Figure 3-1, nightstand products represent 12% of the items sold in terms of sales volume at the furniture manufacturer under study. The 2006 nightstand production line consisted of 80 available different nightstand options (bachelors and bedside chest options have been included in the nightstand line). Of the 80 options, 59 were manufactured during the 2006 year. Approximately 24,500 total nightstands, bachelors and bedside chests were manufactured during 2006. Internal nightstand components for these pieces provide structure to the piece and are unexposed. These pieces are often termed as rails at the manufacturing site and many types of rails exist such as: top front, top blind (Figure 3-2), bottom blind, top back (Figure 3-3), mid and bottom back, shelf back, drawl parting are all examples of rail terms. Nightstand rails were selected as the focus of this study due to the consistency in both dimension and volume of their production at the study site as well as physical commonalities between each style. The manufacturer felt these parts provided the greatest opportunity for value stream mapping based on these reasons.

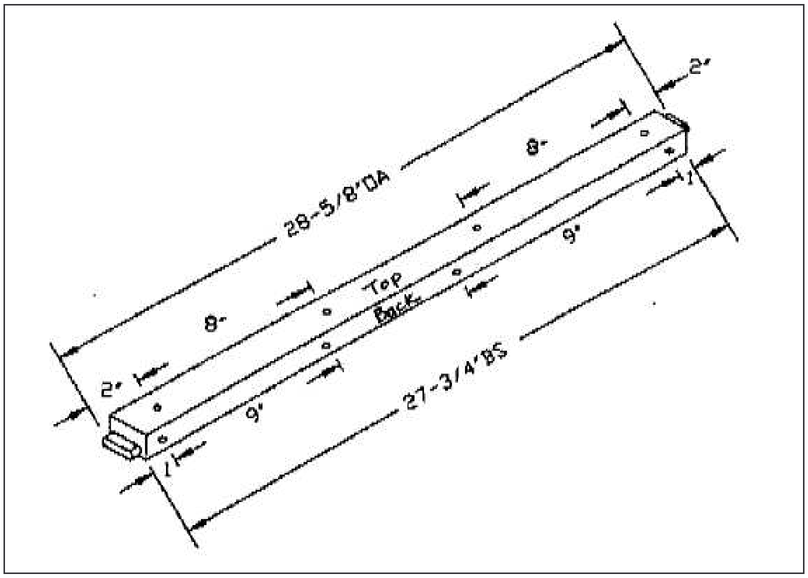


Figure 3-2 Top Blind Rail

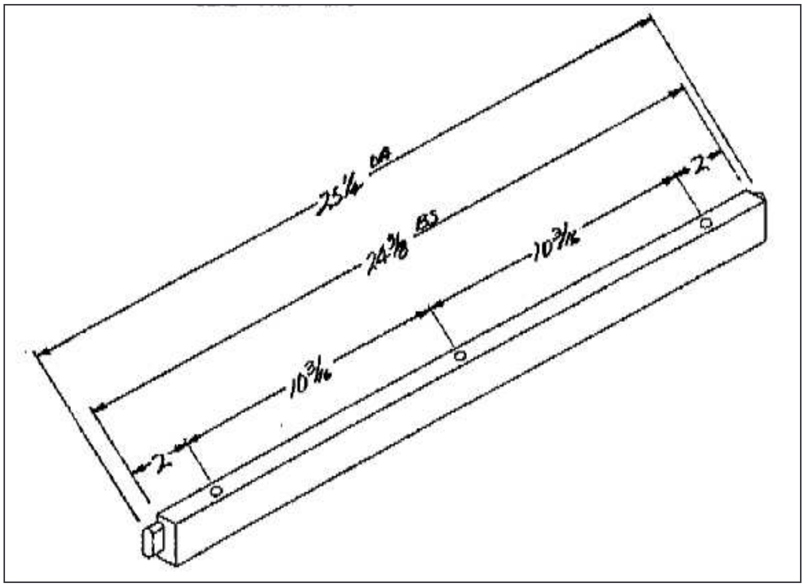


Figure 3-3 Top Back Rail

The rough mill under study processed over 9.3 million GBF (Gross Board Feet) of lumber in 2006. 23.6% (2.1 million GBF) of this was 4/4'' 2-Common (C) yellow poplar (*Liriodendron tulipifera*). 2-C yellow poplar is a readily available from lumber suppliers and inexpensive species at the study mill well suited for use as unexposed furniture parts such as nightstand rails.

3.5 Production Scheduling

Production is currently scheduled using batch and Material Requirements Planning (MRP) methods. Using current inventories and forecasts of demand, a "scheduler" decides which, when and how many product offerings are to be produced. After products have been selected for manufacture based on the scheduler's forecast, they are entered into the company's master production schedule (MPS). The MPS is an aggregate schedule for all products in the furniture plant. Once the MPS has been determined, this information is input into the company's MRP software system. The MRP system produces a disaggregated production schedule for each product in the aggregate schedule. This disaggregate schedule is called a route sheet (Figure 3-4).

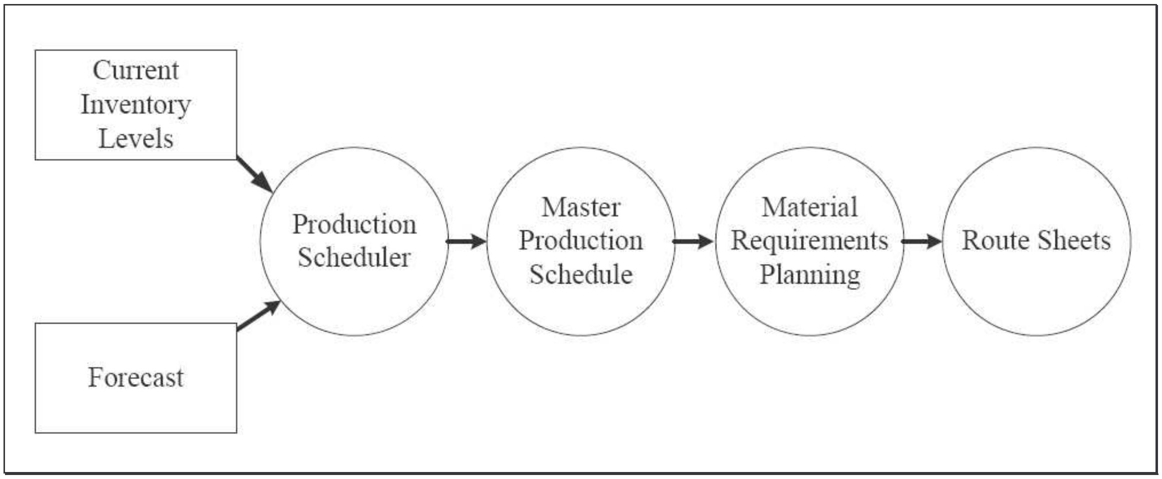


Figure 3-4 Production scheduling

Route sheets are the blueprint for a piece of furniture. Route sheets contain information on rough and finish dimension sizes, exact machining details, material routing through required machine operations, wood species, part quantities, part due dates and some in some cases, pictures of the finished part are included. Depending on how many different pieces are required to complete a furniture piece dictates the number of route sheets. Each batch of specific parts within a single piece of furniture has its own individual route sheet.

The amount of time currently allotted to process a batch of furniture at the study site is 60 days. Thirty days is the amount of time the forecaster uses currently to schedule out selected items (lumber, hardware) and the remaining 30 days is the amount of time the plant is allotted to produce the final product (machining, assembly). A total of 60 days is used to both schedule and produce furniture at the manufacturer and consequently, this time used can add significant costs and customer backlogs if the scheduler is incorrect when forecasting.

3.6 Current State Rough Mill Value Stream

According to rough mill management and past route sheets, internal components flow through one of four different machine routing sequences (Table 3-2). As can be seen, all parts are first gang-ripped into strips and then chopped to length. The routing sequence following ripping and chopping is based on two factors: final part design (dimension, machining requirements) and if parts can be machined from edge-glued panels.

Parts which travel through Sequence 1 and 2 in Table 3-2 are parts that are designed to be moulded. Table 3-2 was developed based on input from rough mill management. Management reported that roughly 80% of internal components required moulding and the majority (50% of total) of these parts were routed through the gluing process prior to moulding. Due to adhesive curing time required, the gluing process increases part lead time as can be seen in Sequences 1 and 3. Parts that do not require moulding consist of roughly 20% of internal components. It should be noted that Sequence 2 has a minimum lead time of possibly 1 hour and is often used for parts that are being expedited due to critical downstream demand backlogs. Route sheets indicate that all internal components may be glued into a panel as required, and assume that all parts require 3 days to process. This is a safety measure in place that provides rough mill management leeway to process parts in a manner that suits the overall system best. By design, the majority of parts come from edge-glued panels (65%) to help maximize rough mill yield.

Table 3-2 Rough mill processing sequences

Rough Mill Processing Sequences							
Sequence	Machine 1	Machine 2	Machine 3	Machine 4	Machine 5	% of Production	Leadtime (L/T)
1	Gang Rip	Chop	Gluer	Multi-Rip	Moulder	50	1 - 3 Days
2	Gang Rip	Chop	Moulder	---	---	30	1 hr. - 2 Days
3	Gang Rip	Chop	Gluer	Finish Planer	Multi-Rip	15	1 - 2 Days
4	Gang Rip	Chop	---	---	---	5	± 1 hr.

Figure 3-5 is the Current State value stream map for internal components that travel through Sequence 1 shown in Table 3-2. This value stream map was based on the principles set forth by Rother and Shook (2003) and discussed in Chapter 2. The information used to create this value stream map was based on on-site investigation as well as management and shop floor employee input. Sequence 1 was used to create this map due to management's reporting that the majority of internal components traveled through this machining sequence. The lead and value added times for the current state value stream was based on observations an actual internal nightstand component order (Table 3-3). Although the order shown in Table 3-3 is an actual order, the order number (BBR#1) shown has been created to maintain confidentiality.

Table 3-3 Internal nightstand component order (BBR#1)

Nightstand - Bottom Back Rail									
	Length	Width	Thickness	Material	Grade	# of Pieces	# of Panels	Total Footage	Lineal Feet
Rough	21’’	23.25’’	1’’	Poplar	2	283	17.75	60	495
Finished	20.25’’	1.25’’	0.71875’’	–	–	–	–	–	–

Table 3-3 is an example of the information that is found on a route sheet at the study site. BBR#1 is a batch order for 283 bottom back rails that will be used in the construction of a specific nightstand. This component’s final dimension and style has been designed for 1 specific nightstand. Many other parts will used be along with order BBR#1 for the final assembly of the nightstand. Rough dimensions (21’’ x 23.25’’) reflect the panel dimensions required for panel glue-up. The number of panels shown indicates how many panels are required for the multi-rip operation to obtain required 283 individual pieces of dimension size (20.25 x 1.25). Other information indicates rough and finished thickness; material (species), part grade, total board and lineal footage for the BBR#1 order. This order was selected to represent the internal nightstand components to provide a common scale; nightstand order sizes vary due to forecasting by the manufacturer and this order was reported to be a common order based on overall component production.

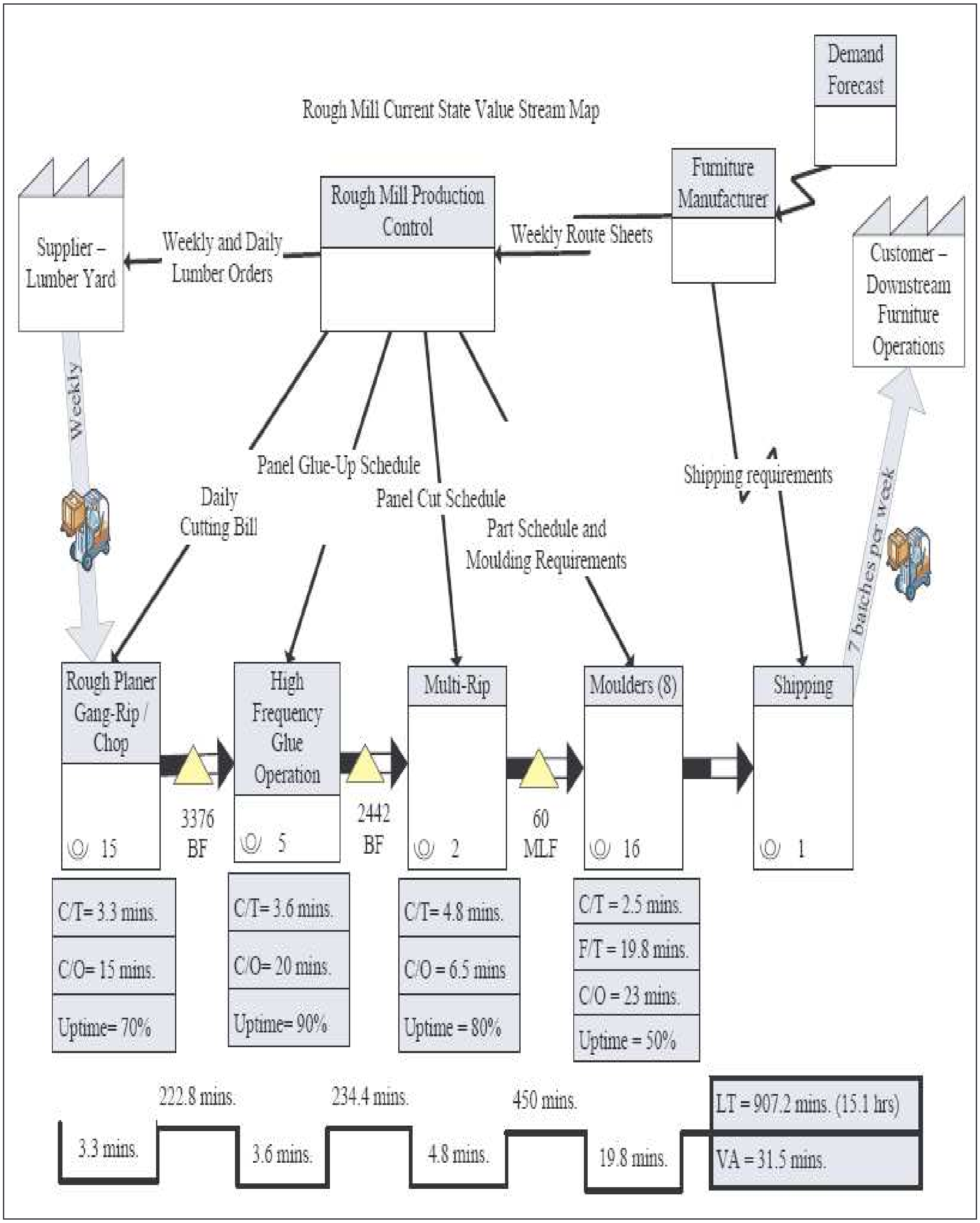


Figure 3-5 Current State Value Stream Map

In Figure 3-5, information is received via route sheets from management as described in Section 3.5. This production information is based on the forecast of demand provided to the manufacturer by the MRP system. Real demand is unknown; the only demand is in the system is forecast based. Two key decisions are made by rough mill management upon receiving route sheets: lumber orders to be released to the lumber yard and the cutting bill to be released to the rough mill. Lumber orders are sent to the lumber yard on a weekly and daily basis. The weekly lumber order is essentially a short term forecast that allows the lumber yard to prepare and stage lumber for the upcoming week while daily orders fulfill actual daily rough mill input requirements. After the cutting bill has been formulated, this information along with gang-rip arbor set-up (pocket sizes) is sent to the Gang-Rip and Chop operations. The cutting bill notifies operations what parts are to be cut for a specific time period.

Once internal components have been ripped and chopped in Figure 3-5 they are processed into a panel at the high frequency glue operation. To breakdown the glued panel back into strips of specified widths, the panel is processed at the multi-rip machine, which is essentially a second gang-rip operation. At this point strips meet rough dimension requirements and are moulded into their final shape before exiting the rough mill.

Each individual order of parts travels through the rough mill on a wheeled cart and each order carries with it its designated route sheet. Work stations (glue, multi-rip, moulder) receive a schedule of the parts to be processed from rough mill management. It is the responsibility of each station to process according to this schedule. Exceptions are made for expedited parts and this decision is made by rough mill management.

Expedited parts are often the result of inaccurate upstream forecasting, unplanned processing delays, and inaccurate inventory counts.

Between each process box shown in Figure 3-5 a black and white arrow exist indicating that parts are “pushed” between each operation. The inventory triangle or WIP held between each work station is shown below the “push” arrows. The number within each process box represents the number of workers at each work station. The moulding operation is the only operation which features the possibility of more than 1 machine (currently 8 moulders are in place) being used for the production of internal nightstand components indicated beside the moulder label in parenthesis in Figure 3-5. Below each process box exists a data box, the data box contains the following information: cycle time, changeover time, and uptime.

Flow time (F/T) was an additional measurement used at the moulders; flow time represents the lead time when 1 moulder is used to process an entire batch. Due to batch constraints, keeping an order confined to one moulder takes 19.8 minutes to process. If the system was more flexible and the order could be distributed among the 8 moulders, it could theoretically take 2.5 minutes. Typically 1 moulder to process a unit in order to process an order. At the bottom of the figure lies a timeline which notes lead time and value added time. The summation of lead and value added time is totaled on the bottom right of the figure. BBR #1 (Table 3-3) of 60 board feet (BF) and 495 lineal feet (LF) of internal components requires 15.1 hours (almost 2 business days) to be processed in the rough mill while only 31.5 minutes of this time is value added time. Table 3-4 provides a brief summary of the information found in Figure 3-5. It should be noted that the rough planer/gang-rip/chop C/T was determined using 110.05 BF input due to rough mill simulation results of 54.52%. This is discussed in detail in Chapter 4.5.

Table 3-4 Current state value stream map breakdown

Current state value stream map breakdown				
Metric	Rough Planer/Gang Rip/Chop	High-Freq. Gluer	Multi-Rip	Moulder
WIP	20 MBF	3376 BF	2442 BF	60 MLF
Throughput	2 MBF/hr.	1 MBF/hr.	750 BF./hr.	25 LF/min.
Cycle Time	3.3 mins./unit	3.6 mins./unit	4.8 mins./unit	19.8 mins./unit
Changeover Time	15 mins.	20 mins.	6.5 mins.	23 mins.
Uptime	70%	90%	80%	50%

Table 3-5 represents the labor as shown in Figure 3-5. Direct labor shown represents the hourly labor employees while indirect represents supervisors on the floor. Supervisors in some cases are shared resources, meaning they may be responsible for more than one machine. This can be seen at the multi-rip and moulder. This information was based on input from rough mill management, the industrial engineering department and observation.

Table 3-5 Rough mill labor per machine per shift

Rough Mill Labor Per Machine per shift		
Machine	Direct Labor	Indirect Labor
Rough Planer	1	0
Gang Rip	2	0
Chop Saw	12	2
Gluer	5	1
Planer	2	0
Multi-Rip	2	0.5
Moulder (8)	2	0.375

3.7 Lumber Yard

Production begins in the lumber yard at the study site. Lumber is brought into the lumber yard as green lumber from one of approximately 50 sawmill suppliers currently used. At this point the lumber is graded to ensure the accuracy of the purchased grade from the supplier. Once lumber has been graded and manually sticked, it is moved to a holding area where it is airdried until demanded. Approximately 3.5 million BF of lumber is held on the lumber yard for airdrying. The reason for holding this amount of lumber is to remove moisture and help reduce the cycle time needed for the kiln drying step. From the airdry storage site, the lumber will be staged for kiln drying. Airdrying times can range from weeks up to several months. The amount of time spent airdrying depends on lumber thickness and demand. Typically, as lumber thickness increases so does the amount of time it will spend in the airdrying area. The time required to kiln dry hardwood lumber is dependent on the lumber species, times can vary from 1 week to 3 or more weeks. The furniture manufacturer operates 12 dry kilns with a total drying capacity of 560 MBF. Once lumber exits the dry kilns and enters dry storage it is physically ready to be staged into the rough mill for the lumber breakdown procedure.

3.8 The Rough Mill

The rough mill represents the first stages of lumber breakdown from kiln dried boards into smaller pieces of wood that will make up the final furniture piece. At the study site the following actions take place in the rough mill: rough planing, gang-rip and chop, high-frequency gluing, finish planing, re-ripping and moulding. As seen in Table 3-2 not every internal nightstand component went through each of these actions. The lead time designated by the company for the rough mill is 3 days and this is the standard time used when determining the overall production schedule even though components can be expedited in less time if needed (Table 3-2).

It should be noted that while internal nightstand components are the focus of this study, many other parts are being processed through the rough mill at the same time. Each machine in the rough mill is a shared resource. A shared resource means that no machine in the rough mill is designated solely for the purpose of manufacturing internal components. Hundreds of different parts create a 4/4’’ 2-C yellow poplar cutting bill and the percent of internal components in a cutting varies on the schedulers forecast. Once the rough mill was set up to run, it was observed that 4/4’’ 2-C yellow poplar was cut typically 2-3 working days in a row.

3.8.1 Lumber Input

As mentioned, route sheets for each component order are produced by the MRP system. Once route sheets have been produced, they are supplied to the rough mill 3 weeks ahead of the scheduled production start date. The rough mill supervisor collects all route sheets due for a production week and separates them based on lumber characteristics. For example, all 4/4’’ yellow poplar route sheets are grouped together and all 5/4’’ yellow poplar bills are grouped together.

Route sheets do not indicate the time of the day parts are to be produced; they only indicate production start date therefore grouping of route sheets is performed to maximize yield by batching parts together and to increase productivity by limiting changeovers at the rough planer and gang-rip operations. Changeovers at these stations are required when lumber input characteristics differ such as thickness and or species.

The individual cutting bill tells the rough mill supervisor the board footage requirement of the finished parts. To determine the lumber input needed to be input from the lumber yard to the rough mill, the individual BF requirements from the route sheets are summed and then a yield factor is applied. For example, if 1 batch of route sheets for 2-C yellow poplar individual component footage requirements totals 1 MBF; the rough mill supervisor will order 2 MBF. The yield for 2-C yellow poplar in the rough mill has been determined by management to be approximately 50%; this is why 2 MBF would be input into the rough mill rather than 1 MBF. Once the BF required to fulfill cutting bill requirements has been determined, the lumber yard will supply the lumber to the rough mill.

3.8.2 Rough Planer/Gang-Rip/Chop Operations

This operation operates like a cell where the 3 pieces of equipment work together as shown in Figure 3-5. Lumber advances from the lumber yard to the rough mill in stacks via forklift. Between the lumber yard and rough planer roughly 18 MBF of inventory is kept to feed the rough planer. The fork lift operator for the rough planer must retrieve the lumber stacks from the lumber yard, stage stacks and feed the rough planer at the same time. It was not observed during this study that the rough planer was ever idle waiting for lumber. The forklift places stacks on a chain that feeds a *Neuman S282* planer. The basic human operations at this station are to unstack and destick the stack and feed boards into the planer. Breakdown of the stack by the rough planer operator is performed using a hoist and each board is manually taken from the top of the stack and feed into the planer by the operator.

The rough planer is operated by 1 person and processing is first-in-first out (FIFO), meaning whatever board comes to the planer operator first is the first board handled. The planer has a 24’’ wide infeed and when the downstream gang-rip operation is running at full capacity the planer operator has to feed the planer 2 boards at a time side-by-side to maximize throughput to ensure the gang-rip is not starving for lumber.

The rough planer is paced by the gang-rip saw. If the gang-rip saw's inventory capacity is full, the rough planer must halt operations. Conversely, if the gang-rip operation is starved the rough planer must increase production to satisfy the gang-rips needs. It was observed during the study that the rough planer did not operate at full capacity because the gang-rip operation was the bottleneck of the Rough Planer/Gang-Rip/Chop operation. A conveyor and FIFO system links the rough planer to the gang-rip saw therefore production matches the gang-rip. The inventory level between the rough planer and the gang-rip was limited to the length of the conveyor system.

Changeover time for the rough planer to go to a different thickness was observed to be 15 minutes. When a new species or thickness is ordered the planer operator must stop operations. The operator must also wait until the downstream gang-rip and chop operations cleared their systems of previous species or thickness before a new thickness or species is planed; this is done to keep orders separated. Clearing the system was observed to happen within the 15 minute changeover.

Lumber exits the planer and enters a *Mareen Johnson* fixed-blade gang-rip saw on a conveyor. Just like the rough planer, the gang-rip operation is a FIFO process. There are 2 operators at the gang-rip operation: one maintains the conveyor system and one feeds the saw. One operator keeps boards exiting the rough planer to the gang-rip saw on the conveyor and straight. This same operator also checks boards for quality and turns the boards with the best face down. From here, boards continue to travel on the conveyor to the next operator who uses a laser light to measure the maximum useable width of the board based on the second best face. Defects such as wane are usually found on the second best face and the best way get a true measurement of a board's useable width is by ensuring that this face is visible to the gang-rip operator. This measurement is used by a computer control system to determine where the board will enter the gang-rip to maximize the strip yield. The arbors in the gang-rip saw are spaced at varying pre-set intervals determined by the cutting bill to maximize yield.

To maximize strip yield, a standard 4/4'' 2-C yellow poplar arbor spacing sequence (Table 3-6) was developed at the study mill using past cutting data. The purpose for having this standard arbor is to maximize yield and decrease downtime from arbor changeover. 4/4'' 2-C poplar is roughly 24% of production therefore minimizing downtime from changeovers which take 10 -15 minutes is required to maximize throughput. As can be seen in Table 3-6 the widest 4/4'' piece that can be obtained from the standard arbor is 2 ¾'' and the narrowest piece attainable is 1 3/8''.

Table 3-6 Standard 4/4'' 2-C Poplar Arbor used by study mill

Standard 4/4 Poplar Arbor	
Arbor	Pocket Size
1	2 3/8"
2	2 3/4"
3	2''
4	1 3/8"
5	2 3/8"
6	2''
7	2''
8	2 3/4"
9	1 3/8"
10	1 3/8"

For all cuttings on the gang-rip that are not 4/4'' 2-C poplar, different arbor set-ups are made depending on the order or bill. The arbor set-up for a non 4/4'' 2-C poplar order is formulated in the production office based on part size requirements from the route sheets. The arbor is built ahead of time by employees in the tooling room. Once the arbor has been built the changeover is performed by the same gang-rip operator that feeds lumber into the machine. This changeover occurs within the 15 minutes allotted for planer set-up time. The saw kerf produced by the saw blades is 3/16''. Once pieces have been ripped out by the gang-rip saw they travel on a conveyor to the chop saw operation.

The current throughput goal of the rough mill set by management is 2 MBF through the gang-rip per hour for 4/4'' lumber, this goal was observed to be met when no lengthy changeovers occur when switching species. The only gang-rip downtime observed was when waiting for the downstream chop operations. Downstream chop operations can manually turn off the gang-rip line when too much lumber accumulates in their small buffer area.

Strips come from the gang-rip saw on a conveyor belt to the chop saw operation. The chop saw is a *Barr Mullin Wondersaw* brand chop saw. Between the gang-rip and chop saw is a FIFO process. The purpose of the chop operation is to cut out unacceptable wood features and cut pieces to required lengths. The defecting process involves approximately 6 workers using fluorescent crayons to mark unacceptable features in the lumber strips that need to be removed by the chop saw. Typically 2 marking workers will operate 1 line. What determines constitutes a removable feature differs between species and is based on the final part end use. An internal component that will go unseen in a furniture piece is allowed to have more “features” than a piece that will be seen on the outside. Markers are instructed how to defect based on cutting bill requirements by a supervisor. Once a strip has been marked for removable features it is sent to the chop saw where the strips will be automatically chopped using a computer vision system that identifies the fluorescent mark on the strip and cuts out the marked section of the strip.

In addition to defecting, the chop saw also cuts the strips to part length requirements. These part length requirements to fulfill orders based on cutting bill requirements that are programmed to the chop saw scanning system. Essentially, the scanning system first identifies marked sections to cut out of a strip and then determines what part length to cut out of the remaining “acceptable” length of a strip. As several hundred lengths and quantities per length may be required to fulfill a cutting bill, emphasis on which part lengths to be cut at the chop operation differs.

Greater priority is placed on longer lengths than shorter lengths. Greater emphasis is placed on longer lengths because these orders are considered to be “harder” to fulfill. For example, it is easier to obtain a feature-free part length of 40’’ than is it a defect-free part length of 60’’ therefore the scanning system first searches for a part of 60’’ and if that length is not obtainable it will search for a part of 40’’. While this process of placing greater emphasis on longer pieces may increase yield it places less emphasis on actual part demand. A piece that is of smaller length may be in more demand however this piece may be passed over routinely by the scanning system because greater emphasis is placed on longer lengths.

Once strips have been defected and cut to length, parts of a specific length and width are then routed to a designated off-loading station where 6 more workers are assigned specific part dimensions to unload. The worker assigned to the specific part unloading station will then load the parts onto a cart until the order requirements are fulfilled. Once the part requirements have been fulfilled, parts will be removed from the chop saw cutting options and a new part will be inserted into its place and the cycle repeats.

In many cases, part width requirements can not be met. This occurs for various reasons such as: arbor pocket size does meet specific part requirements or less emphasis was placed on the obtaining the piece as a solid piece at the chop saw. When parts width requirements can not be meet, random width parts of the same length are edge-glued together into panels.

3.8.3 Edge Gluing Operation

Parts that come from the gang-rip line are either too small (less than 1 ¼’’) or large (2 ¾’’) or if not enough parts come from the gang line as solid to fill an order. The arbor pocket size also determines if parts will be glued into a panel. Obviously if a part width requirement is wider than the widest pocket, random widths will be cut from cut off saw at the required length and subsequently glued into a panel to allow for re-ripping downstream to the desired width. The difficulty of the cutting bill and the range of part sizes also play a role in whether a part will be glued or taken solid from the gang-rip.

Parts are staged after the chop line on carts in a designated area while waiting to be glued. While several types of edge-gluing operations exist at the study site, internal nightstand components are strictly routed to the *Rosenquest* machine. The *Rosenquest* is a continuous edge gluer; meaning one continuous core is produced and then cut off at specific lengths. It takes 5 operators to run the machine. Two operators stage a group of 10 or so parts by feeding the parts across a glue applicator on edge. The next 2 operators take the parts off of the glue applicator and feed the parts edge to edge continuously into the machine where the resin is cured. A chop saw resides on the exiting side of the machine that cuts the continuous panel to length as indicated on the route sheet. From here, the newly sized panel is off-loaded onto a cart by the 5th operator. At this point, the panel proceeds downstream to be re-ripped at a Multi-Rip machine into the strip width that was previously unattainable at the gang-rip operation. The throughput for the Rosenquest was observed to be 1 MBF/hour.

3.8.4 Multi-Rip Operation

The multi-rip operation is essentially a gang-rip operation in that panels are fed through a multiple blade saw. Using the same principles as the initial gang-rip system, arbors in the machine are set to cut strips of specific widths out of a panel. These arbors must be changed frequently depending to meet part width requirements and fulfill the route requirements. The multi-rip machine is operated by 2 workers: 1 operator feeds glued panels into the machine while the other removes the strips and places them onto a cart. Throughput at the multi-rip was observed to be 750BF/hour and a recent study by management determined that changeover is 6.5 minutes.

3.8.5 Moulders

Currently eight *Weinig* moulders are in place at the study site. Each moulder has 2 operators; 1 in-feed and 1 out-feed. The moulding operation is considered by most to be the bottleneck of the study rough mill. Changeovers are frequent and fairly lengthy at this operation. During observation it was apparent that the machines were operated at approximately 50% uptime. Management felt the moulding operation could lengthen part lead time by 1 day if downtime was not minimized.

Much like previous operations, part orders are grouped together at this point if possible. Part grouping is not possible if the designed mould differs between orders. Moulders operate only on the first shift due to the importance of this process and lack of second shift supervision. Changeover times at the moulder operation often vary between each moulder. Depending on operator experience and ability to properly set-up up the machine changeover times differ, however it was observed that an average changeover consumed approximately 23 minutes. This information was based data on obtained from past improvement events and data collection by the manufacturer.

Batches are kept together through 1 moulder and not split to different moulders. Batches are routed though to specific moulders based on availability and specific finished thickness. A recent improvement event assigned each moulder specific part thicknesses in hopes of decreasing downtime and creating standard work (Table 3-7). For example, if a part requires a finished mould thickness of 15/16’’ it would be routed to either Moulder # 2, 3, 5 or 6. Throughput for each individual moulder was measured to be 25 LF/minute; this was based on observation and data collection by the manufacturer.

Table 3-7 Moulder assignments

Moulder	Part Finished Thickness	
1	3/4"	–
2	15/16"	1 5/8"
3	15/16"	13/16"
4	3/4"	15/16"
5	15/16"	1 5/8"
6	15/16"	–
7	Any	Any
8	Expedited and Sample Parts	

3.9 Yield

Fifteen 4/4’’ 2-C poplar cutting results were taken to determine yield results (Figure 3-6). The cutting results were taken from the manufacturer based on output provided by the *Barr-Mullins* Scanning System. A yield of 55% is the current benchmark for 4/4’’ 2-C poplar in the rough mill. The average yield of the 15 cuttings during the case study was 57.74%. Rough mill management uses a rule of thumb of 50% yield which differs from the benchmark and actual results. Management was unable to track of which parts were obtained solid and which would have to be subsequently glued. The only measurement obtained from the software was the yield result even though additional information may have been available. Yield is the most important metric at the study rough mill however this metric is only known by management. Furthermore, the yield measurement used by management comes from the *Barr-Mullins* scanning system report. This yield may or may not be a good measure of actual rough mill yield.

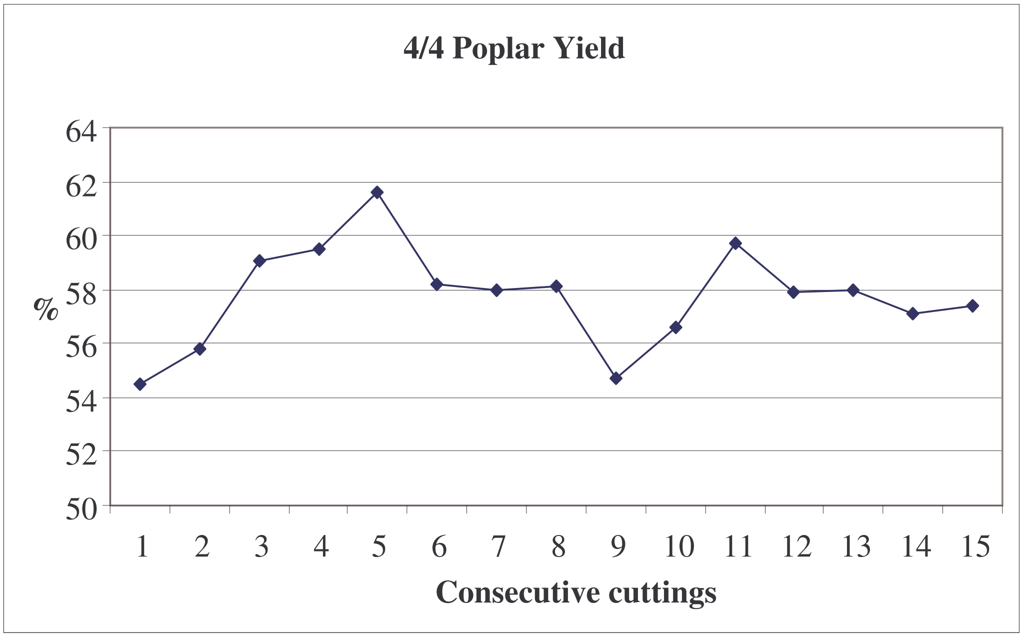


Figure 3-6 Yield Results from 15 4/4’’ 2-C poplar cuttings

The yield results are observed quickly with no discussion as to why the measurement was obtained or how to improve it. Lumber costs drive the focus of the measurement. At the study site, the success of the rough mill's performance is based on its ability to meet or exceed the benchmark established for this metric.

3.10 Work Time

Table 3-8 shows the available work time in the study rough mill. As can be seen, employees work four nine hours shift Monday through Thursday and 4 hours on Friday. The rough mill operates a full first and partial second shift; the rough planer, gang-rip, chop and 2 gluers operate on second shift. Management noted that on occasion the finish planer and multi-rip operate on second shift however this is seldom. The gluing operations on second shift do not include the high-frequency gluer used to produce internal components. To address order backlogs it is not uncommon for overtime to be performed which includes weekends. Including the rough mill manager and 4 department supervisors a total of 101 employees work in the rough mill. Rough mill employee's job experience ranges from 2 to 40 years.

Table 3-8 Available Work Time in Rough Mill

Time Available				Actual Available Work Time	
	Hours	Minutes	Paid Break (mins)	Hours	Minutes
Monday	9	540	20	8.67	520
Tuesday	9	540	20	8.67	520
Wednesday	9	540	20	8.67	520
Thursday	9	540	20	8.67	520
Friday	4	240	10	3.83	230
Total	40	2400	90	38.50	2310

3.11 On-Time Delivery

Past production schedules and input from with the manufacturer's industrial engineer was used to determine the rough mill success in meeting scheduled delivery times to downstream processes. The rough mill's ability to meet on time delivery to downstream demand was observed to be the rough mill supervisor's main concern; if the schedule is not met in the rough mill, all downstream processes suffer. The rough mill supervisor was observed to be under great pressure to meet downstream needs even though much of the rough mill's success was determined by the rough mill's ability to meet the set yield metric. No on-time delivery metric was used by the rough mill supervisor to gauge success in meeting downstream demand.

Through the industrial engineering department in the main office, information was made available to estimate the rough mill's on-time delivery to internal customers. Figure 3-7 represents the rough mill's on-time delivery percentage for 9 weeks of production. This was determined using the manufacturer's "off-schedule". The off-schedule is a production schedule that contains orders that are being produced behind their respective original schedule date. Orders on the off-schedule are the result of the rough mill's inability to meet the schedule's requirements. The rough mill could not produce these orders according to the original schedule therefore they were moved to the off-schedule. Recovering the off-schedule while producing scheduled items is a difficult feat, as can be seen from Weeks 1 through 6. Once the manufacturer gets behind with an off-schedule, the on-time delivery percentages decrease in the following weeks.

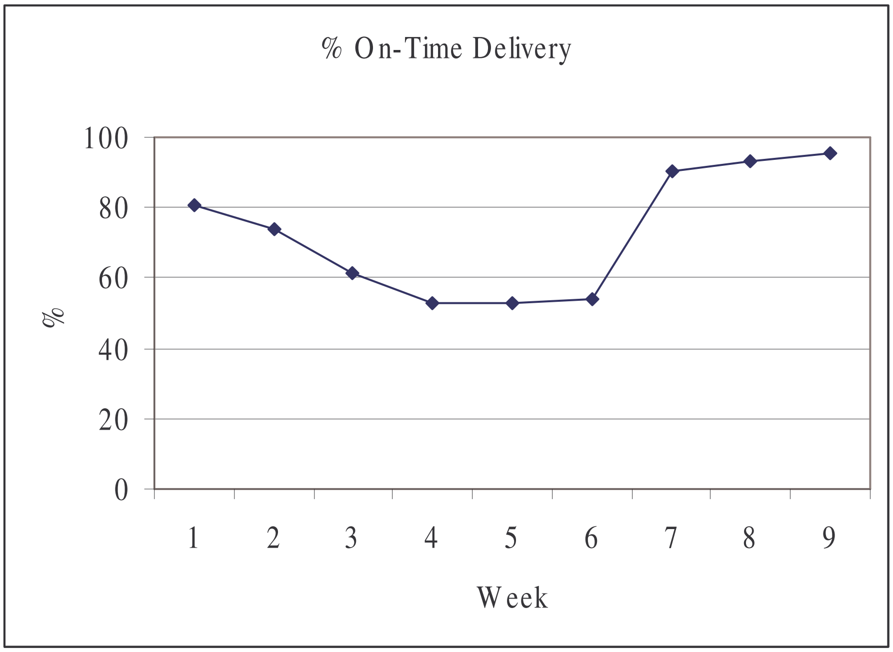


Figure 3-7 Timeline of on-time percentages based on the "off-schedule"

The lowest on-time delivery percentage obtained was 53% which occurred in both weeks 4 and 5. On-time delivery increased in week 7; however, this week was a holiday week and generally the scheduler keeps production at a minimum during holiday weeks. This allowed the rough mill to recover the off-schedule. In week 9, on-time delivery reaches a much improved 96%; however, this is the result of the manufacturer undergoing a production "re-schedule".

A re-schedule is a production schedule change provided by the scheduler that virtually eliminates the off-schedule. In a re-schedule, off and on schedule products production start dates are pushed back to remove the off-schedule. In some cases products that might have been scheduled for manufacture may be removed and replaced with products from the off-schedule. Since all products previously on the off-schedule have been given a new belated production start date the rough mill can increase on-time delivery percentages. A re-schedule is made possible since the original schedule is a forecast; no products are in actual demand by the final furniture customer. Re-schedules effect all processing at the manufacturer, not just the rough mill. The process of a re-schedule was observed to be chaotic for management and production actually halted. Production in the rough mill stopped during the study period and workers were sent home to avoid working ahead of schedule. The implications of a re-schedule on overall rough mill effectiveness has a significant impact, but this impact is beyond the scope of this study.

3.12 Current State Improvement Opportunities

Many improvement opportunities exist for the rough mill however for the purpose of this study they were limited to: overproduction, unnecessary inventory, waiting, inappropriate processing, defects, transportation and motion. Identifying these areas of opportunity in the Current State will provide focus points in the design and evaluation of the Future State value stream maps (Chapter 4). Opportunities for improvements were found based on observation and employee input.

3.12.1 Overproduction

Overproduction provides the greatest opportunity for improvement in the rough mill and is often the root cause of waste in most manufacturing settings (Rother and Shook 2003). Overproduction exists at the study site due to the nature of production scheduling currently in place. Like most mass production models the current state schedules production at multiple points throughout the rough mill. Each scheduling location, or machine operation, produces to a forecasted schedule and then pushes the products downstream to the next machine where the products must be recounted and staged until that particular's machine schedule indicates production. By producing to a forecast and pushing products through the system waste can occur in: unnecessary inventory, waiting, inappropriate processing, defects, transportation and motion. For this reason, overproduction has been labeled the root cause of manufacturing waste. The goal of the rough mill should be to schedule production at one point based on actual demand and produce only to replenish consumed parts to alleviate manufacturing wastes associated with overproduction.

3.12.2 Unnecessary Inventory

Unnecessary inventory is the result of overproduction. By producing too early and pushing parts through the rough mill from one machine to another based on multiple schedules, WIP levels of undemanded products increase. This inventory must be re-counted and stored which results in additional manpower cost and production time. By scheduling at one point based on demand, unnecessary inventory is not produced initially, but only when needed, which should be the goal of the rough mill.

3.12.3 Waiting

Due to the lack of any systematic product flow, orders throughout the rough mill are disorganized and workers could spend as much as 15 minutes locating which order to process next. Work in progress for each machine is held in a specific location generally, however that location may not be right beside machine and often several areas were used to hold one machine's WIP. As WIP levels increased, the disorganization of the rough mill increased creating less flow and more downtime in finding the right orders to process.

It was not observed that workers spent time waiting on orders to process. If an order on the schedule was not ready, supervisors were notified and the workers continued onto the next batch of parts, possibly producing ahead of schedule further adding to unnecessary inventory. Machine utilization requirements dictated that if a scheduled order could not be found, then any order in WIP would be processed to avoid a machine being idle. Running orders out of sequence further reduces the ability of meeting downstream demand on-time. WIP for a specified machine in the rough mill should be kept at one standard location to eliminate time spent locating orders throughout the rough mill and to prevent producing ahead of schedule.

3.12.4 Inappropriate Processing

What determines inappropriate processing can be defined as processing that is considered to be value added or non-value added. Value added processing is considered appropriate processing, while non-value added processing is considered inappropriate processing. In the Current State value stream, 4 processing steps take place to produce internal components of which 2 are considered value added (rough planer/gang-rip/chop and moulding operation) and 2 are considered non-value added (edge gluing and multi-ripping). These 2 non-value added operations were deemed necessary by management to increase yield thus reducing lumber costs. But, these extra steps add cost and are not essential for the function and form of internal components. The goal of the rough mill should be to decrease inappropriate processing (non-value added processing) whenever possible. Inappropriate processing does nothing to add value to the final product form that could not be accomplished with the primary rough mill operations and only increase lead time and decrease the rough mill's ability to meet downstream demand.

3.12.5 Defects

Overproduction hides defects in products until the downstream processes use the part which results in shortages. When an order does not contain the required amount, a new batch of parts must either be expedited back through the system or pulled from another order. The further an order gets through the rough mill before employees notice a shortage the more complex and problematic it can be to find the source of problem and to expedite parts.

To prevent shortages, an overage factor is applied to each part order by the MRP system. At each specific machine, there is a chance that a small percentage of the parts that enter the machine will not exit the machine in an acceptable state (due to quality issues). Machine errors such as moulder bites or improper machine set-up may cause parts to be deemed unacceptable and therefore these parts must be set aside and not processed further.

Table 3-9 Overages example according to MRP

MRP Overages		
Machine	Part Requirements (MRP)	Overage
Gang-Rip/Chop	165	10
Gluer	160	5
Multi-Rip	158	3
Moulder	155	–
Actual Part Requirements	155	–

Table 3-9 is an example of the spoilage factor the MRP system applies to determine the number of parts each machine requires to meet the actual part requirement of 155. As can be seen, the Gang-Rip/Chop operation must produce 165 parts to ensure that the subsequent machines have enough parts to fulfill the order. It is assumed that 10 parts will be “spoiled” during all steps in rough mill manufacturing. Current management was unsure of how the spoilage factor was determined or adjusted as the factors were created more than 20 years ago.

When parts are not spoiled as according to the MRP, these extra parts are disposed before they exit the rough mill. In the example in Table 3-9, if no parts are spoiled, then 10 parts are thrown away. This means that the extra work in processing, transporting those 10 parts are wasted. When the spoilage factor does not cover the degree of machine and human error, part shortages occur.

An order that is short on parts is bypassed and moved to the side until the shortage is rectified. This delays the schedule as orders that were supposed to be processed at a later time are being processed early while the scheduled order falls even further behind. The entire rough mill can be off schedule due to shortages, especially if the lumber input in the rough mill at the rough planer must change over to accommodate for expedited orders.

Lumber input changeover due to expediting was not observed to occur during the study however management indicated that the possibility exists. In the case that multiple part orders of the same species fell short of requirement, these orders would be moved off the schedule until the next time that particular lumber species was pulled from the lumber yard. It is difficult to accurately obtain, track and maintain the correct number of pieces and ensure these parts remain on the cart while being transported through and stored in the rough mill.

3.12.6 Transportation

Because of overproduction and inappropriate processing, transportation in the rough mill is extensive, part orders must be moved continuously to make room for more orders. Parts travel through the rough mill on wheeled carts (approximately 3' x 5'). Management discovered parts may travel as much as 1.5 miles on carts before exiting the rough mill. These carts are old, heavy and create clutter. Due to the design of the rough mill, these carts are moved excessively and oftentimes moved solely for the purpose of creating space for more carts. The majority of floor space in the rough mill consists of these carts.

Generally each cart in the rough mill holds the parts to fulfill one order requirement. As the study site decreases order size and increases order variety, issues concerning cart usage and part transportation flexibility may increase. Decreased order size results in carts not being filled to their full capacity to keep orders separate and increased order variety yields increased the number of carts. The number of carts in the rough mill is already at an observed maximum and the number currently in place should only decrease. The goal of the rough mill should be to reduce part transportation throughout the rough mill by providing a central location for WIP holdings. Locating orders in an organized and standard manner, the chance of orders being transported 1.5 miles through the rough mill can be reduced.

3.12.7 Motion

Wasted motion in the rough mill is the result of inappropriate processing. Because the manufacturer produces to a forecast it is entirely possible for the manufacturer to produce a piece of furniture that will not be sold. Unless the manufacturer is producing to fulfill immediate customer demand the act of forecasting creates a wave of excess motion in actual manufacturing. Every action that takes place in manufacturing, whether value or non-value added, is performed based on the belief that customers desire the product being produced. If ultimately the customer does not demand the product after final manufacturer, then even the value added steps throughout the system would be considered waste in motion. The previously mentioned improvement opportunities affect the amount of motion in the rough mill currently and focusing on these areas will decrease the amount of excess motion. Addressing this issue of linking actual demand to production scheduling is critical for ultimate business success, but is beyond the scope of this study.

3.12.8 Opportunities Summary

As shown, opportunities exist for the current state to better respond to downstream demand by eliminating processing waste. The following chapter will focus on rough mill system design that will target each of the previously mentioned wastes. Ultimately, by reducing these wastes the rough mill will be able to better serve downstream demand appropriately. The priority of the future state value stream maps discussed in Chapter 4 is to ensure customer demand is met, first, and then it will be evaluated in terms of cost effectiveness.

4 Rough Mill Future State Evaluation

4.1 Introduction

The purpose of this chapter is to describe a methodology to create improved rough mill value streams. A case study was used to evaluate the cost effectiveness of two future state value stream maps for the study site's rough mill using pull production techniques. The future state value stream maps are based on opportunities from the current state value stream evaluation performed in Chapter 3. Just as in Chapter 3, the future state value stream maps were based on internal nightstand component order BBR#1 (Table 3-3) and processing sequence #1 (Table 3-2).

The purpose of pull system implementation is to reduce overall lead time at the furniture manufacturer and increase on-time delivery from the rough mill to downstream furniture operations. A yield analysis was performed using the ROMI-3 (Weiss and Thomas 2005) simulation program on the current and both future state value stream cutting bills to quantify and account for differences in yield.

4.2 Methods

The second objective involved the development of two future state value stream maps (Future State #1 and Future State #2) based on the findings from the Current State evaluation (Chapter 3). Both future state value streams were developed using the same product as the Current State, internal nightstand component order BBR#1 (Table 3-3). The purpose of future state value stream mapping was for the development of a pull based system to better link production with demand; this was accomplished with the implementation of supermarkets.

The amount of inventory to be held in supermarkets was based on the total internal nightstand component piece production in 2006. All production data was obtained from the furniture manufacturer. Internal nightstand components vary between each finished nightstand style in dimension and part grade therefore previously mentioned ABC part analysis was used to determine which components level will be held in the supermarket and respective inventory levels. Supermarket inventory levels were determined by using Smalley's (2004) formulas for cycle, safety, and buffer stock.

To determine the effects of yield in the Future State value stream maps ROMI-3 (Weiss and Thomas 2005) simulation was used. Using simulation, a model was created to validate the current state value stream. Validation was determined by simulating an actual cutting at the furniture manufacturer. Part yield results from both the manufacturer and simulation were compared. Using the validated current state simulation, changes in the future state value stream were simulated to determine effects on yield.

Future State value #1 remained similar in processing activities as the Current State. However, Future State #2 was designed based on the elimination of inappropriate processing waste found in the Current State evaluation in order to decrease lead time and increase on-time delivery to downstream demand. The effects of the supermarket based pull system on manufacturing waste found in Objective 1 are discussed.

4.3 Future State Value Stream Mapping

The purpose of current state value stream mapping is for further development of future state value stream maps. Using the findings from the Current State evaluation (Chapter 3), future state value streams can be developed using pull techniques to limit overproduction. As mentioned, overproduction is the root cause of not meeting downstream demand (Chapter 3.12.1). Overproduction prohibits meeting downstream demand in a timely manner by tying up the system with products that are not in current demand.

To reduce overproduction, supermarkets of parts have been implemented into both rough mill future state value maps to pull and control production. Supermarkets maintain standard predetermined levels of finished goods which are based on normal variations in past demand. As parts are removed from the supermarket, a kanban signal which describes the type, quantity and processing method regarding parts removed from the supermarket is sent to upstream production for supermarket replenishment. This eliminates problems arising due to production forecasting and multiple scheduling points which currently exist in the rough mill and limit it's ability to meet downstream demand.

The standard types of inventory held in the supermarket are: cycle, buffer and safety stock (Figure 4-1). As can be seen in Figure 4-1, cycle stock covers average weekly demand, buffer stock, and safety stock is in place in the supermarket if actual demand is greater than the cycle stock. Demand changes can be observed by monitoring weekly supermarkets inventory levels and inventory levels can be adjusted accordingly to avoid stock-outs and overproduction. The details of how the supermarket is applied in this case study are discussed further in Chapter 4.4.

Future State value stream #1 does not represent a big change in the rough mill. It utilizes the supermarket concept discussed above to address many of the issues discussed in Chapter 3.12, particularly to provide limits to help control overproduction. The lead time of this proposed value stream system has not been improved but the ability to respond to downstream demand has been addressed. Non-value added activities have not been removed in the value stream which may have system interactions and subsequent cost implications. Future State #2 provides a potential second step to reduce significant non-value added activities (Chapter 4.11.4) for parts that are obtainable as solid directly from the gang-rip operations; the lead time in this value steam has been reduced significantly as well. Future State value stream #2 also features a part supermarket similar to that in Future State #1.

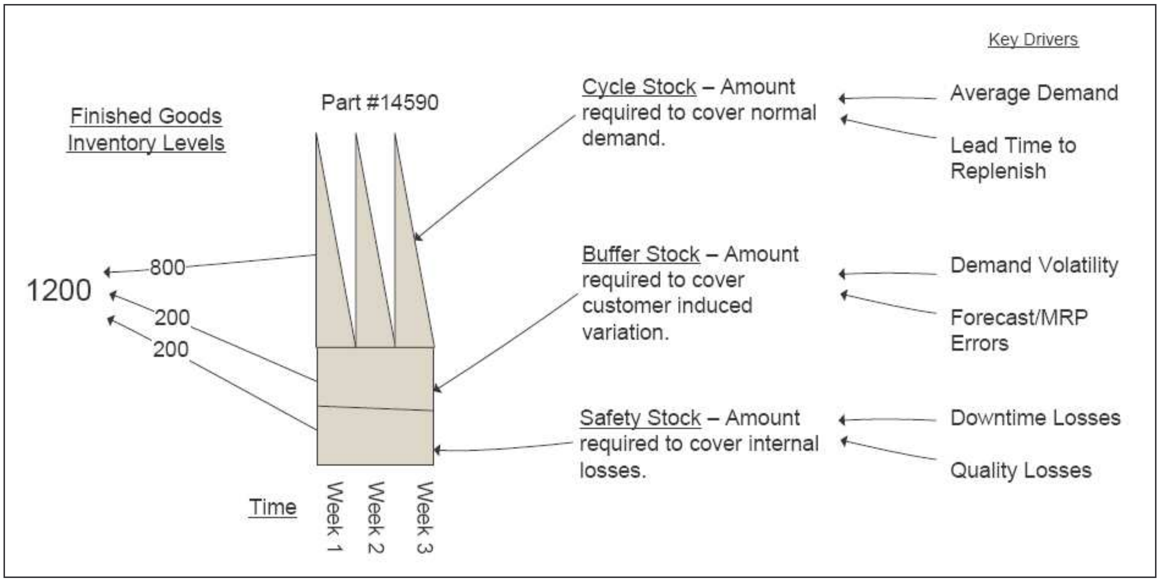


Figure 4-1 Finished goods inventory example (Rother and Shook 2003)

All machine processing descriptions shown in Figure 4-2 and Figure 4-3 (Rough Planer, Gang-Rip, Chop Saw, High-Frequency Gluing, Multi-Ripping and Moulding) have not been altered from the Current State evaluation in Chapter 3. Cycle time (C/T), changeover time (C/O), and Uptime remain unchanged and only the lead and value added time differ in Future State #2. The purpose of this study was not to improve machine efficiencies as this is beyond the scope of this study.

4.3.1 Future State Value Stream Map #1

As mentioned, Future State value stream map #1 (Figure 4-2) is similar to the current state value stream map with the addition of a part supermarket as well as FIFO (First-In-First-Out) lanes. Both value stream maps lead and value added times are based on the example order (BBR#1) (Table 3-3) found in Chapter 3.6.

The part supermarket has been implemented in front of the moulding operation. This location for the supermarket was based on constraints presented by varying finished component moulding styles. By placing the supermarket upstream from the moulding operation, internal components can be kept in a rough blank state and then moulded to fulfill certain style requirements as needed. The number of differing moulding styles would significantly increase the size of the supermarket if located downstream from the moulding operation.

The implementation of the supermarket means the moulder operators simply pull the required blank pieces from the supermarket immediately as indicated by the "part schedule and moulding requirements" information provided. As parts are pulled from the supermarket, the multi-rip machine operators notify management of parts withdrawn for supermarket replenishment by kanban cards. This signals the rough planer/gang-rip/chop cell to produce the withdrawn parts during the next 2-C poplar cutting. First-In-First-Out lanes have been put into place for quality issues, the longer a part sits on a cart the greater the potential for spoilage. Basically, the FIFO lane dictates a standard predictable and visual route for internal parts through the system to ensure easy tracking of parts to be replenished. Also in Future State #1, the part schedule and moulding requirements are sent directly to the moulders eliminating possible schedule alterations by management and allowing for production to be based on downstream MRP based demand.

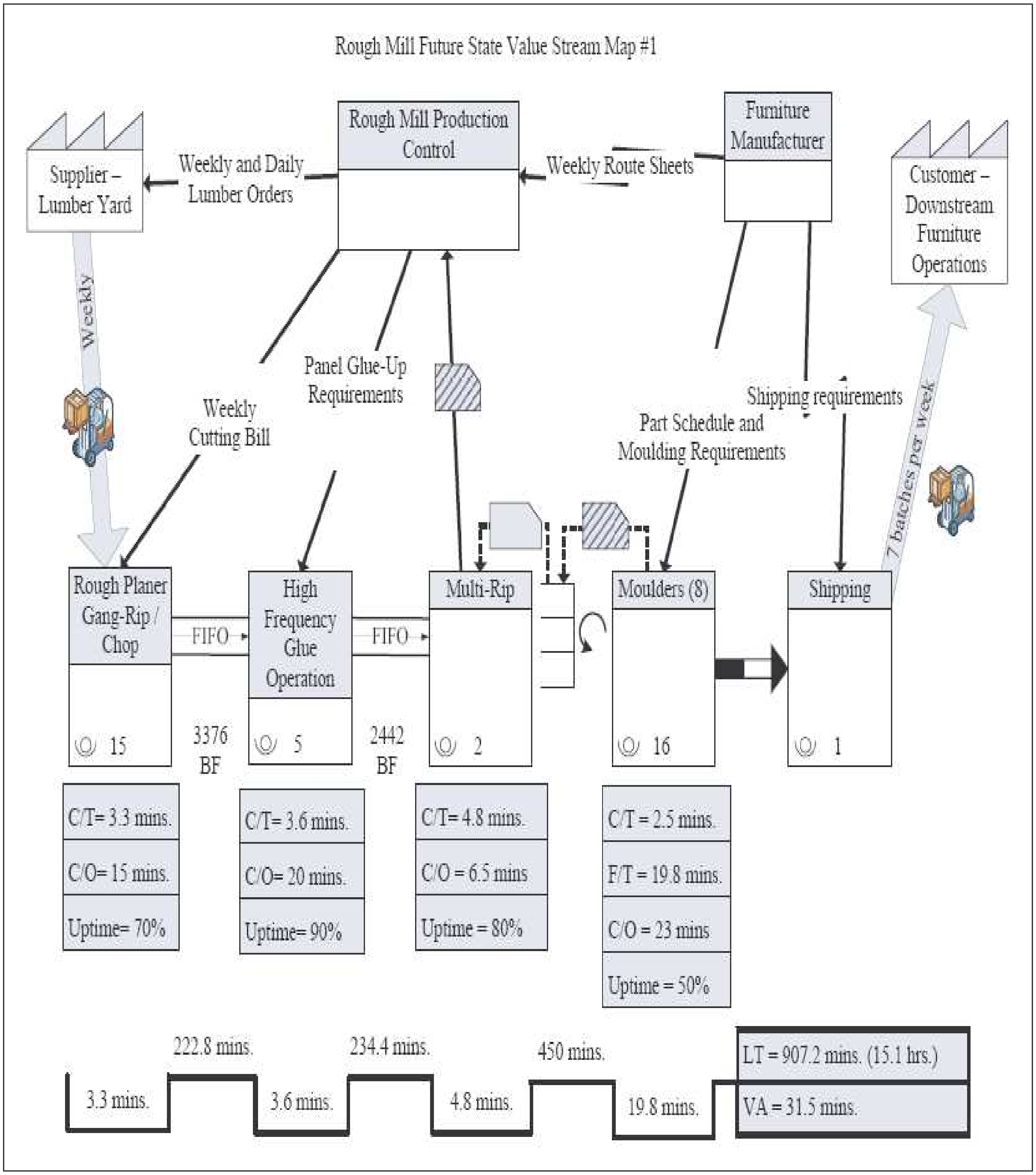


Figure 4-2 Rough mill Future State Value Stream Map #1

4.3.2 Future State Value Stream Map #2

Future State #2 (Figure 4-3) is a simplified version of Future State #1 where only value-added activities exist to supply the part supermarket reducing inappropriate processing. For this to be possible, Future state value stream #2 requires that the gang-rip and chop operations obtain the correct part width and length to avoid necessary non-value activities associated with panel production. The supermarket analysis in Chapter 4.4 found that some internal components can not be obtained as solid from the gang-rip operation because their dimensions were greater than any of the standard arbor pocket sizes used at the study site for 2-C yellow poplar cuttings. Due to these arbor limitations, panel production would be considered a necessary non-value added activities in this case. These parts must be routed through Future State value stream #1; this routing is represented in Figure 4-3 by two supermarket symbols.

By removing the non-value added processes, information flow and processing documentation throughout the system has been decreased. Just as Future State #1, as parts are withdrawn from the supermarket, the kanban signal is sent to rough mill management for replenishment during the next poplar cutting. The flexibility of Future State #2 is greatly increased by eliminating processing steps; not only will the supermarket be able to supply downstream processes with the parts efficiently but the lead time to replenish the supermarket is reduced as well. Because machines require maintenance and occasionally may be non-operational the predictability of Future State #2 is greater than both the Current and Future State #1. The overall lead time was reduced by more than half of the Current State and Future State #1. The effects of eliminating the panel glue-up activities are discussed in Chapter 4.5.

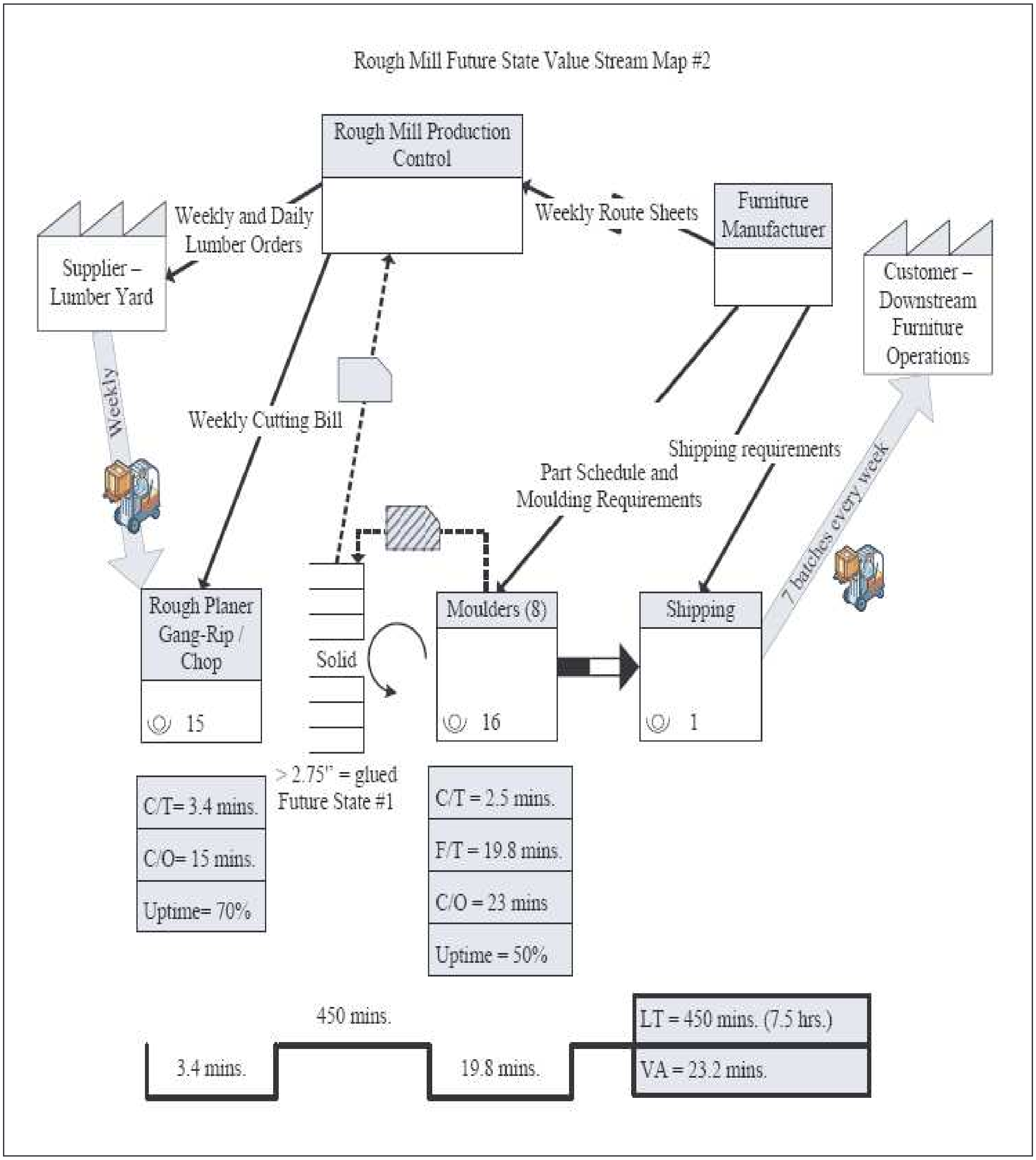


Figure 4-3 Rough mill Future State Value Stream Map #2

4.4 Supermarket

As mentioned, both future state value stream maps were developed using supermarkets of internal components. Supermarkets are areas on the shop floor which hold small levels of controlled inventory (Chapter 2.4.2). Inventory levels and which items are held in the supermarket was based on 1 year of past production figures provided by the manufacturer. *A* items represent 60% of demand and represent those parts that are ordered frequently. *B* items constitute 20% of the total demand past *A* items, these items are demanded frequently but not as frequent as *A* items. *C* items account for the remaining items produced. *C* items are considered to be ordered infrequently and in highly variable amounts (Smalley 2004). Orders for parts held in the supermarket receive first priority since the orders are based on actual demand. All other MRP based orders will be processed accordingly since a 3 day leeway has been built into the system to process orders.

4.4.1 *A, B, C* Analysis

The 2006 nightstand production line consisted of 58 nightstand styles that are constructed using 210 different internal component nightstand styles or Stock Keeping Units (SKU). From the 210 SKU's used during 2006 year, 109,858 individual internal components were produced. In order to minimize the number of varying SKU's in the supermarket, parts of similar dimensions were grouped together. As seen in Table 4-1, it is possible for differing SKU's to have the same physical characteristics but be been given different SKU's. The quantity and SKU are the only differing features between parts. Table 4-2 is an example of part grouping based on the differing SKU's shown in Table 4-1. The SKU's have been eliminated and part quantities summed.

Table 4-1 Differing SKU's with identical physical characteristics

SKU #	Length	Width	Thickness	Quantity
12607	20''	1.5''	4/4''	165
28995	20''	1.5''	4/4''	200

Table 4-2 Part grouping based on Table 4-1

Length	Width	Thickness	Quantity
20’’	1.5’’	4/4’’	365

To further reduce the amount of individual part groups, downstream machine capabilities were taken into consideration. Moulders are capable of handling rough parts up to 3/8’’ wider than the finished dimension. Machines downstream from the rough mill are capable of handling parts up to 2’’ longer than the specified finished length. Rough mill management noted that often parts exit the rough mill with a length and width greater than design indicated and does not effect quality or process speed. Taking this into consideration, groups that have previously been limited to specific lengths and widths were grouped further into “ranges” of lengths and widths as seen in Appendix 1 and Appendix 2. Appendix 1 and Appendix 2 is the determined A and B part widths and lengths to be held in the supermarket for both future state supermarkets and the total quantity of parts produced in 2006. Part widths have been separated based on the gang-rip saws ability to obtain parts as either solid or glued. Component part grades (Grade 1 and Grade 2) were also used in the part analysis. Part Grades 1 and 2 are discussed in Chapter 4.5.1.

As mentioned in Chapter 4.3.2, due to fixed-blade gang-rip, the widest part that can be obtained is 2 ¾’’. The supermarket size was not limited to this constraint in the Future State #2, even though the gluing process has been removed. Some parts contained in the supermarket for Future State #2 must be routed through the gluing process. The purpose of this study was not to provide a new arbor spacing sequence therefore the current state arbor setting will remain unchanged. In this study, any part dimension that is not within Appendix 1 and Appendix 2 is considered a C component and must be made to order. These parts are given greater priority and processed before supermarket replenishment stock. A total of 10 parts were classified as “A” components and 19 components were classified as “B”. Order BBR#1 (Table 3-3) which all value stream maps were based upon is considered an A component.

4.4.2 Supermarket Inventory Levels

The part dimensions shown in Appendix 1 and Appendix 2 are the parts to be held in the supermarket. The amount of finished goods to be held in the supermarket was determined using Smalley’s (2004) calculation. Smalley’s calculation is the summation of cycle, buffer and safety stock (Table 4-3).

Table 4-3 Finished goods inventory level calculation

Cycle Stock +
Buffer Stock +
Safety Stock =
Finished goods inventory level

Cycle stock according to Smalley (2004) is “average daily demand multiplied by the lead time to replenish (days)”. To determine the cycle stock of the selected internal components, the total annual amount of parts produced in each dimension category in Appendix 1 and Appendix 2 was divided by the total number of work days (240) for the year 2006. The lead time to replenish used to determine cycle stock was 5 days, or essentially 1 work week. This lead time was used because the rough mill under study typically only processes 4/4’’ 2-C yellow poplar in one batch 1 time per week and parts of similar dimensions are grouped together when batched.

Buffer and safety stock exist in the supermarket to reduce the chances of supermarket depletion. Buffer stock is percentage of the cycle stock to cover normal demand variation (25%) (Smalley 2004) while safety stock is a percentage of both cycle and buffer stock. 20% of cycle and buffer stock was used for safety stock. Because demand variation from the manufacturer was unavailable, Smalley's (2004) example for buffer and cycle stock calculations was used. Table 4-4 is an example of how finished goods inventory levels were determined for the part dimensions shown in Appendix 1 and Appendix 2. The example in Table 4-4 reflects how finished goods were calculated for the part dimension group of 25.25'' - 27.25'' in length and 1.188'' - 1.563'' in width and Part Grade 1. Table 4-5 and Table 4-6 are the determined finished good inventory levels for A and B components.

Table 4-4 Finished good inventory level example

Finished Goods Inventory Level Example for 1 Part Dimension		
Annual Production	4373 Total parts	–
Cycle Stock	Daily Demand x 5 Days	91
Buffer Stock	25% x Cycle Stock	23
Safety Stock	20% x (Cycle and Buffer Stock)	23
Total Quantity	Cycle + Buffer + Safety Stock	**137**

Table 4-5 “*A”* Supermarket finished goods inventory levels

	Width						
	Solid				Glue		
	1.188 - 1.563		2 - 2.375	2.438 - 2.750	3.563 - 3.813	4.188 - 4.5	
Length	Grade 1	Grade 2	Grade 2	Grade 2	Grade 2	Grade 2	Quantity
18.75 - 20.75	-	201	-	-	-	-	
20.875 - 22.875	-	292	-	-	-	-	
23.125 - 25	-	264	-	-	140	-	
25.25 - 27.25	137	-	277	-	-	-	
27.375 - 29.375	-	136	-	86	-	-	
32.5 - 34.5	-	99	-	-	-	-	
34.625 - 36.625	-	-	-	-	-	83	

Table 4-6 “*B*” Supermarket finished good inventory levels

	Width											
	Solid								Glue			
	1.188 - 1.563		1.625 - 1.938		2 - 2.375		2.438 - 2.750		3.563 - 3.813		4.188 - 4.5	
Length	Grade 1	Grade 2	Grade 1	Grade 2	Grade 1	Grade 2	Grade 1	Grade 2	Grade 1	Grade 2	Grade 2	Quantity
18.75 - 20.75	-	-	-	-	72	75	-	-	-	-	-	
23.125 - 25	17	-	-	-	-	-	-	-	-	-	-	
25.25 - 27.25	-	62	-	-	-	-	23	47	33	23	-	
27.375 - 29.375	-	-	-	63	61	76	-	-	-	64	-	
30 - 31.5	-	-	-	-	-	-	-	-	-	-	63	
32.5 - 34.5	33	-	56	71	78	-	68	54	-	-	-	

The required number of pieces to fulfill BBR #1’s (Table 3-3) order requirements is 283, which is less than the supermarket’s projection (292 pieces). When BBR #1 is ordered downstream from the rough mill, moulder operators will be able to immediately stage the required stock amount from the supermarket to fulfill downstream demand in essentially 19.8 minutes (lead time to mould). If the supermarket was not in place, this order would have to be either scheduled in with the next 2-C poplar cutting or expedited through the rough mill. The supermarket prevents overproduction by producing to actual demand by maintaining replenishment standards. During the next time the rough mill schedules 2-C yellow poplar the gang-rip/chop operation will replenish exactly what is consumed.

4.5 Yield Simulation

Since yield is currently the most important performance measure that is used industry wide (Cumbo et al. 2006), testing the effects of cutting for solid parts on yield in the second future state value stream was critical in determining the full impact of the proposed changes. Currently, yield measurements at the study site are reported to management daily via *Barr-Mullins* report. The yield report provides information solely on overall yield and does not provide information on individual parts obtained during the cutting that fulfill the current state value stream precisely. To get an unbiased difference of yield, simulation is needed. ROMI-3 (Weiss and Thomas 2005), a rough mill simulation software package described in Chapter 2.3.5 was used to simulate the yield of the rough mill under study.

4.5.1 Current State ROMI-3 Settings

All information used to set-up the ROMI-3 (Weiss and Thomas 2005) simulation was based on input from rough mill management and the company's industrial engineering department to best reflect the current state lumber cut up procedure at the study site. Following ROMI-3 configuration settings, the rip saw setting selected was

Fixed-Blade-Best-Feed; the arbor spacing for all 4/4'' poplar cuttings is shown in Table 3-6. As previously mentioned, the arbor spacing for 4/4'' poplar is assumed not to change between cuttings, this standard arbor configuration has been predetermined by management and is assumed to maximize yield and limit changeover for all 4/4'' poplar cuttings. Additional information concerning gang-rip saw and chop-saw inputs is shown in Table 4-7 and Table 4-8.

Table 4-7 Rip-saw inputs

Gang-Rip Inputs	
Current Arbor Width	22 1/16"
Saw Spacing Count	10
Ripsaw Kerf Size	3/16"
Left Edging Kerf	3/16"
Right Edging Kerf	3/16"

Table 4-8 Chop-saw Inputs

Chop-saw Inputs	
Endtrim allowance for each end	4/16"
Chop-saw Kerf size	3/16"

Table 4-9 represents inputs for the mill control feature. The term "salvage" indicates parts require re-ripping to fulfill cutting bill requirements. Salvage parts in the current system are obtained using "primary" lengths and widths; primary lengths and widths represent part dimensions found in the cutting bill (Table 4-10).

Table 4-9 Mill control

Mill Control
Processing units are in inches
Part priorities are updated constantly
Primary operations avoid orphan parts
Salvage cuts to cutting bill requirements
Random width strip parts okay in panels
Minimum random width for panel parts = 1 1/4"
Maximum random width for panel parts = 2 3/4"
Board cutup optimization step = 4/16"

Table 4-10 Salvage Parts Inputs

Salvage Parts
Salvage uses primary widths
Salvage uses primary lengths

Part prioritization was best defined in the simulation by the Complex Dynamic Exponent (CDE) feature available; based on study site findings in Chapter 3.8.2. CDE is a dynamic method of varying the priority emphasis placed on parts to be produced. CDE allows part emphasis to change priority from one part to another as part quantities are fulfilled (Weiss and Thomas 2005).

There are two part grades at the study site for internal nightstand components: Part Grade 1 and Part Grade 2 (Table 4-11). Part Grade 1 requires both faces of the part to be clear and free of defects (C2F). Part Grade 2 allows for sound knots and sap stain and mineral streak.

Table 4-11 Part Grade parameters

Part Grades		
Grade	Defect allowable	Side
1	Clear, No defect	Both Faces
2	1. Sound knots ‹ = .50 inch area	Both Faces
	2. Sap stain/mineral streak	Both Faces

4.5.2 Future State ROMI-3 Settings

The majority of Future State ROMI-3 settings were assumed to not change: Arbor spacing (Table 3-6), Rip-Saw Inputs (Table 4-7), Chop Saw Inputs (Table 4-8), Salvage Parts Inputs (Table 4-10) and Part Grade Parameters (Table 4-11) all remained unchanged. The only differences between the current and future state ROMI-3 (Weiss and Thomas 2005) settings are:

- Modifications to the cutting bill (discussed in Section 4.5.4)
- Salvage cuts no longer fulfill cutting bill requirements

In order for salvage cuts to not fulfill cutting bill requirements, *"Salvage cuts to cutting bill requirements"* feature has been turned off in the "Mill Control" (Table 4-9) inputs. Salvage parts are the result of re-ripping and the future state's goal is to produce the correct dimensioned part from the gang-rip and chop operations without re-ripping salvage. The yield difference between Current State and Future State ROMI-3 settings is assumed to be representative of real differences.

4.5.3 Lumber Input

Using "The Databank for Kiln-Dried Red Oak" (Gatchell et al. 1998) within ROMI-3, lumber used for the simulation was created based on an actual lumber load input into the study rough mill. 2-C is the predominate grade when cutting 4/4'' yellow poplar. At the study site, lumber is only graded as green upon receiving and the actual dried grade prior to lumber cutup is unknown. Table 4-12 is approximately the green grade distribution of an 8748 BF 2-C yellow poplar cutting. Management felt this grade distribution was representative of 2-C lumber inputs. Board lengths were made available (Table 4-13) however width distribution were not available; therefore no minimum or maximum board width was input into the system and boards of random width were selected by the program. Fifteen different lumber files were created using for simulation based on the information shown in Table 4-12 and Table 4-13.

Table 4-12 BF Grade Distribution

BF Grade Distribution		
Grade	BF	%
1C	437.4	5
2C	7873.2	90
3C	437.4	5
Total	8748	100

Table 4-13 Board Length Distribution

Board Length	
Minimum Length	78"
Maximum Length	102"

4.5.4 Cutting Bills

Cutting Bill #1 (Appendix 3) is an example of an actual cutting bill used at the study site and the cutting bill used to simulate the Current State value stream yield and Future State value stream map #1. The cutting bill (Bill #1) for these value streams does not change since panels are being produced. Again, the Current and Future State Value stream map #1 assumes internal components will be glued in panels for multi-ripping.

Due to ROMI-3 restrictions on the amount of varying lengths and widths, adjustments to the bill had to be made. The original cutting bill had more varying lengths and widths than the software was capable of handling. To accommodate for software limitations, parts whose lengths and widths were within 7/8’’in dimension in both length and width were grouped together based on the greatest dimension (Table 4-14). Bill #1 has 59 part requirements with total 5,585 BF. Internal component requirements for Bill #1 represent 9.8% of total BF requirements.

Table 4-14 Example of part length adjustment

Original Length (in.)	Adjusted Length (in.)
24.625	24.625
24.375	
24.375	
24.25	
24.25	
23.75	

Cutting Bill #2 (Appendix 4) is the cutting bill used to simulate the yield for Future State Value Stream #2 (Figure 4-3). The majority of the bill remains the same since multiple orders are being produced along with internal components. The only changes made to the bill are the internal components that in Cutting Bill #1 were produced into panels are now required to be made directly as solid parts (Table 4-15) of specified dimensions. Table 4-15 shows the differences in cutting requirements for internal components in Bill 1 and 2. As can be seen, component requirements in Bill #1 are fulfilled using panels and Bill #2 requirements are fulfilled using solid parts.

Table 4-15 Internal nightstand components in Bill #1 and Bill #2

Bill #	Width	Length	Quantity	Grade	Panel *(1=panel, 0=solid)*
1	14.875	34.625	19	2	1
2	1.375	34.625	187	2	0
1	22.875	24.625	17	2	1
2	2	24.625	168	2	0
1	21.625	21.5	66	1	1
2	2.375	21.5	528	1	0
1	23.75	24.625	17	2	1
2	2	24.625	168	2	0
1	14.875	24.625	52	2	1
2	1.375	24.625	338	2	0
2	2	24.625	169	2	0

Due to the current state system which features a fixed blade best feed system gang-rip saw, not all internal components could be successfully obtained in the correct dimension. The arbor sizes did not exactly fit components required widths therefore part sizes were increased to the closest arbor width of a greater size. For example, if an internal component final part width requirement was designed to be 1.25''; in Bill #2 the part width was adjusted to 1.375'' (closest arbor width of greater size). This resulted in a total yield loss of 28 BF in the cutting and was accounted for in simulated yield results found in Table 4-16. This loss would occur during the moulding operation of the product. Future studies would require the determination of an optimum arbor spacing design should Future State #2 be adopted, this would perhaps improve yield.

4.5.5 Panel Production

According to Weiss and Thomas (2005) a panel is defined as “a panel or glue-up part is made of two or more solid parts that have been edge glued together”. ROMI-3 simulates panel production by cutting for: 1.) Solid parts of specified length and 2.) Solid parts of either specified or random width. The user is given the option to cut for specified or random width. This option is found in the Mill Control feature under the option “Random width strip parts okay in panels”.

Random width is generally selected when a movable blade arbor is present when no specified part widths are present and parts are of “true” random width. Even though “true” random width parts are not obtained at the study site because the arbor is fixed blade, the “Random width strip parts okay in panels (Table 4-9)” was still enabled. This feature was enabled because no specific solid part width for panels is defined at the mill and any of the solid part widths can be used at random to create panels, thus creating random width part panel production.

4.5.6 Methods

Yield in ROMI-3 is broken down into 4 categories: 1.) Primary, 2.) Salvage, 3.) Excess salvage and 4.) Total. *Primary* indicates yield that is obtained to fulfill cutting bill requirements. *Salvage* yield is the result is re-ripping to fulfill cutting bill requirements as mentioned previously. *Excess Salvage* is yielded parts that do not fulfill cutting bill requirements and require storage until a need is found for that particular part. Total yield is the summation of primary, salvage and excess salvage.

Using ROMI-3, 30 simulations were made to determine whether a difference in yield existed when the gang-rip cut parts for glue up (Current and Future state #1) or for solid parts (Future State #2). The cutting bill for the Current and Future state #1 (Bill 1; Appendix 3) was replicated 15 times and the cutting bill for Future State #2 (Bill 2; Appendix 4) was also replicated 15 times. Since 15 yield results from the manufacturer were obtained (Control), each simulation was replicated 15 times.

The overall yield obtained from the ROMI-3 simulations was the measurement used to define the Current and Future State #1 yield. Primary, Salvage and Excess Salvage are all included in the yield measurement of the study site. Overall yield best reflects the manner which yield is determined at the study site.

The primary yield was the measurement used to define the yield for Future State #2. Because Future State #2 calls for the elimination of non-value added activities, the salvage yield was not applied in the simulations (Chapter 4.5.2). One limitation of ROMI-3 (Weiss and Thomas 2005) was the programs inability to turn off excess salvage production (unusable parts); therefore the overall yield differed from the primary yield. The primary yield measurement was separated from the overall yield measurement.

Using the Statistical Analysis System Institute SAS (1988) software, the following yield results were compared for differences among means:

1. <u>Null Hypothesis</u> = Overall yield of Control and Bill #1 will be the same.
   <u>Research Hypothesis</u> = Overall yield of Control and Bill #1 will be different.
2. <u>Null Hypothesis</u> = Overall yield of Bill #1 and Bill #2 will be the same.
   <u>Research Hypothesis</u> = Overall yield of Bill #1 and Bill #2 will be different.
3. <u>Null Hypothesis</u> = Overall yield of Bill #1 and Primary yield of Bill #2 will be the same.

Research Hypothesis = Overall yield of Bill #1 and Primary yield of Bill #2 will be different.

Test #1 of overall yield of both the control (actual study site reporting) and Cutting Bill #1 (Current and Future State #1) will determine whether ROMI-3 simulation is an acceptable program for use in assessing possible yield differences in Cutting Bill #1 (Current and Future State #1) and Cutting Bill #2 (Future State #2). Test #2 was performed to determine whether overall yield differs between Cutting Bill 1 and 2. Test #3 will determine whether a difference in yield exists between the Overall yield of Bill #1 (Current and Future State #1) and the Primary of Bill #2 (Future State #2).

4.5.6.1 Results

Two sample t-tests were used to compare means of actual (control) and simulated results (SAS 1988; Proc TTest). Sample and actual samples were first tested for equality of variances using the Folded Form F Statistic. If variances were statistically found not to be equal, the Cochran and Cox Approximation (SAS 1988) of the approximate t statistic was used. Otherwise, the t test for independent samples with pooled variances was used. All tests were considered significant at $P < 0.05$.

Table 4-16 T-test results and statistics of actual and simulated yield models

Test #	Comparison	Mean	SE	Folded F Test	T-Test
1	Control Bill #1	57.75 54.52	0.49 0.06	P < 0.001	P < 0.001
2	Overall Bill #1 Overall Bill #2	54.52 55.43	0.06 0.05	P = 0.61	P < 0.001
3	Overall Bill #1 Primary Bill #2	54.52 53.01	0.06 0.05	P = 0.51	P < 0.001

4.5.6.2 Discussion

Thomas and Buehlmann (2002) validated ROMI-RIP (Thomas 1996) (original simulation of ROMI-3) and found simulated yields were significantly higher (7%) than actual rough mill yield. This contradicts findings shown in Table 4-16 which found that simulation results to be lower than actual results (Test #1); however, in the authors study (Thomas and Buehlmann 2002) all part requirements were solid and not glued panels. Part dimension adjustment due to software limitations (Table 4-14) may have also contributed to a decrease in yield. However, it was previously mentioned (Chapter 4.4.1) that parts often exit the rough mill with greater dimension indicating that part dimension adjustment in the simulation may not have affected yield.

Currently, no validation study of ROMI-RIP has been performed using panel parts as cutting bill requirements therefore it is unknown whether Thomas and Buehlmann's (2002)'s findings apply to panel part production. As solid parts requirements increase in Bill #2 from Bill #1 (Test #2), so does the overall yield (Table 4-16). This may support Thomas and Buehlmann's (2002) validation study findings that ROMI-RIP outperforms rough mill yield when producing solid parts and also suggests that ROMI-RIP may underperform when producing panel parts as compared to actual rough mills. At this point in time it can only be assumed that ROMI-3 is sufficiently valid for relative comparison of cutting bills. Therefore, results found in Table 4-16 were considered applicable for this study's purposes of assessing potential yield differences that exist for Future State #2.

In Test #3 the Primary yield of Bill #2 (determined yield measurement of Future State value stream #2) differs from the Overall yield of Bill #1 (determined yield measurement of Current State and Future State value stream #1). This can be explained by Salvage and Excess salvage yield that remained in the ROMI-3 simulations of Bill #1. The average effect of yield loss (1.51%) in Bill #2 will be used as the basis of comparison in the financial analysis of Chapter 5.

4.6 Lead Time

By eliminating inappropriate processing the lead time of Future State #2 (7.5 hours) is reduced by more than half of the Current and Future State #1 (15.1 hours). It should be noted that lead time for all value streams, current and future is relative to once 2-C yellow poplar is scheduled to run through the rough mill. The addition of part supermarkets in both future state value streams allows for immediate response to actual demand downstream. With the implementation of a part supermarket, all lead and value added operations upstream from the supermarket have already been performed based on previous actual part demand. This differs from the Current State where operations are performed based on a forecast of demand. If demand changes in the Current State, all processing steps must be performed starting at the rough planer. In both future states, as long as the supermarket has the specified inventory levels, only the moulding operation is required to meet an immediate change in demand.

4.7 On-Time Delivery

To obtain an accurate representation of on-time delivery the supermarkets must physically be in place and as of the time of this study supermarkets were not present at the study site. Although on-time delivery is a measure that can not be defined in this study it is believed that the supermarkets would only increase the percentage of parts exiting the rough mill. Supermarkets provide safety in the system by maintaining predetermined demanded inventory levels which buffer against possible machine breakdown and order expediting. Decreased lead time in Future State Value Stream #2 (Chapter 4.6) allows for increased probability of meeting downstream demand in a more timely manner.

4.8 Improvement Opportunities

As mentioned in Chapter 3.12 opportunities exist at the study site for improvement in the areas of: overproduction, unnecessary inventory, waiting, inappropriate processing, defects, transportation and motion. Based on the findings of Chapter 3.12 in these areas the following opportunities exist based on the implementations of the proposed supermarket pull system.

4.8.1 Overproduction

Multiple point scheduling and forecasting in the Current State was determined to be the reason for overproduction. Since overproduction has been determined to be the root cause of all manufacturing waste, it was essential to focus on this area in both Future State value streams. To reduce overproduction, production scheduling has been reduced to 1 point; at the supermarket. Scheduling at the supermarket means production is based on actual downstream demand, and not to a forecast. Production in forecasting results in the production of parts that are not in current demand. This 1 point schedule based on actual demand results in the reduction of all other waste opportunities found in the Current State evaluation (Rother and Shook 2003).

4.8.2 Unnecessary Inventory

Unnecessary inventory in the Current State has been replaced with necessary supermarket inventory that maximizes production effectiveness in meeting demand. Overproduction and multiple point scheduling resulted in unnecessary inventory in the Current State. By producing to supermarket requirements in both Future States, all inventories are standardized in that it provides a buffer to best deal with current system uncertainties. Through scheduling production at 1 point based on demand, inventory will not be produced until demanded, which is the goal of the rough mill

4.8.3 Waiting

It was found that waiting at the study site was the result of machine changeover and operators locating orders. The purpose of this study was not to decrease machine changeover time as currently the manufacturer is undergoing this practice. With the supermarket, all orders for the moulding operation are kept in one location and no searching is necessary. Searching for orders upstream from the supermarket in Future State Value Stream #1 (Figure 4-2) should decrease with the implementation of FIFO lanes. The FIFO lanes, if properly designed will keep order in the system. In Future State Value Stream #2 (Figure 4-3), inappropriate operations have been removed therefore searching for orders has virtually been eliminated.

4.8.4 Inappropriate Processing

Two processes were found to be non-value added in the Current State; edge-gluing and multi-ripping. While these activities remained in Future State #1 as necessary operations, they were eliminated in Future State #2 for parts that fit within the standard gang-rip arbor set-up. Additional processing results in increased labor and overhead costs and limits the flexibility of the system to meet demand. The lead time was reduced to more than half of the Current and Future State #1 by removing these processes in Future State #2.

4.8.5 Defects

Defects in the Current State evaluation were observed in overages and shortages. Overages in the current state exist due in part to the spoilage factor applied by the MRP scheduling system. If the overage applied to an order as seen in Table 3-9 is too great (no parts are spoiled), these excess parts are essentially thrown away. With the addition of the supermarket, only the correct amount of parts is withdrawn from the supermarket eliminating the possibility of wasting excess product when the order leaves the rough mill. By decreasing overages in the system, time wasted machining excess parts has been reduced if not eliminated. Excess parts which exist from operations upstream from the supermarket are maintained as part of the supermarkets inventory.

Shortages led to expediting parts through the Current State Value Stream (Chapter 3). Expediting parts is a confusing and cumbersome undertaking when many different parts are being produced simultaneously. It is critical when expediting to make sure not only the expediting parts are manufactured but also the current schedule is maintained.

If a part shortage occurs currently, the entirety of the rough mill manufacturing procedure must be undergone. With the addition of the supermarket, all rough mill procedures other than the moulding operation have already been undergone eliminating unnecessary manufacturing. In essence, the supermarkets in both Future State's create an organized systematic way to avoid expediting. If moulder bites or other machining defects occur at the moulding operation, additional product can be withdrawn as needed from the supermarket. The safety factors (buffer and safety stock) built into the supermarket are in place to cover overage occurrences.

4.8.6 Transportation

Internal components will remain on the previously discussed carts (Chapter 3.12.6) for transportation throughout the rough mill before entering the supermarkets. In Future State #1, cart usage will remain an issue however Future State #2 cart usage is reduced significantly with the elimination of inappropriate processing activities. Parts in Future State #2 will travel straight from the chop operation to the supermarket. The supermarket provides a central inventory holding location and will decrease the number of occupied carts that workers must sort through when finding orders to process at other operations.

4.8.7 Motion

With the reduction or elimination of previously mentioned shortages and overages, waste in unnecessary production motion has been reduced. Although Future State #1 maintains non-value added activities, Future State #2 has eliminated non–value added activities and reduced unnecessary motion. The supermarket provides a central location for internal nightstand components which reduces the amount of motion currently spent on locating orders to process. Production in both Future State’s is based on actual demand, unlike the Current State where production is based on a forecast. When production in based on a forecast, all motion (value added and non-value added activities) is wasted if the forecast is inaccurate.

5 Value Stream Evaluations for Cost Effectiveness

The purpose of this chapter was to evaluate the cost feasibility of all rough mill value stream maps discussed (Current State, Future State #1 and Future State #2). Figure 5-1 displays the rough mill costs as compared to all costs at the study site. As can be seen, rough mill costs rank third of all manufacturing processes.

The following information was used for this evaluation: 1.) Labor, 2.) Overhead and 3.) Lumber Costs. This information was provided by the manufacturer and figures have been adjusted to maintain confidentiality. This evaluation will determine whether the Future state value stream maps (Figure 4-2; Figure 4-3) proposed in Chapter 4 are economically viable as compared to the Current State value stream map (Figure 3-5) when producing the sample internal component order BBR #1 (Table 3-3).

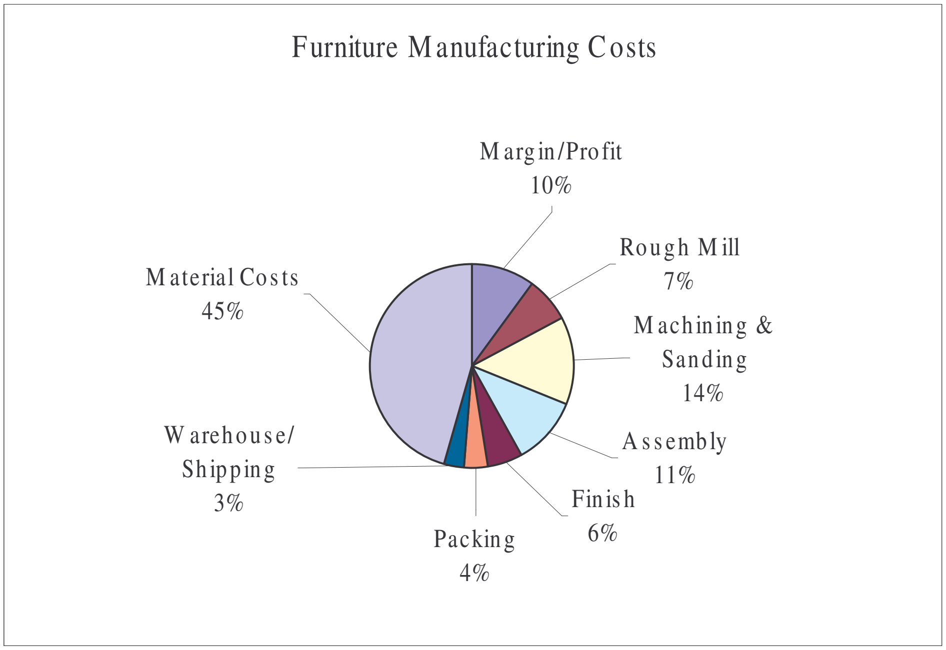


Figure 5-1 Furniture manufacturing costs (provided by study site)

5.1 Methods

To determine the cost effectiveness the following information was used to determine the Total Cost to manufacture order BBR#1 (Table 3-3): Lumber, Labor and Overhead costs. The summation of Lumber, Labor, and Overhead cost per value stream determined the Total Cost of each value stream. Labor and overhead are shown for each machining operation. This information was based on the information provided by the manufacturer.

The yield metric is the driving metric at the rough mill under study and it is hypothesized that an emphasis to focus on reducing material costs increases labor and overhead costs. The yield simulation results found in Objective #2 were used to determine whether a decrease in the yield measurement due to the removal of the panel glue-up operation in Future State #2 outweighs the processing costs.

5.2 Current State Value Stream

In the Current State Value Stream (Chapter 3) the following processes were considered in the cost analysis: Rough Planer, Gang-Rip, Chop Saw, High Frequency Gluing, Multi-Ripping and Moulding. While the actual rough mill yield obtained from the study site was found to be 57.74% (Figure 3-6), the overall yield of 54.52% (Table 4-16) obtained from ROMI-3 (Weiss and Thomas 2005) was used in the financial analysis to maintain a repeatable standard yield basis to compare all Future State cases. Even though a statistical difference exist between the actual (Control) and ROMI-3 (Bill 1) results (Chapter 4.5.6.2), the ROMI-3 measurement will allow for an applicable cost comparison in the Future State Value Stream Map #2 analysis (Chapter 5.4) where yield measurements were obtained using ROMI-3 simulations. A lumber input cost of $300/MBF or $0.30/BF for 2-C yellow poplar remained constant throughout the analysis.

5.2.1 Lumber, Processing and Total Costs

Table 5-1 represents the lumber costs for the current state value stream based on the finished BF requirement of 60 (Table 3-3). Table 5-2 through Table 5-5 represent the processing costs for the operations found in the Current State Value Stream Evaluation (Chapter 3) to produce order BBR#1. 110.05 BF (Table 5-1) and 495 LF (Table 3-3) was used in determining operating costs. The total costs to produce order BBR#1 are displayed in Table 5-6 and Figure 5-2.

Table 5-1 Current State Value Stream Lumber Costs for order BBR#1

Lumber Costs	
Finished BF Required	60
Yield	54.52
Rough BF Required	110.05
Cost Per BF	$0.30
Total Lumber Cost	$33.02

Table 5-2 Rough Planer/Gang-Rip/Chop-saw costs

Rough Planer/Gang-Rip/Chop Saw	
Total labor required	17
Average wage	$10.92
Labor Cost/hr.	$185.64
Variable OH Costs/hr.	$154.41
4/4 2-C Poplar BF/hr.	2000
Operating Costs per BF	$0.17
110.05 BF Operating Costs	$18.71

Table 5-3 High-frequency gluing operation processing costs

High Frequency Gluer	
Total labor required	6
Average wage	$11.36
Labor Cost/hr.	$68.16
Variable OH Costs/hr.	$47.43
4/4 2-C Poplar BF/hr.	1000
Operating Costs per BF	$0.12
60 BF Operating Costs	$6.94

Table 5-4 Multi-Rip operating costs

Multi-Rip	
Total labor required	2.5
Average wage	$11.36
Labor Cost/hr.	$28.40
Variable OH Costs/hr.	$23.71
4/4 2-C Poplar BF/hr.	750
Operating Costs per BF	$0.07
60 BF Operating Costs	$4.17

Table 5-5 Moulder costs

Moulder (1 of 8)	
Total labor required	2.375
Average wage	$11.80
Labor Cost/hr.	$28.03
Variable OH Costs/hr.	$28.22
4/4 2-C Poplar LF/hr.	1500
Operating Costs per LF	$0.04
495 LF Operating Costs	$18.56

Table 5-6 Total Cost of Current State value stream to produce order BBR #1

Total Processing Cost	
2-C Yellow Poplar BF Costs	$33.02
Rough Planer/Gang-Rip/Chop Saw	$18.71
High Frequency Gluer	$6.94
Multi-Rip	$4.17
Moulder (1 of 8)	$18.56
Total Cost To Produce Order BBR #1	$81.39

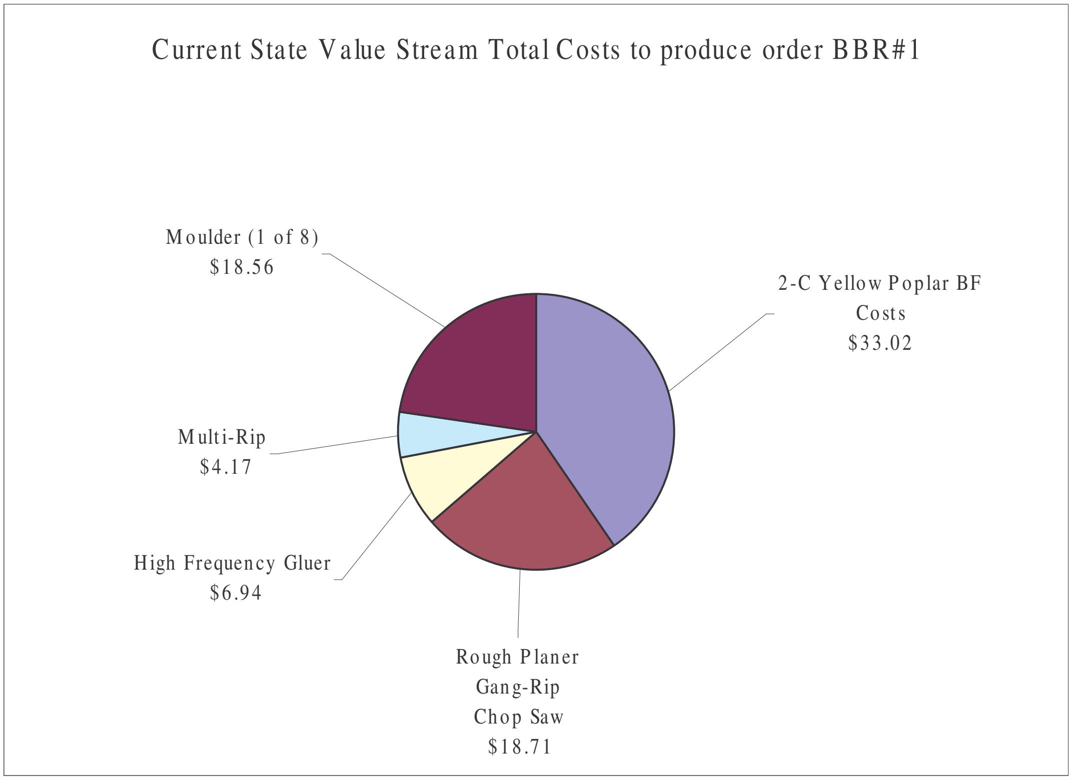


Figure 5-2 Total Cost of Current State Value Stream to produce order BBR #1

5.3 Future State Value Stream #1

Future State Value Stream Map #1 (Figure 4-2) processing and cutting bill (Appendix 3) does not differ from the Current State Value Stream therefore direct material, labor and processing costs do not differ. The only difference between the Current and Future State #1 is the implementation of a part supermarket in Future State

#1. While processing improvements currently exist in the Current State system that could possibly reduce operating costs, testing these improvements were outside of the scope of this project therefore all operations and costs remain the same.

5.4 Future State Value Stream #2

The following processes were considered in the cost analysis in Future State Value Stream #2: Rough Planer, Gang-Rip, Chop Saw and Moulding. Future State Value Stream #2 was designed to reduce inappropriate processing that may prevent the rough mill from meeting downstream demand. Therefore, non-value added processes (gluing or multi-ripping) and their respective costs were eliminated. To eliminate these activities, internal components were obtained as solid parts in Cutting Bill #2 (Appendix 4) from the Gang-Rip and Chop operation as opposed to panel parts in Cutting Bill #1 (Appendix 3; Current State and Future State 1).

The primary yield measurement (53.01%; Table 4-16) from Bill #2 ROMI-3 simulation was used in the evaluation. The primary yield, not overall yield, was selected for evaluation because overall yield includes salvage yield which is the result of inappropriate processing (Chapter 4.5.6). Reducing waste such as inappropriate processing is the goal of Future State #2.

5.4.1 Lumber, Processing and Total Costs

Table 5-1 represents the lumber costs for the current state value stream based on a finished requirement of 60 BF (Table 3-3). 113.19 BF (Table 5-7) and 495 LF (Table 3-3) was used in determining operating costs (Table 5-8). Table 5-8 represents the operating costs Future State Value Stream #2 (Figure 4-3) to produce order BBR#1; the moulding costs shown in Table 5-5 does not change therefore this cost is only shown in the Total Costs (Table 5-9).

Table 5-7 Future State Value Stream Map #2 Lumber Costs

Lumber Costs	
Finished BF Required	60
Yield	53.01
Rough BF Required	113.19
Cost Per BF	$0.30
Total Lumber Cost	$33.96

Table 5-8 Rough Planer/Gang-Rip/Chop-saw Costs

Rough Planer/Gang-Rip/Chop Saw	
Total labor required	17
Average wage	$10.92
Labor Cost/hr.	$185.64
Variable OH Costs/hr.	$154.41
4/4 2-C Poplar BF/hr.	2000
Operating Costs per BF	$0.17
113.19 BF Operating Costs	$19.24

Table 5-9 Total Cost of Future State Value Stream #2 to produce order BBR #1

Total Processing Cost	
2-C Yellow Poplar BF Costs	$33.96
Rough Planer/Gang-Rip/Chop Saw	$19.24
Moulder (1 of 8)	$18.56
Total Cost To Produce Order BBR #1	$71.76

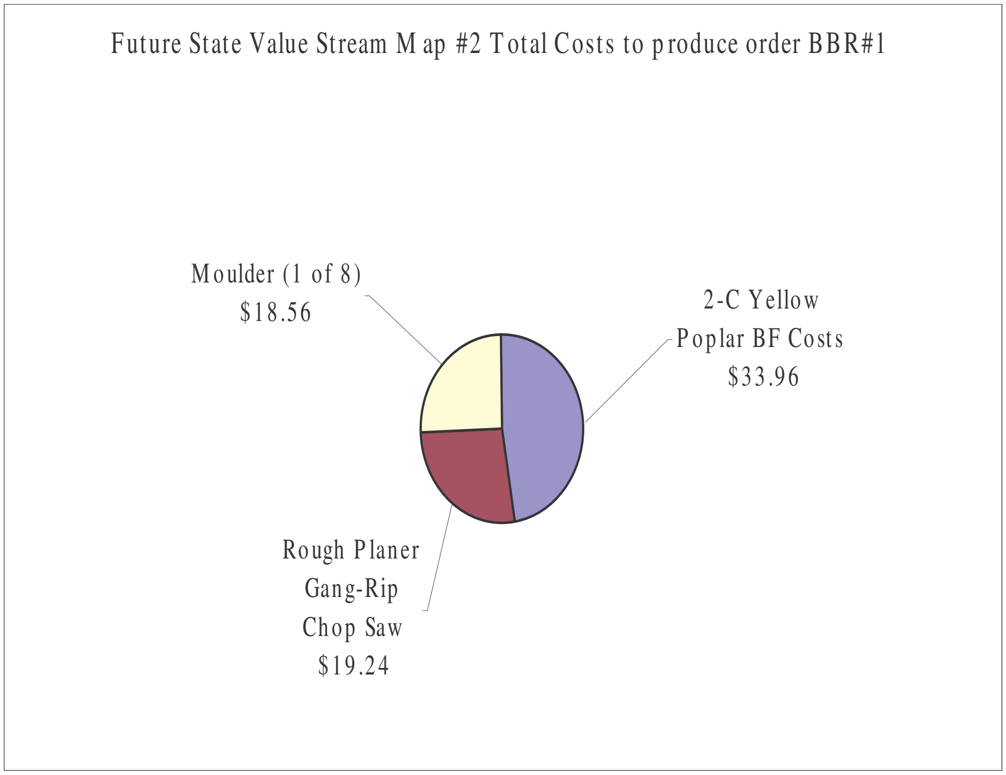


Figure 5-3 Total Cost of Future State Value Stream #2 to produce order BBR #1

Figure 5-4 displays the operating costs by machine work center. As can be seen, Future State #2 lumber input and Rough Planer/Gang-Rip/Chop Saw costs were higher than Current and Future State #1. More lumber and machine processing is needed to fulfill Future State #2 needs due to the yield simulation results found in Chapter 4.5.6.1. While these costs are higher in Future State #2, they do not outweigh the costs to edge-glue and multi-rip found in the Current and Future State #1. The costs associated with the yield difference in Future State #2 were minimal compared to the costs associated with edge-gluing and multi-ripping. This shows that a focus on the yield metric does not always guarantee a cost effective system.

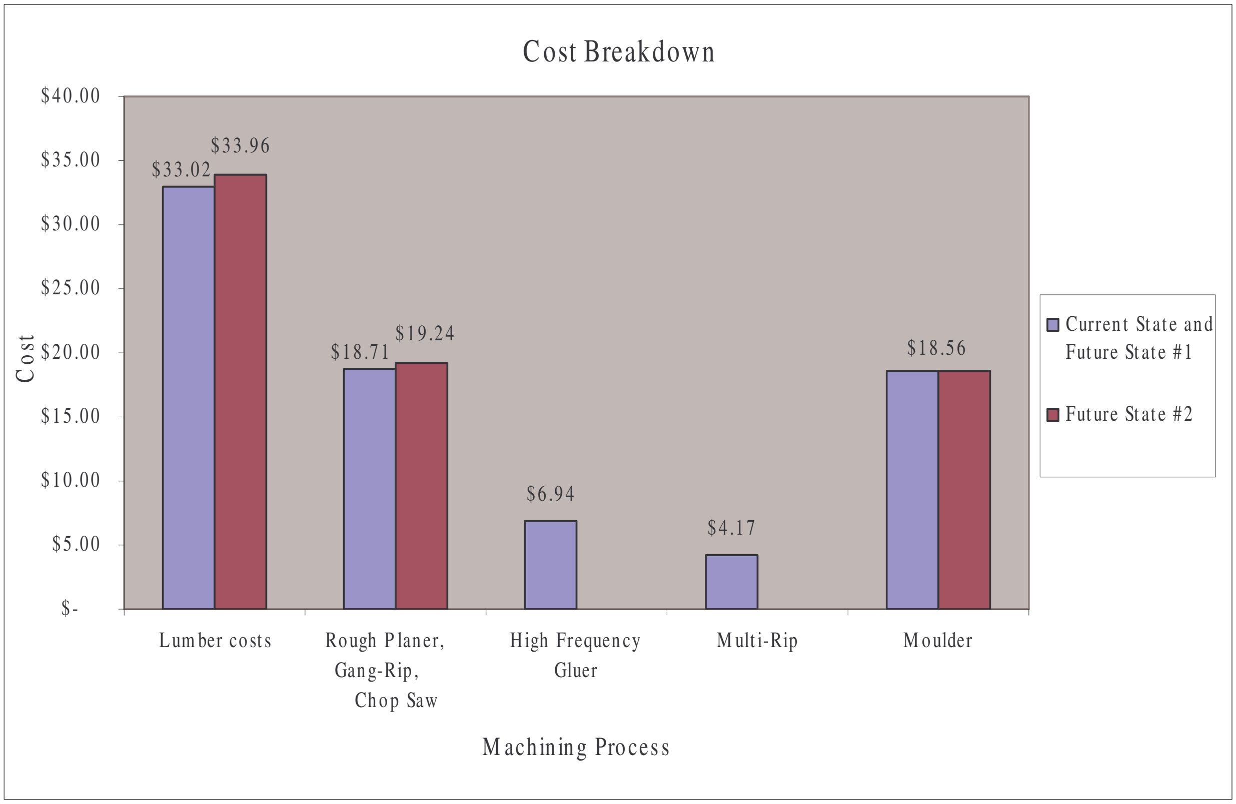


Figure 5-4 Total Cost breakdown

5.5 Break Even Point

Even though Bill #1 (Appendix 3; Current and Future State #1) produced a higher yield than Bill #2 (Appendix 4; Future State #2), Future State #2 total costs ($71.76) (Table 5-9) was found to be less than the Current and Future State #1 (Table 5-6). The elimination of non-value added activities (gluing and re-ripping) outweighed the costs of yield loss. The primary yield measurement would have to drop to 44.89% or below in Future State Value Stream #2 before a monetary loss in experienced.

Table 5-10 Yield Adjustments to Determine Break Even Point

Future State Value Stream #2 Break Even Analysis						
Yield (%)	53.01	51	49	47	45	44.89
Yield loss (%)	—	2.01	4.01	6.01	8.01	8.12
Monetary difference	$71.76	$73.86	$76.12	$78.57	$81.23	$81.39

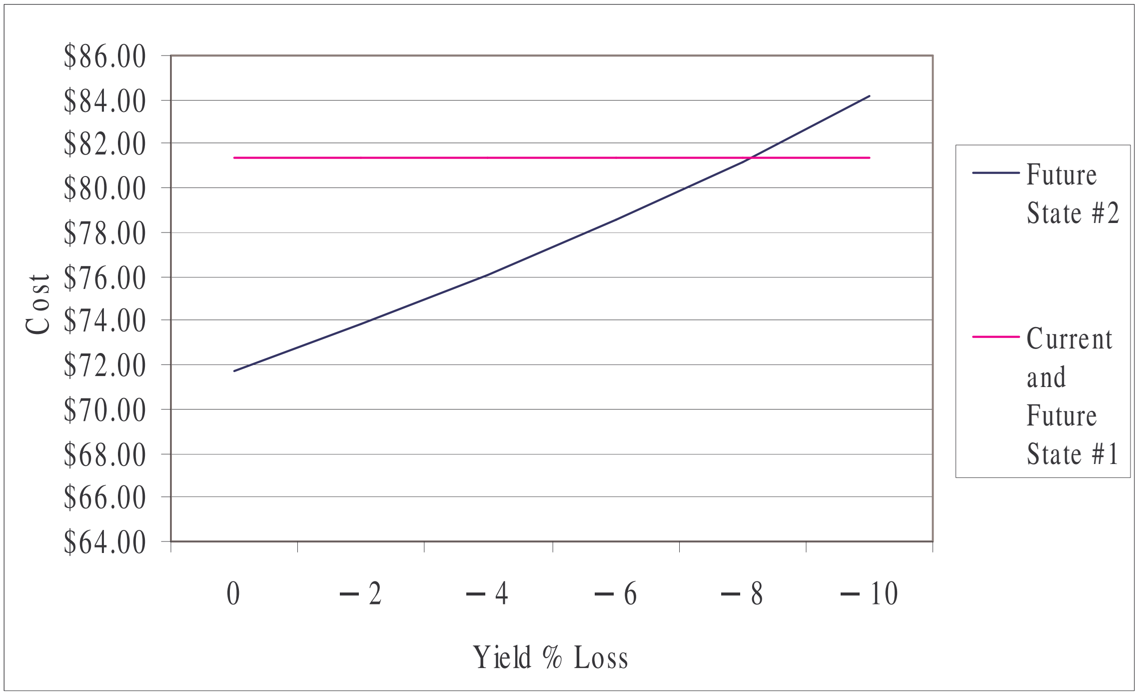


Figure 5-5 Break even yield measure

5.6 Total Cost Saving Potential

Table 5-11 displays the total cost to produce the 109,858 internal nightstand components in 2006 assuming all internal components have the same physical characteristics as order BBR #1 (Table 3-3). Even though this is will not be the case as each finished nightstand is different in style, Table 5-11 does represent savings potential. As gluing increases from 100% solid (Future State #2) to 100% glued (Current and Future State #1), so does the yearly costs. Not only is Future State #2 a more cost effective way to meet downstream demand but it also is a more cost effective way to manufacture internal nightstand components.

Table 5-11 Yearly costs to produce internal nightstand components

100% Solid	70% Solid, 30% Glue	70% Glue, 30% Solid	100%Glue
$27,856.57	$ 28,978.06	$ 30,473.37	$31,594.85

Figure 5-6 represents the total yearly costs to manufacture all internal components, not solely nightstand components. Similar to the findings in Table 5-11, as gluing increases so does the total costs to manufacture these components. While not all internal components can be obtained as solid parts due to part dimension requirements and gang-rip operation arbor limitations, Figure 5-6 represents the potential yearly savings by reducing edge-glued panel production.

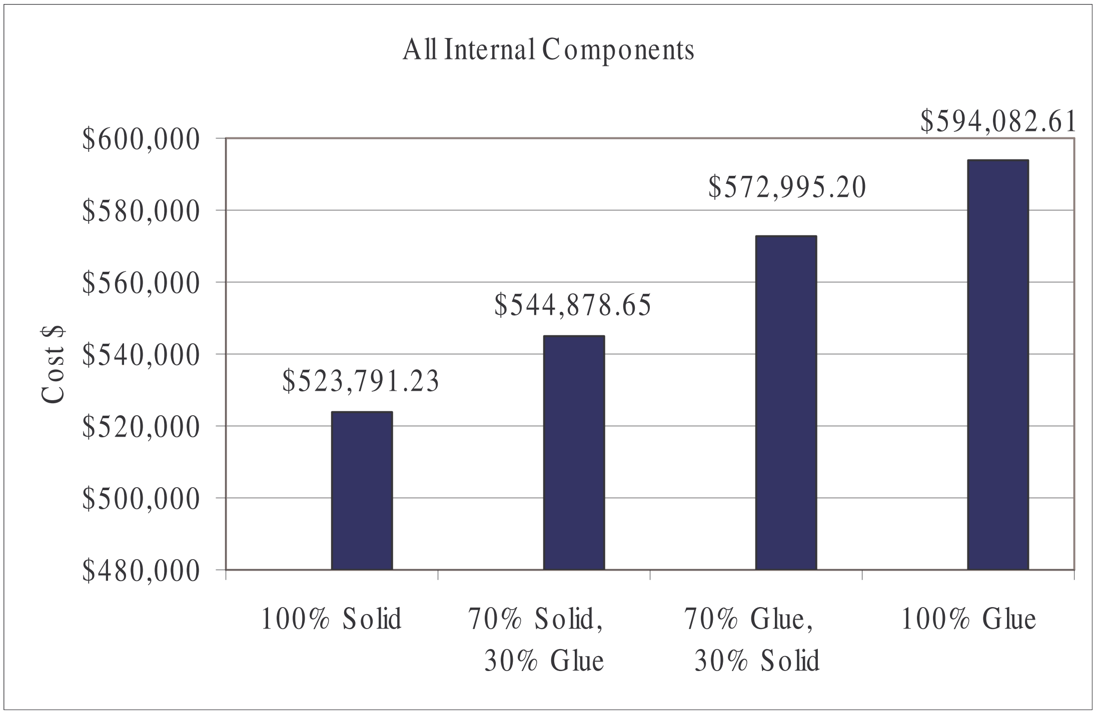


Figure 5-6 All Internal Components Yearly Costs

6 Conclusions

The major advantages for domestic furniture manufacturers are proximity to the final customer and ability to meet demand customer due to decreased lead times. Lower labor costs available in foreign countries have pushed many organizations towards the import market thus widening the gap between proximity and customer demand. Opportunity exists for domestic secondary manufacturers by increasing their ability to meet customer demand.

The Rough Mill is the first step in furniture manufacturing and carries the responsibility of meeting downstream demand of all furniture operations. Traditionally, the rough mill has been a push based yield driven system. Because lumber represents a significant cost, non-value added yield recovery activities such as edge-gluing and salvage operations have been put into place in rough mills. While these activities are necessary when solid parts are unobtainable by the gang-rip arbor type due to dimension requirements, they only increase lead times and manufacturing costs of obtainable solid parts. The push based system coupled with non-value added activities limits the rough mill's ability to meet downstream demand changes in not only the furniture plant but ultimately to the final customer.

One manufacturing method proven in other industries to successfully respond to customer demand is "pull" manufacturing. In a pull system, production is not based on a forecast like so many manufacturers have relied upon; it is based on actual demand. By producing to demand, overproduction and inappropriate processing does not tie up rough mill production with undemanded products which will eventually lead to finished good inventory. Lead times can be reduced significantly by maintaining small amounts of known demanded inventory in the manufacturing process in “supermarkets”. Because the rough mill is the first manufacturing process, the success of the furniture operation to meet final customer demand weighs heavily on this process. The reduction of lead time in the rough mill ultimately reduces the furniture operations overall lead time to the customer, increasing the competitive advantage it maintains against foreign competitors.

The domestic cabinet industry has found success using such techniques. On-time delivery to downstream demand has increased through the reduction of lead times and manufacturing waste. The cabinet industry has proven these techniques are applicable to the wood products industry and this opportunity exists for all wood products manufacturers (Merillat 2003; Ray et al. 2006).

This project demonstrates how manufacturing techniques such as pull systems and value stream mapping can be applicable to the rough mill. These techniques have proven that manufacturing steps that are currently in place to salvage yield result in increased lead time and cost. While this project focused on only one of many products at one study site, its findings are applicable for any manufacturer of dimension lumber pieces.

6.1 Research Objectives Findings

The purpose of this research was to provide a method for rough mill systems to become more competitive by decreasing lead time to meet downstream demand. The objectives of this research project were:

1) To perform a current state value stream evaluation of the rough mill manufacturing system.
2) To design an improved rough mill future state value stream that is responsive to downstream demand using pull system methodologies.

3) To demonstrate the cost effectiveness of the future state value stream using a furniture manufacturing case study.

6.1.1 Objective 1

The first objective concerned a current state value stream evaluation of the rough mill manufacturing system at a furniture company located in Virginia. The evaluation focused on the manufacturing processing currently in place to produce internal nightstand components, specifically order BBR#1 (Table 3-3). The information used to create this value stream was based on on-site investigation and input from management and shop floor employees.

The current state evaluation found that production scheduling for the rough mill was performed based on forecasting using an MRP system. Lead time was determined to be 907.2 minutes (15.1 hours) while value-added time was 31.5 minutes. Two activities were determined to be non-value added (high-frequency edge gluing and multi-ripping). On-time delivery from the rough mill to downstream processes was highly variable and ranged from 53% to 96%. Overproduction was determined to be the root cause of the rough mill's inability to meet downstream demand. Overproduction was caused by forecasted production and multiple point scheduling and resulted in products being produced before they are in actual demand. To alleviate overproduction, production should be based on actual demand and scheduled at 1 point.

6.1.2 Objective 2

The second objective involved the design of 2 value streams (Future State #1 and Future State #2) using pull and supermarket system methodology. Future State #1 and #2 were developed based on the findings from the Current State evaluation (Objective #1). Just as the Current State, both Future State value stream maps were developed using example internal nightstand component order BBR#1 (Table 3-3). Production was scheduled at 1 point in both Future States decreasing all waste associated with overproduction.

Future State #1's design was similar to the Current State evaluation in that all machining processes remained (value added and non-value added). The overall lead time of Future State #1 did not differ from the Current State (15.1 hours). However, the implementation of a part supermarket allows the system to pull parts through the rough mill to satisfy immediate customer demand in a more efficient manner.

Future State #2 is a simpler version of the Current State and Future State #1. The only processes that were included in this design were value-added processes. Edge-gluing and subsequent multi-ripping were removed to reduce inappropriate processing. The overall lead time of Future State #2 was reduced by more than half (7.5 hours) and the time to replenish the part supermarket was decreased as well, meaning the system is more flexible to respond to downstream demand. However, Future State #2 produced a lower yield measurement than the Current and Future State #1.

6.1.3 Objective 3

The third objective involved a cost evaluation of the Current State, Future State 1 and Future State 2 value stream evaluations performed in Chapter 3 and 4. The information used to perform this analysis was: lumber, labor and overhead costs. Future State #2 proved to be the most cost efficient value stream even though it produces the lowest yield measurement. The elimination of inappropriate non-value added processes outweighed the additional lumber costs required. Yield in Future State #2 would have to be 8.12% lower than the Current and Future State #1 before Future State #2 would prove to be not cost effective.

6.2 Future Research and Limitations

This project was limited to the boundary of the rough mill of a furniture manufacturer. While this project may prove to be beneficial for the rough mill, the real opportunity is beyond the rough mill. The cost of not meeting demand in the studied operation was outside the scope of this project as all costs associated with backlog and reschedules were unavailable. However, it is an area that future research should focus on and should not be limited to just the rough mill.

The value stream was limited to internal nightstand components. This was performed because the system is too complex to take on all value streams. The methods used focus on all issues in-depth for one component; this approach is applicable for other component value streams as well. Similar opportunities are hypothesized and require future states.

Yield simulation was used in this project and can only be assumed to represent the study rough mill. While simulation is a working research tool, it cannot simulate exactly what a rough mill does. Sensitivity studies showed that yield would need to drop lower than 8% over current yield before proposed changes would cause a negative cost impact. The material used in this study (2-C yellow poplar) is a lesser valued species and this would not be the case for higher value species but the relatively large margin indicates potential for many other component value streams. Future research is needed to understand this better.

Furniture part design currently exists without knowledge of how it affects manufacturing procedures. Many similar part sizes exist for different part SKU's, a standard design system can be created to impact yield positively while maximizing part flexibility for many different part value streams. While past research has been performed which looks into solid parts and panel standardization (Araman and Lucas 1975; Araman and Hansen 1983), future research should focus on the applicability of standard part design for pull system implementation.

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Appendix

Appendix 1 Determined A components by length and width

	Width						Quantity
	Solid				Glue		
	1.188 - 1.563		2 - 2.375	2.438 - 2.750	3.563 - 3.813	4.188 - 4.5	
Length	Grade 1	Grade 2	Grade 2	Grade 2	Grade 2	Grade 2	
18.75 - 20.75	-	6,417	-	-	-	-	
20.875 - 22.875	-	9,331	-	-	-	-	
23.125 - 25	-	8,463	-	-	4,477	-	
25.25 - 27.25	4,373		8,850	-	-	-	
27.375 - 29.375	-	4,363	-	2,746	-	-	
32.5 - 34.5	-	3,162	-	-	-	-	
34.625 - 36.625	-		-	-	-	2,668	

Appendix 2 Determined B components by length and width

	Width											Quantity
	Solid								Glue			
	1.188 - 1.563		1.625 - 1.938		2 - 2.375		2.438 - 2.750		3.563 - 3.813		4.188 - 4.5	
Length	Grade 1	Grade 2	Grade 1	Grade 2	Grade 1	Grade 2	Grade 1	Grade 2	Grade 1	Grade 2	Grade 2	
18.75 - 20.75	-	-	-	-	2,290	2,393	-	-	-	-	-	
23.125 - 25	557	-	-	-	-	-	-	-	-	-	-	
25.25 - 27.25	-	1,996	-	-	-	-	743	1,490	1,040	720	-	
27.375 - 29.375	-	-	-	2,013	1,958	2,418	-	-	-	2,037	-	
30 - 31.5	-	-	-	-	-	-	-	-	-	-	2,008	
32.5 - 34.5	1,060	-	1,783	2,260	2,480	-	2,187	1,728	-	-	-	

Appendix 3 Cutting Bill #1

Width	Fixed Length	Quantity	Part Grade	Panel *(1=panel, 0=solid)*
2	27.5	102	1	0
2	32.375	105	1	0
2	38.75	71	1	0
2	39.5	26	2	0
2	41.25	71	2	0
2	43.375	104	1	0
2	58.75	57	2	0
13.625	43.375	10	2	1
14.875	17.625	6	2	1
14.875	19.5	15	2	1
14.875	21.5	33	2	1
14.875	23	5	2	1
14.875	**24.625**	**52**	**2**	**1**
14.875	25.5	18	2	1
14.875	32.375	33	2	1
14.875	**34.625**	**19**	**2**	**1**
14.875	39.5	16	2	1
14.875	42.625	5	2	1
14.875	43.375	10	2	1
14.875	44	19	2	1
14.875	57	75	1	1
14.875	69.625	9	2	1
16.125	20.5	7	2	1
16.125	21.5	28	2	1
16.125	29.5	2	2	1
17.5	17.625	3	2	1
17.5	67.25	65	1	1
18.75	23	9	1	1
18.75	49.5	15	1	1
21.625	**21.5**	**66**	**1**	**1**
21.625	39.5	24	1	1
21.625	41.25	33	1	1
21.625	58.75	8	1	1
21.625	64.75	13	1	1
22.875	23	24	2	1
22.875	24.625	44	1	1
22.875	**24.625**	**17**	**2**	**1**
22.875	26.75	6	1	1
22.875	39.5	6	1	1
22.875	41.25	5	2	1
22.875	58.75	3	1	1
22.875	68.5	12	2	1
22.875	70.75	22	1	1
23.75	17.625	2	1	1
23.75	20.5	13	1	1
23.75	21.5	17	1	1
23.75	23	3	1	1
23.75	**24.625**	**17**	**2**	**1**
23.75	26.75	16	1	1
23.75	29.5	2	1	1
23.75	32.375	6	2	1
23.75	33.125	9	2	1
23.75	36.875	10	1	1
23.75	38.75	64	1	1
23.75	39.5	8	2	1
23.75	41.25	14	2	1
23.75	45	45	1	1
23.75	58.75	11	2	1
23.750	64.75	31	2	1

** **Bold** items represent internal componet panels*

Appendix 4 Cutting Bill #2

Width	Fixed Length	Quantity	Part Grade	Panel *(1=panel, 0=solid)*
1.375	**24.625**	**338**	**2**	**0**
1.375	**34.625**	**187**	**2**	**0**
2	**24.625**	**505**	**2**	**0**
2	27.5	102	1	0
2	32.375	105	1	0
2	38.75	71	1	0
2	39.5	26	2	0
2	41.25	71	2	0
2	43.375	104	1	0
2	58.75	57	2	0
2.375	**21.5**	**528**	**1**	**0**
13.625	43.375	10	2	1
14.875	17.625	6	2	1
14.875	19.5	15	2	1
14.875	21.5	33	2	1
14.875	23	5	2	1
14.875	25.5	18	2	1
14.875	32.375	33	2	1
14.875	39.5	16	2	1
14.875	42.625	5	2	1
14.875	43.375	10	2	1
14.875	44	19	2	1
14.875	57	75	1	1
14.875	69.625	9	2	1
16.125	20.5	7	2	1
16.125	21.5	28	2	1
16.125	29.5	2	2	1
17.5	17.625	3	2	1
17.5	67.25	65	1	1
18.75	23	9	1	1
18.75	49.5	15	1	1
21.625	39.5	24	1	1
21.625	41.25	33	1	1
21.625	58.75	8	1	1
21.625	64.75	13	1	1
22.875	23	24	2	1
22.875	24.625	44	1	1
22.875	26.75	6	1	1
22.875	39.5	6	1	1
22.875	41.25	5	2	1
22.875	58.75	3	1	1
22.875	68.5	12	2	1
22.875	70.75	22	1	1
23.75	17.625	2	1	1
23.75	20.5	13	1	1
23.75	21.5	17	1	1
23.75	23	3	1	1
23.75	26.75	16	1	1
23.75	29.5	2	1	1
23.75	32.375	6	2	1
23.75	33.125	9	2	1
23.75	36.875	10	1	1
23.75	38.75	64	1	1
23.75	39.5	8	2	1
23.75	41.25	14	2	1
23.75	45	45	1	1
23.75	58.75	11	2	1
23.750	64.75	31	2	1

**Bold items represent internal component solid pieces*