ABSTRACT

ROLL, JOSHUA CALEB. Assessment of Timber Harvesting and Logging Capacity in North Carolina's Coastal Plains-A Simulation Approach. (Under the direction of Dr. Frederick Cubbage).

This research will analyze timber harvesting and logging capacity in North Carolina's coastal plain regions given structural economic trends and conditions after the recent recession and consequent downturn in the forest products industry. The timber and forest products industry value chain begins with standing timber in forests and extends to a variety of manufactured forest products. Key members of this supply chain are logging firms, which have often been characterized as high capital/low profit enterprises. Industry profits have been squeezed by the housing and general economic recession and the long-term survival of logging firms is in doubt. Manufacturing capacity at assembly plants has begun to return but concerns remain that a reduced logging force could hinder the sustainability of logging firms. This study will investigate whether or not the timber supply chain has sufficient logging capacity to meet the anticipated growth over the next "recovery" years. Using Rockwell Automation's Arena simulation software, a model of the supply chain path from the stump to the processing mills was constructed to estimate production levels of harvesting crews in the Coastal Plains of North Carolina. Using simulated production results, we estimate that at a 0.5, 1, and 1.5 percent annual increase in timber demand, an additional average of 34, 37, and 39 "in-woods" logging employees will be needed each year to supply this new demand. On a "per million" basis, we estimate that on average an additional 29 "in-woods" logging employees will be required per year to supply an additional 1 million green tons.

Assessment of Timber Harvesting and Logging Capacity in North Carolina's Coastal Plains-A Simulation Approach

by

Joshua Caleb Roll

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APPROVED BY:

Dr. Karen Abt

Dr. Joseph Roise

Dr. Frederick Cubbage
Chair of Advisory Committee

BIOGRAPHY

Joshua Caleb Roll was born to Deborah Noblin Roll and Thomas Mack Roll in Garland, Texas. In total, the Roll family consisted of Nathan, Jessica, Joshua and Kendall. The opportunity for employment brought Thomas and his household to the High Point/Winston-Salem, North Carolina area where Joshua spent a majority of his youth. Education was heavily emphasized throughout Joshua's childhood by Deborah and as a high school freshmen he transferred from High Point Central High School to the newly established Early College at Guilford College.

Upon graduating as a dual-enrollment student at Guilford Technical Community College, Joshua decided to pursue a business degree at the University of North Carolina at Greensboro. Joshua considered studying marketing, small business entrepreneurship, and finance but felt most passionate about economics. Specifically, he was interested in world economies and economic policy. He was presented with the idea of studying business abroad. UNC-Greensboro was a partner school with Universitaet Mannheim in Germany and proved to be a perfect fit. During his two semesters, he studied various subjects such as German arts and culture, social corporate responsibility, consumer behavior, German language and conversation topics, international business, and problems in economics. He was also blessed with the opportunity to travel to nine different European countries during his studies. Joshua returned to Greensboro for his senior year and graduated with a Bachelor of Science degree in Applied Economic Analysis, International

Business, a minor degree in German, and the Dean's Service Award for exemplary service to the Bryan School of Business.

Post-graduation, Joshua considered immediately applying for graduate school to continue his economic studies. Instead, he accepted a natural resource intern position with the Student Conservation Association in Bear Brook State Park, New Hampshire where he was able to engage the outdoors. The successful completion of the internship led to Joshua spending the next 4 years in a natural setting. After ten months in New Hampshire, he performed natural resource and trail-related work in Northwestern Montana, Idaho, California, Washington, South Carolina, Virginia, Texas, and Hawai'i.

Joshua always intended to pursue graduate school and he decided to apply to North Carolina State University to integrate his undergraduate economic studies with his professional natural resource experience. He was accepted into the Natural Resource Masters Program at N.C. State University and took on a study of logging capacity in eastern North Carolina under Dr. Frederick Cubbage. During this time he also studied other forestry related subjects such as international forestry, forest operations, financial analyses of silvicultural treatments, natural resource policy, and operational research methods. Joshua has accepted a position at International Paper as a Fiber Supply Associate and aspires to use this opportunity to study and promote efficient timber procurement strategies on an international level.

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CHAPTER 1: Introduction

The residual effects of the housing and financial crisis has left the forest products industry at a critical turning point (Taylor 2012). Since 2009, mills have mostly been operating in a survival mode leaving supply relationships strained for logging firms (Taylor 2012). In a 2011 *Timber Harvesting* survey, half the respondents reported making no profit in 2009 (Knight 2011). According to Smidt et al. (2009), "total cost per ton" is the number that most directly reflects a contractor's ability to generate net income. Smidt et al. (2009) also emphasizes that understanding and measuring the productivity of labor and capital is vital for loggings firms to achieve cost and production goals. For logging systems, productivity can be described as tons harvested per united of capital and labor used. In the US South, the forest products industry is largely fully mechanized and increases in capital productivity are difficult to obtain (Greene et al. 2013). For this reason, our study will focus on labor inputs when examining logging productivity.

Greene et al. (2013) believes labor issues in the logging sector are a concern with an aging labor force and highly qualified workers seeking other employment. *Timber Harvesting* (Knight 2011) describes the logging workforce across the eastern United States as "economically challenged." Greene et al. (2013) notes that the age of logging firm owners in the US South has "increased nearly 10 years over the past two decades." Not only is the workforce aging or altogether leaving, a similar survey reports that recruiting workers is also a significant concern to business success by firm owners (Ward 2013). A technical release from WSRI (Taylor and Barynin

2013) states that “new entrants into the wood supply business will be spotty at best,” leading to the conclusion that any expansion in capacity with mostly be supported by existing wood suppliers.

Another area of concern is the business environment and working relationship between consuming mills and loggers (Taylor 2012). Mills reduced procurement staffing in an effort to reduce costs and soften the blow of the recession (Taylor 2012). This and a general lack of communication has been viewed by wood suppliers as a “lack of concern for the sustainability for the logging and transportation businesses” (Taylor 2012). From the mill’s view, cost controls are top priority and the market will determine how many logging businesses survive or fail (Taylor 2012). Integrated decision making and joint planning on volume commitments are both avenues to secure logging capacity and prevent wood suppliers from leaving the industry.

When asked to report the biggest problem facing their logging firm, contractors listed logging rates and general finances (Greene et al. 2013). Historically, logging rates and logging costs tend to track closely, with logging rates generally higher than logging costs (Baker et al. 2014). For example, when diesel prices increased in 2008 (an increase in fuel costs for machinery), logging rates increased as well (Baker et al. 2014). However, logging rates did not follow the increase in logging costs between 2009 and 2011 (Baker et al. 2014).

The increase in logging costs may be due to higher maintenance and repair costs for aging harvesting equipment. According to WRSI (2012), logging firms are using equipment past its useful age in part because of landowners' decision to delay harvesting. Greene et al. (2013) notes that while an increase in the operating life of equipment has occurred, some of this may be a result of financing challenges and the purchase of used machinery from crews that left the industry during the recession. A survey by Hahn (2015) shows that the oldest feller-buncher owned among North Carolina loggers was manufactured in 2000 with an average economic life of 10 years. The oldest skidder and loader used were a 1984 model with an average economic life of 8 years and a 1990 model with an average life of 10 years, respectively. Returns to capital among firms are also flat signaling that additional capital investments no longer means additional productivity as mechanization has plateaued (Greene et al. 2013). A reprieve to equipment owners has been the drop in diesel fuel prices from $3.97 in early 2014 to $2.42 in late 2015 (EIA 2016).

At the same time, projections show that a recovery in wood demand could be just around the corner. Globally, industrial roundwood consumption is projected to be 45% higher in 2020 than its peak levels in 2005 (FIM 2015). Demand for softwood solid products is strongly correlated with housing markets (Wear et al. 2013). Since its low in 2009, housing starts totaled just above its 1.1 million unit forecast for 2015, showing possible signs of a sustained recovery (Forest2Market 2016). Southern sawtimber demand is predicted to surpass 18 billion board feet (BBF), up

27% from its 2012 levels and should be supported by higher pulpwood demand (RISI 2013).

Positive signs in the housing sector are coupled with the emergence of biomass markets in the form of wood pellets. In 2014, the US South exported about 3.6 million metric tons to European markets (Forest2Market 2015). Assuming the US maintains its current market share of wood pellet exports, an additional 3.4 million metric tons of industrial pellets could be sourced from the US South over the next few years (Forest2Market 2015). The presence of Enviva Biomass in North Carolina specifically has led to 3 manufacturing facilities in the state with a combined annual capacity of 1.37 million metric tons. In mid-2016, International Paper will complete the conversion of its Riegelwood, NC plant to 100% fluff-pulp with an estimated annual production capacity of 1.4 million dry short tons. Fluff pulp is typically used in the production of baby diapers and hygiene products, which is often demanded in developing countries as they increase their standard of living. Fluff-pulp is projected to grow 3%-4% globally per year (International Paper 2016).

Members of the wood supply chain in North Carolina's coastal plain must be prepared in order to fully participate in this growing and changing market. While there may be concerns that the current state of the forest products supply chain may not be fully suited to an increase in wood demand, the wood supply system has never run out of wood. One particular concern is logging capacity. This study uses a simulation approach to model the productivity of logging crews in the North

Carolina coastal plain. With per-crew production levels, we will estimate the total number of loggers necessary to meet current and forecasted levels of wood demand.

CHAPTER 2: Overview of the Forest Products Supply Chain

Introduction

The timber supply chain be categorized into 5 main functions. These are purchasing, harvesting, transportation, storage and production (Lang and Mendell 2012). The flow of wood along the supply chain can vary based on different levels of vertical integration (or disintegration). As proposed by Jones & Ohlman (2012), vertically integrated operations are those where multiple functions in the timber supply chain is performed by a single party. Conversely, vertical disintegration in the forest products industry applies to each supply chain function being completed by separate entities.

Timber Purchasing

Timber is usually purchased via a contract between the timber-owner and buyer where the buyer pays a “stumpage” which represents the value of merchantable timber at the stump. Timber owners include Real Estate Investment Trusts (REITs), Timber Investment Management Organizations (TIMOs), and Non-industrial private forest owners.

The introduction of “wood dealers” into the procurement process has theoretically increased competitiveness in the purchase of standing timber. Prior to the introduction of wood dealers, standing timber was usually purchased by a logging firm from a forest consultant who represented the landowner. In some cases today, logging firms employ their own forest consultant and purchase timber directly from the landowner. Large corporate landowners typically sell their standing timber to wood dealers who are either employed by mills or are a separate entity altogether.

The process of purchasing timber in the US South is normally conducted in one of three different methods: 1) Lump-sum payment for a specific timber sale, 2) Per-unit payment for timber in a specific timber sale and 3) Per-unit payment for a minimum supply through the use of a timber supply contract (McClure 2009). In a “lump sum payment,” the buyer pays the full negotiated price which is calculated from the total value of the timber to be harvested. A “per-unit payment” such as a “per ton” rate, is derived from the type of forest product being harvested (softwood/hardwood pulpwood, softwood/hardwood sawtimber, Chip-n-Saw, veneer logs), the amount harvested, and the market price for each forest product. Each type of sale utilizes a bidding process where multiple buyers bid on a predetermined tract whose value, depending on the size and type of timber. Landowners may sell direct to a buyer or do so with the assistance of a forest consultant. The timber is sold to the winning bidder or buyer who negotiated the sale and harvesting operations begin.

Timber Harvesting

Harvesting operations can vary in size and complexity depending on tract size and desired products to be harvested. The two main products harvested in the US South are sawlogs and pulpwood. The mechanized harvesting process consists of felling specified trees using a feller-buncher, de-limbing the trunk, and transporting it to the landing area using a skidder where it will be loaded and hauled to a mill (Mcdonald and Clow 2010). Sawlogs are processed in one of two ways. Stems can be delimbed and sorted as full tree-length logs, or they can be "cut to length" to accommodate specific products (Borges et al. 2014). The full tree-length approach is utilized heavily in the US South according to Baker et al. (2010). Less mechanized systems using chainsaws and cable skidders still exist, especially in hardwood operations in the mountains.

Harvesting operations are carried out by a logging crew which can vary in skill level, age, and size. Greene et al. (2013) note that over the past two decades, the age of logging firm owners has increased nearly 10 years. Sorting logs according to mill specifications by either product/grade class or a pre-specified timber supply agreement requires experienced personnel. Mis-sorting and eventually delivering incorrectly graded logs can lead to penalties from mills (Sessions et al 2005). Harvesting operations can be fully integrated with other functions, partially integrated, or completely disintegrated.

Transportation

Transportation plays a vital role in all wood procurement systems. Transportation of wood fiber to the mill or woodyard can take the form of tractor-trailer trucks, railroad cars, barges (Harris et al. 1986), or may be floated down a river, as in the Pacific Northwest. Wood fiber loads may be taken to a satellite woodyard that can be owned by a mill or by a wood dealer who is contracted by a mill.

Higher weight restrictions leads to increased fuel, labor, and maintenance costs due to the need to make more trips. Variability in the actual weighted loads can lead to inefficiencies in hauling operations (Hamsley et al. 2007). As with other supply chain processes, transportation activities can be operated by a logging firm who owns their own tractor-trailers or it can be contracted by a separate trucking firm.

Storage

Wood fiber can be stored directly at the mill as part of their inventory or at a satellite woodyard owned by the mill or by a wood dealer contracted by the mill. Satellite woodyards are utilized when a mill is too far away for timber supplier to haul directly to the mill. Managing the level of inventory at both of these facilities plays a key role in the successful operation of the entire forest products supply chain. Holding inventory longer causes the woodyard owner to incur higher maintenance and handling costs.

The flow of wood from suppliers to the mill also often arrives in "surges" due to environmental factors limiting the productive hours of a harvesting operation. To cope with this, mills use their satellite woodyards as buffers when inventory is low and utilize quotas for suppliers when inventory is high (Harris et al. 1986). Sorting incoming loads from timber suppliers takes place at both satellite and mill woodyards. Once timber reaches the mill's woodyard, it is inspected more vigorously and incorrectly graded logs or improper specifications are identified. Since payments are usually made on a per-ton basis, the load is also weighed before it is unloaded and sorted.

Production

Mills can range in size and typically produce a specific product or set of products such as paper, dimensional lumber, and wood pellets. These products require the mill to procure timber inputs such as pulpwood for paper and sawlogs for dimensional lumber. Wood pellet mills procure mostly standing timber for production but can also utilize forest residues. At the mill gate, the mill pays a "delivered" timber price which represents the value of the timber at the mill. A mill must continually plan and reassess procurement requirements based on expected supply, demand, and inventory levels. Satellite woodyard locations and their variance in responsiveness adds even more complexity to procurement planning. Procurement requirements not only specify volume needed but aspects such as the product required, species, quality of wood, as well as the time constraint.

Timber supply agreements are often formed between mills and timber suppliers (dealers/harvesting firms) to ensure timber supply at the mill is adequate. While many other regions around the world utilize supply contracts from 1-3 years in length (Siry et al. 2006), many suppliers in the US South have reported volume commitments varying from week to week (Taylor, 2012).

CHAPTER 3: Literature Review

Forest Products Industry

In the past 50 years, the forest products industry has transitioned through different technologies and harvesting methods. In the 1960s, technology advancements allowed southern plywood manufacturers to produce construction-grade plywood that could compete with western counterparts. In the 1970s and 1980s, mechanization became heavily integrated into most logging operations in the United States leading to increases in productivity (Smidt et al. 2009) but less demand for labor (Bush 1988). The 1980s also marked the use of chemical treatments for southern pine decking for outdoor applications (Prestemon and Abt 2002). The business environment also became more complex in the 1990s with new regulations and forest certifications (Smidt et al. 2009); and in 1990, North Carolina introduced 9 mandatory "Forest Practice Guidelines" related to water quality during any forestry activity.

In 1952, the South produced 41 percent of the country's wood fiber output and 58 percent in 1997. Its segment of the world's industrial wood production rose 9.5 percent over that time period (Prestemon and Abt 2002). Operations became fully mechanized and few new technologies were introduced causing productivity in capital to plateau. Research in the last few decades on forest harvesting performance has focused on increasing these productivities as well as technical and operational efficiency and cost reduction (Stuart et al. 2007). Increasing output from labor has alleviated some of the impacts of employment losses to southern logging capacity (Baker et al. 2014). Between 2005 and 2009, forestry and logging, wood manufacturing, and paper manufacturing sectors have lost a combined 322,805 jobs (Woodall et al. 2011). This has also led to logging managers optimizing equipment use to control costs and efficiency (Smidt 2009).

The onset of globalization has also intensified competition in the marketplace. From 2000 to 2005 the timber industry experienced unprecedented growth, growing at 5 percent annually and requiring record volumes of panels and sawn softwood (UNECE/FAO 2006). Roughly 2.1 million new housing units were started in 2005-a 33-year high (US Census Bureau 2015). By 2009, new housing starts fell to their lowest levels since World War II due to the US housing and financial crisis (Wear et al. 2015). From its record highs in 2005, US softwood lumber consumption fell 50 percent and softwood lumber production fell 43 percent by 2009 (Woodall et al. 2011). In the U.S. South, harvesting firms were faced with depleted savings, worsening debt, strained business relations with mills, and the inability to reinvest in new equipment due to tight credit markets (Taylor and Barynin 2013).

Industrialization of wood pellets in the US is not a new occurrence. However, pellets for export and energy production abroad have become a staple in the US South only in the past decade. Wood pellets can utilize sawtimber, lower quality wood fibers from logging residues, and higher quality fibers from mill residues (Abt et al. 2014).

The first industrial wood pellet export mill, owned by Green Circle Energy (now Enviva), began operating in 2008 in Florida. Since then, nineteen wood pellet mills have opened or are under construction in the US South-none have closed (Forest2Market 2015).

Growth in the export of pellets is due in large part to the European Commission's 2020 climate and energy plan which aims to decrease greenhouse emissions, increase renewable energy output, and improve energy efficiency (European Commission 2016). Total pellet exports from the US doubled from 1.6 million tons in 2012 to 3.2 million tons in 2013. Nearly 99 percent of this volume originated from ports in the southeastern and lower Mid-Atlantic parts of the country (EIA 2014). US Exports reached 4.4 million tons in 2014. Nearly 4 million tons exported to Europe came from the US South, accounting for 40 percent of Europe's industrial pellet consumption (Forest2Market 2015).

The US South has been well suited to respond to this fiber demand with its abundant feedstock supply and relatively low shipping costs. There are concerns that this additional demand in wood fiber will reduce forest inventories, will utilize ecologically valuable forests, will indirectly cause negative changes in land use, or will reduce the overall carbon stored in the forest (Stephenson and MacKay 2014).

Current State of the Forest Products Supply Chain

In procurement and harvest planning, timber demands are often used as a base for measuring the required logging capacity required to meet that demand (Epstein et al. 2007). Taylor and Barynin (2013) indicate that improved working relationships between wood suppliers and consuming mills can improve industry capacity to meet demand requirements. Hurdles include (1) the lack of investment in new equipment, (2) a subsequent over-utilization of aging equipment leading to high maintenance and repair costs, (3) an aging labor force and (4) less trust. The lack of investment is a result of recessionary credit markets making it difficult for trucking and logging firms to reinvest and could be a barrier for new entrepreneurs (Baker and Greene 2008). Greene et al. (2013) found that feller-bunchers were twice as old and hauling trucks to be 40 percent older in 2012 than in 2007.

The labor force for logging operations is also aging and new logging entrants into the industry are scarce. Greene et al. (2013) also found that the age of logging firm owners has increased almost 10 years in the past 2 decades, signaling decreasing interest in entrepreneurship. Furthermore, business relationships between wood suppliers and mills have less trust, as evidenced by shorter supply agreements. Taylor (2012) notes in his survey that suppliers expressed a lack of attention from consumer mill procurement representatives and a lack of concern for the sustainability of the logging and transportation businesses. Declining or stable stumpage prices also discourage landowners from selling their timber but rather wait until prices recover (Conrad et al. 2010).

Given these obstacles, it is difficult to determine whether the timber industry in the U.S. South is healthy enough to adequately meet future consumption demands. To depict its importance, in 2006 the southern region represented 57 percent of all roundwood harvested in the United States (Smith et al. 2009). This has led to the question, "Does the wood supply system have sufficient logging capacity to meet the anticipated growth in harvest demand over the next 'recovery' years?" This study will use simulation software to estimate production of each component in the harvesting and transportation process. These estimates will be aggregated to portray annual production volumes of a typical logging crew in the 2 coastal plain regions of North Carolina.

Operations Research Models in Forestry

Operational research models can been used to optimize and/or simulate operational, tactical, and strategic decision making for firms in the wood supply chain and have been used as early as the 1960s. The decision to use optimization vs. simulation depends upon the nature of the decision to be made.

Optimizing a set of decisions is generally useful when attempting to resolve an issue absolutely while satisfying a given set of constraints. Optimization methods are often coupled with sensitivity scenarios to analyze specific cases of uncertainty. Some optimization models address particular functions in the procurement process such as transportation (Weintraub et al. 1996) and the extraction of logs (Carlsson et al. 1998). Burger and Jamnick (1995) developed a linear programming model that integrated harvest methods, transportation, and wood requirements to reduce a pulp mill's wood cost by 5.1%. Other optimization studies have included the entire procurement planning horizon from the forest to the mill (Beaudoin et al. 2007). Beaudoin et al. (2007) utilized a Mixed-Integer Programming approach to analyze wood procurement and distribution decisions. These optimization models are formed using deterministic inputs, outputs, and constraints.

However, decision making in every activity in the forest products supply chain is affected by, in one way or another, stochastic variables. In these cases, simulation is more appropriate because the outcomes of the problem can be highly variable. For this reason, simulation models are frequently used to measure system performance under varying degrees of stress and/or flexibility. Zhang et al. (2012) simulated the procurement and processing of biomass for biofuel to estimate delivery costs, energy consumption, and GHG emissions for different locations and plant sizes. Moore et al. (2011), used a Monte Carlo simulation to assess sensitivities in their financial analysis of harvesting in Canadian boreal forests to different harvesting approaches. Aedo-Ortiz et al. (1997) used simulation software to assess the capability of limited field observations in a softwood thinning operation to estimate system production.

Using OR models to support decision making in all functions of the forest product supply chain has been suggested in the literature to result in an increase (decrease) of profits (costs) of, on average, 5% when using deterministic models (Burger 1991; Williamson and Nieuwenhuis 1993; Hecker et al. 2000; Bergdahl et al. 2003) and upwards of 8.8 percent when conducting a scenario-based simulation (Beaudoin et al. 2007). While increasing profits/reducing costs are important and a subplot in the analysis of logging capacity, this study intends to use simulation to estimate labor-based metrics.

Previous Logging Production Studies

Logging production surveys have become a staple at the University of Georgia's Warnell School of Forestry and Natural Resources. Since 1987, Dale Green has administered production questionnaires for logging contractors in Georgia every 5 years. One objective of this study has been to gauge the proportion of Georgia's timber output that is represented by survey respondents. In the 2007 iteration, Greene and Baker (2007) note that average weekly production of Georgia logging firms has increased 83 percent since 1987.

Lebel (1993) completed a production capacity utilization study at Virginia Tech. The study's survey included production estimates from 22 independent contractors in the Coastal Plain, Piedmont, and southern Appalachia regions. Specifically, contractors estimated their maximum production capacity and their achieved production on a daily basis. Firms operating in the coastal plain were reported to utilize 70 percent of their production capacity (Lebel 1993). Taylor (2007) determined that logging capacity utilization rates of 75 percent were close to the maximum possible due to mill procurement practices, stand conditions and terrain, and weather.

Greene et al. (2004) estimates that wood supply systems in the southern United States and Maine are using only 65 percent of their production capacity. This 20-month study in 2000 and 2001 recorded wood production values and loads missed from in-woods logging crews and recipient mills. Specifically, data was collected from field visits, weekly production reports, weekly receipts from consuming mills, and surveys. The objective of this study was to model the percentage of loads missed per crew per week. Weekly production potential was calculated by combining actual production and loads reported as missed. Missed loads were then taken as a proportion of weekly production potential to estimate capacity utilization. Reasons cited for unused production capacity were market conditions (including mill quotas), inclement weather such as extended wet periods, planning, and mechanical equipment (Greene et al. 2004). According to this study, unused capacity costs an average of $1.66 per delivered ton of wood, although there's no empirical evidence to suggest who in the supply system bears the brunt of this unnecessary cost.

More recently, Baker (2015) estimates the impact of the housing recession in 2008 on logging capacity in the US South. Where prior logging capacity studies have used surveys and in-field equipment cycle times to report production levels, Baker uses a more methodical approach. Using data from published Timber Product Output (TPO) reports and quarterly BLS employment levels for the logging industry (peak production levels prior to the recession), Baker constructed a ratio that compared each states production per employee in 2006 and 2007 to the production of the production per employee per Georgia's logging survey (previously mentioned). This ratio was used to derive a potential harvest production estimate for each state in the US South from that of Georgia's potential harvest production. Excess logging capacity could then be obtained by taking the difference between each state's actual harvest and its derived potential harvest output. Baker notes that, out of the US South, the NC-VA region experienced the least decline in total logging employment

(14 percent) but is the only reason to show continuous reductions in total harvest levels since 2009. He concludes that excess logging capacity in the NC-VA region increased in all years of the study except 2011. In 2012, excess logging capacity in the region was roughly 40 percent of the total production.

Conrad et al. (2013) designed an experiment that observed and contrasted the harvesting productivities of a contracted crew for three separate treatments. The first treatment was a traditional roundwood only harvest, the second treatment incorporated a traditional roundwood harvest with residues for energy conversion, and the third treatment was a chip-only harvest for energy conversion. The contracted crew used in this study typically delivered between 2,200-2,700 tons per week. Conrad et al. (2013) concluded from the study that the chip-only treatment harvested the most volume per hectare, while different blocks within the first and second treatments resulted in differing levels of roundwood production. Conrad et al. (2013) mentions that site conditions and different loggers could play a role in harvesting productivities in a traditional roundwood harvest versus an integrated harvest.

Most relevant to this study is Hahn's (2015) survey, part of which gathered essential production data from logging crews in the piedmont and coastal plains of North Carolina. Respondents in the logging portion of the survey were asked to report average weekly production (tons) for softwood and hardwood, the percent of sawtimber, chip-n-saw, pulpwood, and biomass that was harvested, average hours worked per week, weeks worked per year, and number of employees in the firm.

According to Hahn (2015), average weekly crew production was 1,554 tons of pine and 1,279 tons of hardwood. The percentage of pine-based forest products harvested were 47 percent pulpwood, 32 percent sawtimber, 12 percent chip-n-saw, and 9 percent biomass. The reported hardwood product mix was 32 percent pulpwood, 44 percent pulpwood, 5 percent chip-n-saw, and 19 percent biomass. Interestingly, when asked about future business expansion, 67 percent of coastal plain logging firms indicated plans to expand while no piedmont loggers indicated as such.

This study will employ similar methods to that of Baker (2015) in that it will employ TPO and BLS data for North Carolina's coastal plain regions. However, instead of using Georgia's Logging Survey to measure production per employee, a harvesting simulation has been designed to model the annual output of a typical harvesting crew in the coastal plains. Using the results from our harvesting simulation, we can utilize the appropriate TPO and BLS data to determine how many crews operate in the coastal plain of NC and estimate the additional number of crews necessary to meet future wood demand.

CHAPTER 4: Methods

Overview

Harvesting systems within a region can vary among different sites and from crew to crew. An example of this is the different levels of integration among firms in the forest products supply chain. Included in the appendix is a brief analysis of historical and current wood procurement systems. In this analysis we have mapped five procurement systems that emphasize the paths that wood flow can take from the stand to the mill based on various levels of supply chain integration. Methods of wood procurement and varying degrees of firm integration can differ from mill to mill and from crew to crew. Because of the complexity of modeling a harvesting system under this premise, this study is more practical for making inferences of a regional system rather than individual logging crews.

Traditionally, the metric of "logging capacity" is expressed as how much a harvesting crew actually produces as a proportion of how much a crew could produce, during a given time period. Excess capacity can then be described as the proportion of potential logging production that is unused. According to Greene et al. (2004), excess capacity between 20-25 percent is perceived as efficient for the logging industry. While expressing logging capacity this way is certainly useful, it may not be the most pragmatic metric when assessing if the logging industry is capable of supplying adequate levels of wood fiber. Because most crews run at near-full mechanization, expansion in potential timber output are likely to stem from additional labor. This study will therefore analyze logging capacity in terms of additional labor required to meet wood demand as it pertains to the NC coastal plains.

The process of analyzing logging capacity is separated into sequential steps here and explained in detail later. First, we applied a simulation model to approximate annual softwood and hardwood harvest levels for an individual logging crew. Next, we converted the most recent Timber Product Output (TPO) data in 2011 from cubic feet to tons using Timber Mart-South's weight equivalents. Next, employment in the logging industry (NAICS 113310) was retrieved from the Bureau of Labor Service for coastal plain counties. To get a rough estimate of average "in-woods" crew sizes, we consulted a previous logging survey in the coastal plain of Virginia (Barrett et al. 2012). With this information we were able to estimate the number of logging crews required to produce 2011 levels of timber output as well as increased wood demand in subsequent years as forecasted by the Southern Forest Futures Project (Wear et al. 2015).

Introduction to Arena Simulation

This simulation used Rockwell Automation's Arena Simulation software provided by North Carolina State University. Arena simulation offers user flexibility in designing a model to measure system performance across applications such as manufacturing, customer service, supply chain management, and planning/scheduling. This study in particular will measure the performance and utilization of harvesting equipment in order to estimate the annual hardwood and softwood harvest volume of a typical logging crew in the NC Coastal Plain.

The basic building blocks used to create custom environments in Arena are modules which eventually form the model template. Modules contain the logic of the system that is being modeled and can take the form of creating/disposing of entities, basic processes, batching/separating, transfers, and assigning entities a particular attribute. Entities are what enter and travel through the system while the simulation is active. In a customer service setting, the entity is the customer moving along a queue and eventually being processed by a clerk. For this study, an entity will represent a single ton of wood travelling through each component of the harvesting operation.

Once the simulation template is complete and the logic is established, parameters can be set for simulated replications. Significant parameters for this study are number of replications, base time units, and hours per day. Number of replications indicate how many times the simulation will be run. Base time units specify what units of time will be reported once the simulation is complete. Hours per day defines how many hours will be modeled in a simulated day. Once the simulation has run and is complete, reports are generated to summarize the results. Reports include system performance criteria as well as more detailed indicators. System performance criteria can include the number of entities that moved through the entire model and those that were still "in progress" when the simulation was complete. Arena is also able to generate targeted key performance indicators on entities, resources that were used in processes, queues, and other user specified attributes. Resource utilization, queue times and lengths, and attributes such as hardwood or softwood tons are among these targeted criteria.

The simulation model designed in this study is subdivided into 4 interrelated segments to group activities that occur in the same harvesting activity (felling, sorting, skidding). The 4 segments are shown and described in their function below:

Product Classification

Before any harvesting operation takes place in the simulation, each entity (ton of wood) is assigned an attribute based on its product class. The simulation is initiated at the Create, or "Stumpage" module where each wood-ton is generated. Tons are generated at a user-specified rate and can enter the system as batches or single entities. For the purposes of this model, a generic generation rate for each ton of wood is set. The logic behind this is that in a real-world harvesting system, standing timber does not "enter" the harvesting system at any particular rate. Later in the

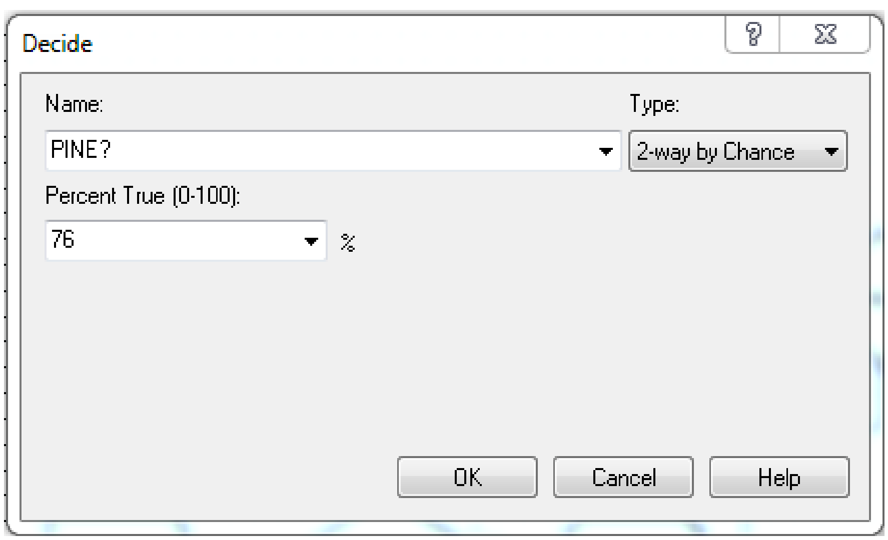

Figure 1: "Two-way by chance" Decide Module.

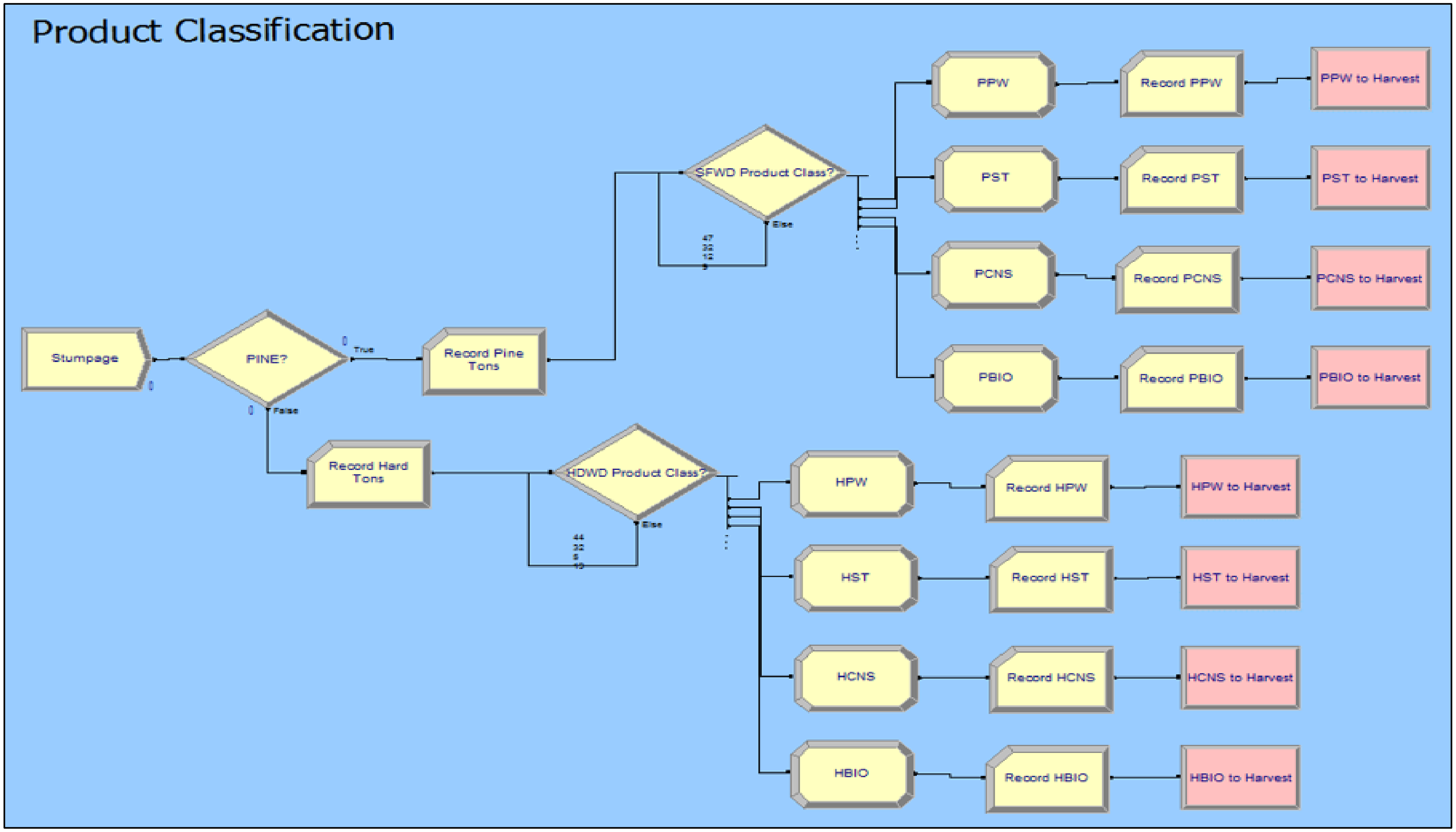

Figure 2: Product Classification Segment.

model, we will utilize a basic "hold" module where entities will wait until seized by a harvesting machine, in order to align the model closer to a real-world situation. Once the stumpage (or ton) is generated, it enters into a "two-way by chance" decision module where, based on user specifications, an assigned percent of entities that enter this module are designated as pine while the rest become non-pine. In other words, an entity follows the "True" path if it is labeled as pine, or the "False" path if labeled as non-pine.

According to the Forest Inventory Data Online (FIDO) database, 76 percent of the average annual harvest removals for growing stock trees (greater than 5 inches diameter at breast height) in North Carolina's coastal plain were softwood, or "pine" species for 2014. Once designated, entities follow their respective paths and are recorded as a "softwood ton" or "hardwood ton" for reporting purposes. At this point, each softwood and hardwood ton enters a "4-way by chance" decision module where each ton receives a product designation based on a defined product mix distribution. Product class distributions are taken from Hahn's (2015) North

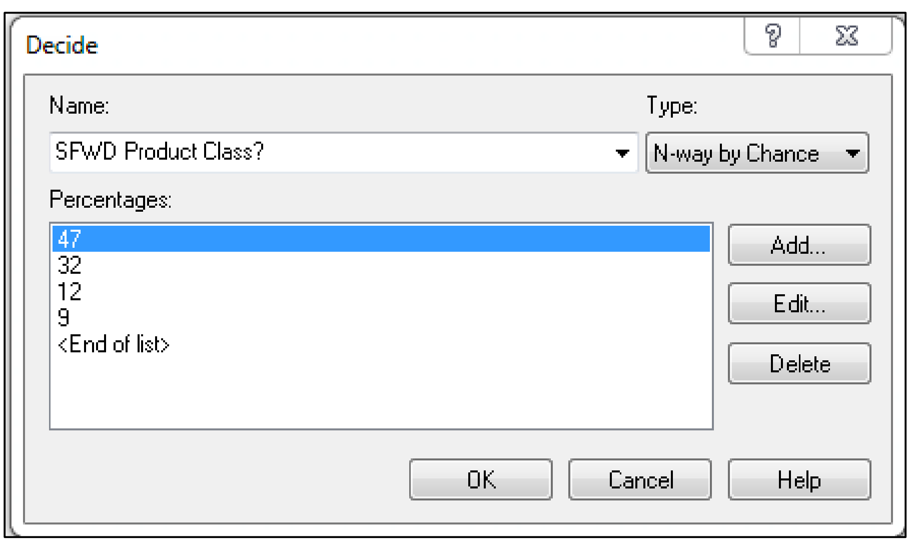

Figure 3: "Four-way by chance" Softwood Decide Module.

Carolina logging questionnaire. According to the questionnaire, 47 percent of harvested pine is pulpwood, 32 percent is sawtimber, 12 percent is chip-n-saw, and 9 percent of pine is biomass for energy. 44 percent of harvested hardwood is pulpwood, 32 percent is sawtimber, 19 percent is biomass for energy, and 5 percent of hardwood is chip-n-saw. For reporting purposes, entity tons listed as pine receive a "PPW" attribute for pine pulpwood, "PST" for pine sawtimber, "PCNS" for pine chip-n-saw, and "PBIO" for pine biomass for energy. Entities listed as hardwood receive a "HPW" attribute for hardwood pulpwood, "HST" for hardwood sawtimber, "HCNS" for hardwood chip-n-saw, and "HBIO" for hardwood biomass for energy. After an entity receive a product attribute the ton is tallied and enters a "Route" module where it is transferred to its respective softwood and harvesting system.

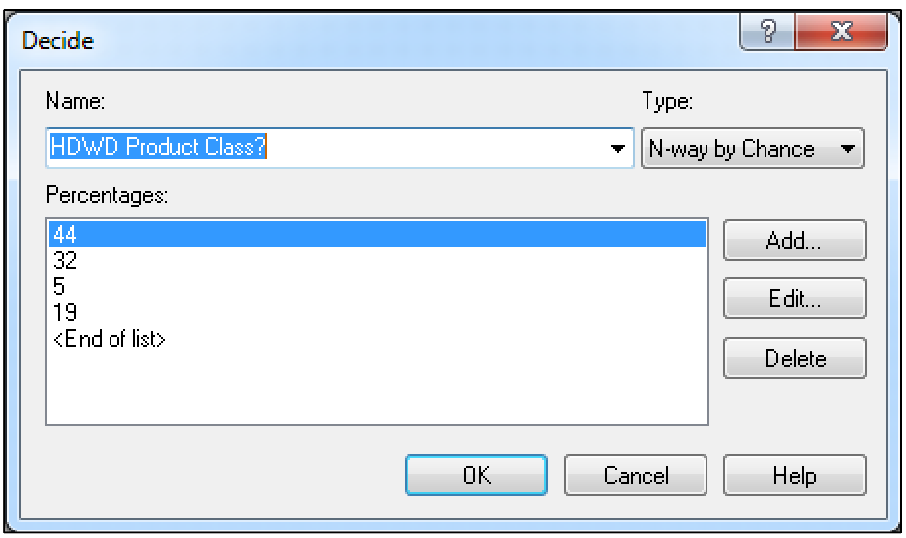

Figure 4: "Four-way by chance" Hardwood Decide Module.

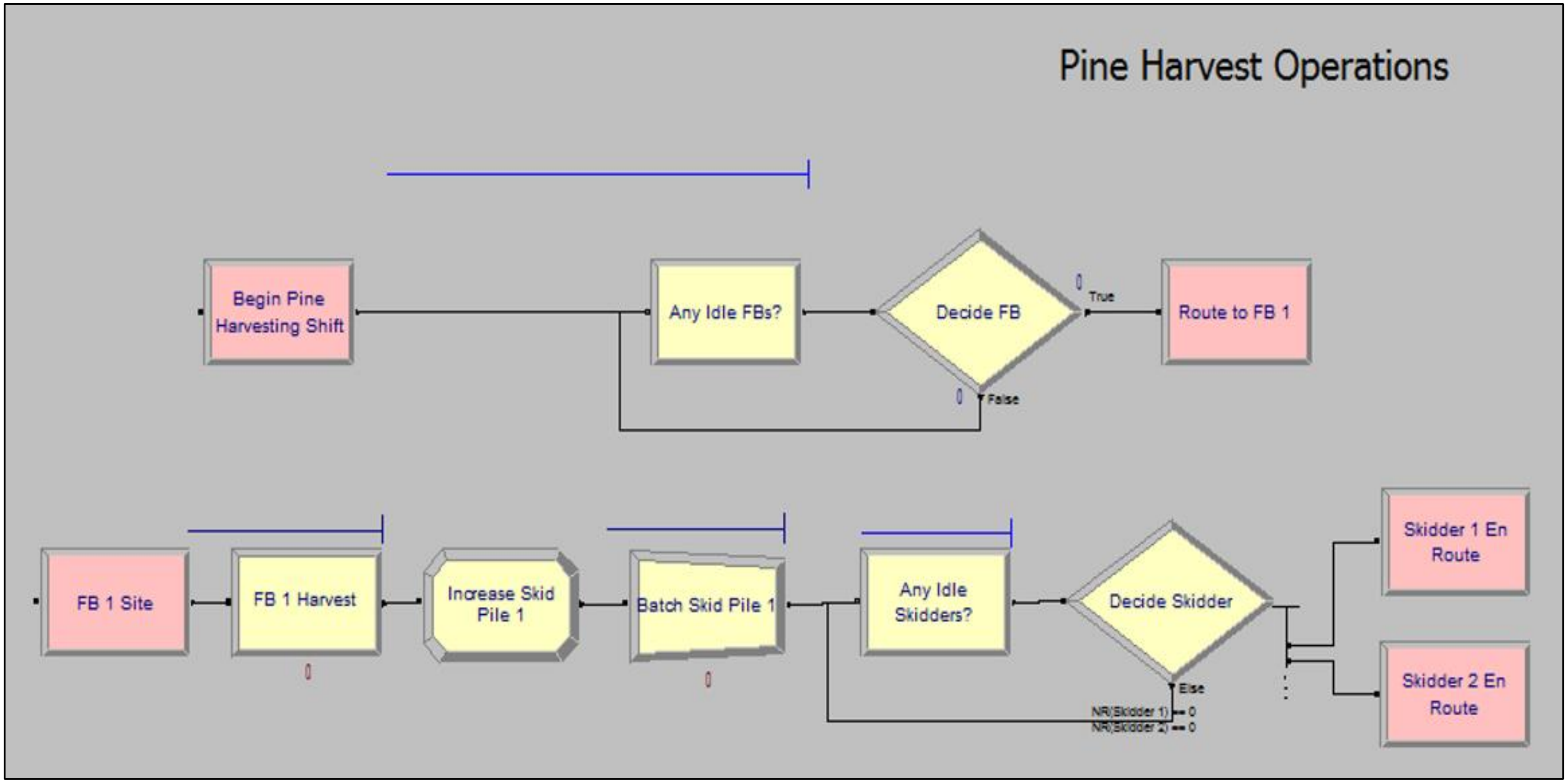

Figure 5: Pine Harvest Operations Segment.

Pine Harvest Operations

Once an entity ton has entered the system, has been attributed as pine, and has further been attributed within its respective species product mix, it enters the "Pine Harvest Operations" segment of the model at the station module defined as "Begin Pine Harvesting Shift." Only tons which have a pine designation may enter this module. Each unit of equipment used in this simulation is modeled as resource in the system. Resources that are available for both pine and hardwood harvesting portions of the system are one feller buncher and two skidding units. At this point, the entity enters a queue in the "Any Idle FBs?" Hold module where the model determines if the feller buncher is available for harvesting. If the feller buncher is

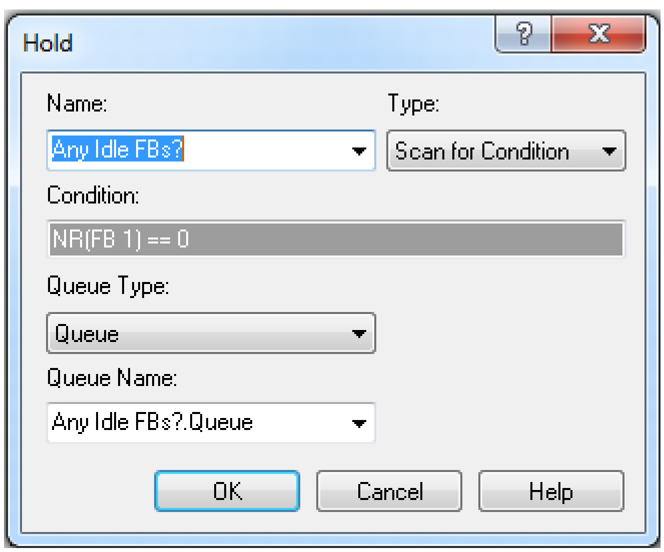

Figure 6: "Hold" Module for Idle Feller-Buncher Scan.

module. Each unit of equipment used in this simulation is modeled as resource in the system. Resources that are available for both pine and hardwood harvesting portions of the system are one feller buncher and two skidding units. At this point, the entity enters a queue in the "Any Idle FBs?" Hold module where the model

determines if the feller buncher is available for harvesting. If the feller buncher is unavailable, entities form a queue until it completely processes its current entity. Once the resource becomes available, the entity-ton moves through the "Decide FB" module true-path and is ready to be processed. Once routed to the "FB 1 Site" Station module, entities enter the "FB 1 Harvest" Process module where the act of felling is simulated.

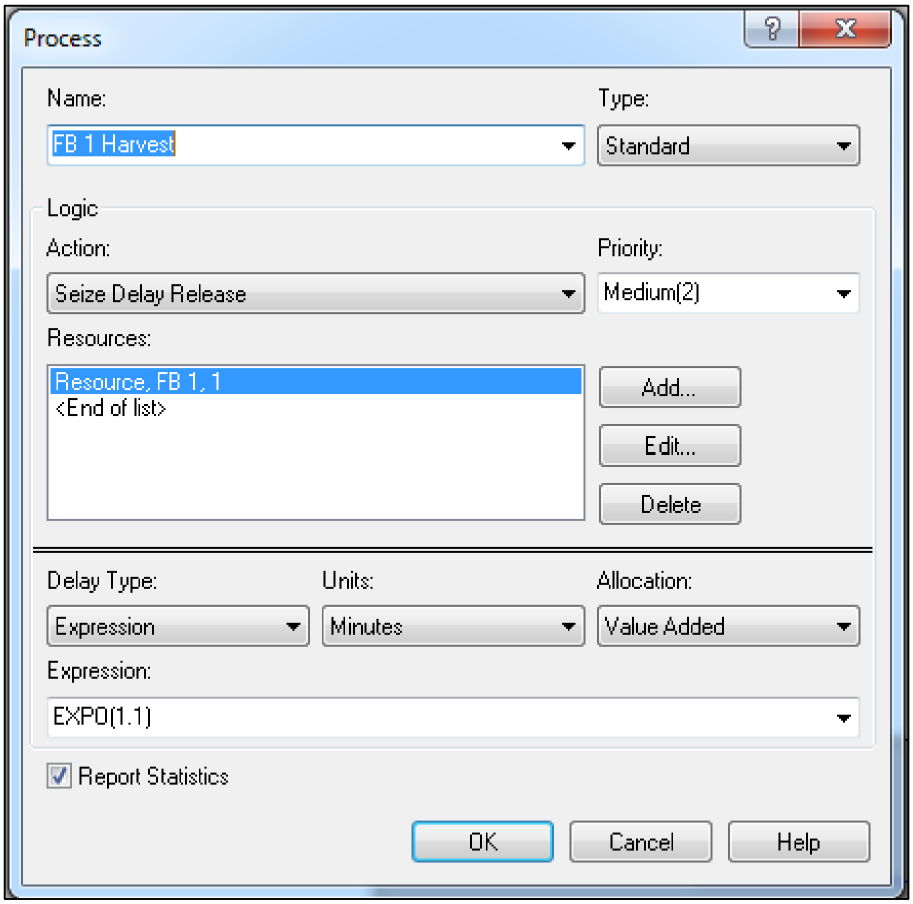

Figure 7: "Process" Module for Pine Feller-Buncher Production.

In the process module, users are able to define the resources that will seize the entity as well as distributions for processing times of the resource. An exponential delay with a mean time of 1.1 minutes is used for the feller buncher when harvesting pine. Arena has a variety of built-in distributions available for use depending on the process being simulated. After the harvesting process, the entity passes through the "Increase Skid Pile 1" assign module which is capable of tracking of how large or small a skid pile becomes between harvesting and skidding operations. While not emphasized in this study, this aspect can be utilized and/or enhanced in later studies. To ensure that the skidder resource is transporting more than a single entity-ton per cycle, entities are grouped in the "Batch Skid Pile 1" Batch module. Entities are batched temporarily in sizes of 2-tons. Later, once the batch has been transferred to the landing it will be separated again into single entities. Each ton is queued in the batch process until the required batch size is met.

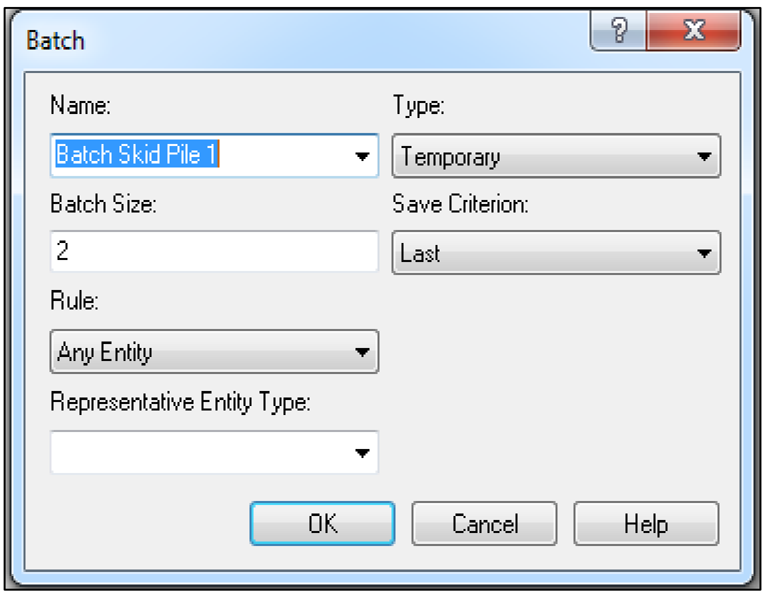

Figure 8: "Batch" Module for Grouping Skid Loads.

Similar to the way the system checks for the idle feller buncher, the system now scans to see if either of the skidder resources are idle and available. Once available, the batch moves along the Decide module, is assigned a skidder resource, and proceeds to the "Skidder En Route" Route module. As the skidder "arrives," the batch moves to the "Skid-Load-Transfer" segment of the model.

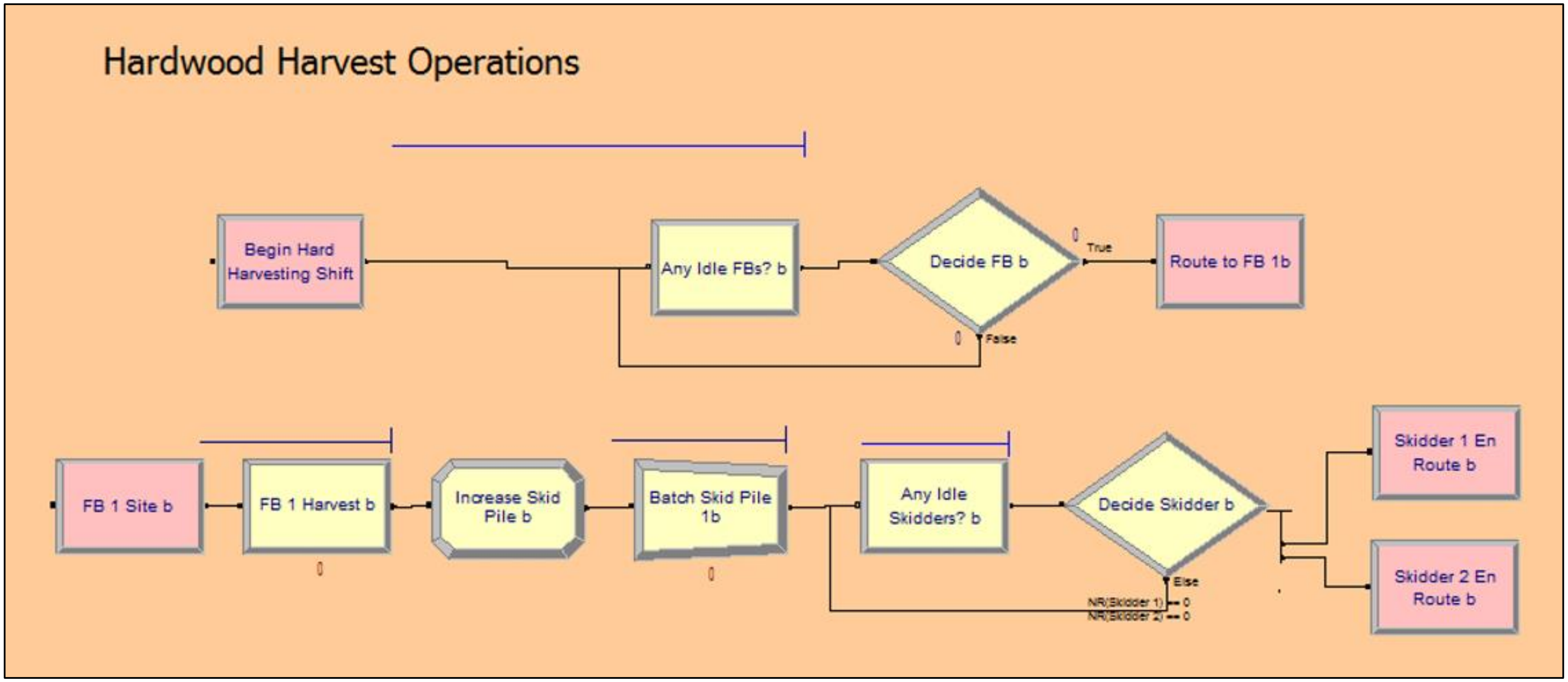

Figure 9: Hardwood Harvest Operations Segment.

Hardwood Harvest Operations

The logic behind the hardwood harvesting segment of the model is very similar to that of the pine harvesting segment. The main difference here is that the processing time for a feller buncher to harvest a hardwood stem is slightly longer than it is for a pine stem. Before an entity can enter this segment, it must receive a non-pine attribute from the Product Classification portion of the simulation. From here, the entity is driven through the hardwood product mix distribution and proceeds to the "Begin Hard Harvesting Shift" Station module. Entities are then queued as the system scans for an idle feller buncher resource. Once the resource becomes available, the entity travels along the path to the "FB 1 Site b" Station module via the Route module.

The entity-ton arrives at "FB 1 Harvest b" Process module, is seized by the feller buncher resource, and the entity flow is delayed by the appropriate processing time. As shown in Figure 10, the entity is to be seized by the resource, delayed by the amount of time designated, and release once that time has elapsed. The delay here is also an exponential delay with a mean time of 1.2 minutes. After the harvesting processing is complete, entities continue to flow along the path and the skid pile increases as each ton is processed by the feller buncher. Here, the tons are batched temporarily and the system once again scans both skidding resources to determine if they are idle or busy. If a skidding resource is determined to be available, the batch is assigned the available resource. The hardwood harvesting operation is

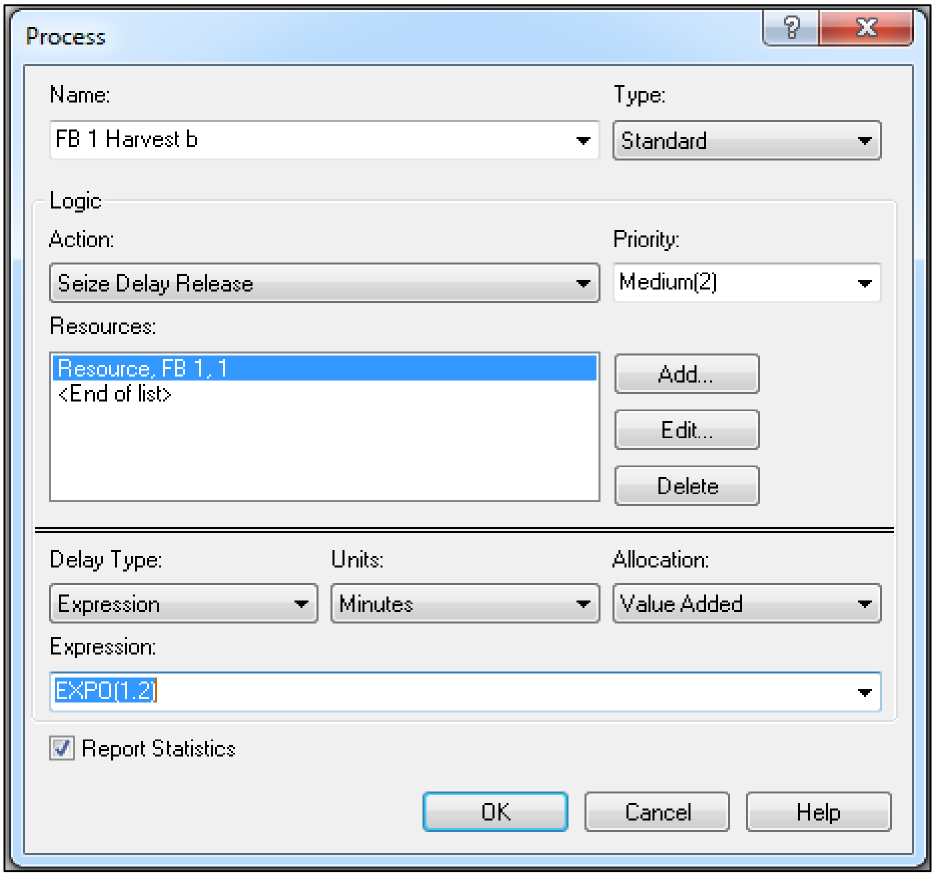

Figure 10: "Process" Module for Hardwood Feller-Buncher Production.

complete when the batch enters the "Skidder En Route b" Route module and the skidding resource "arrives.

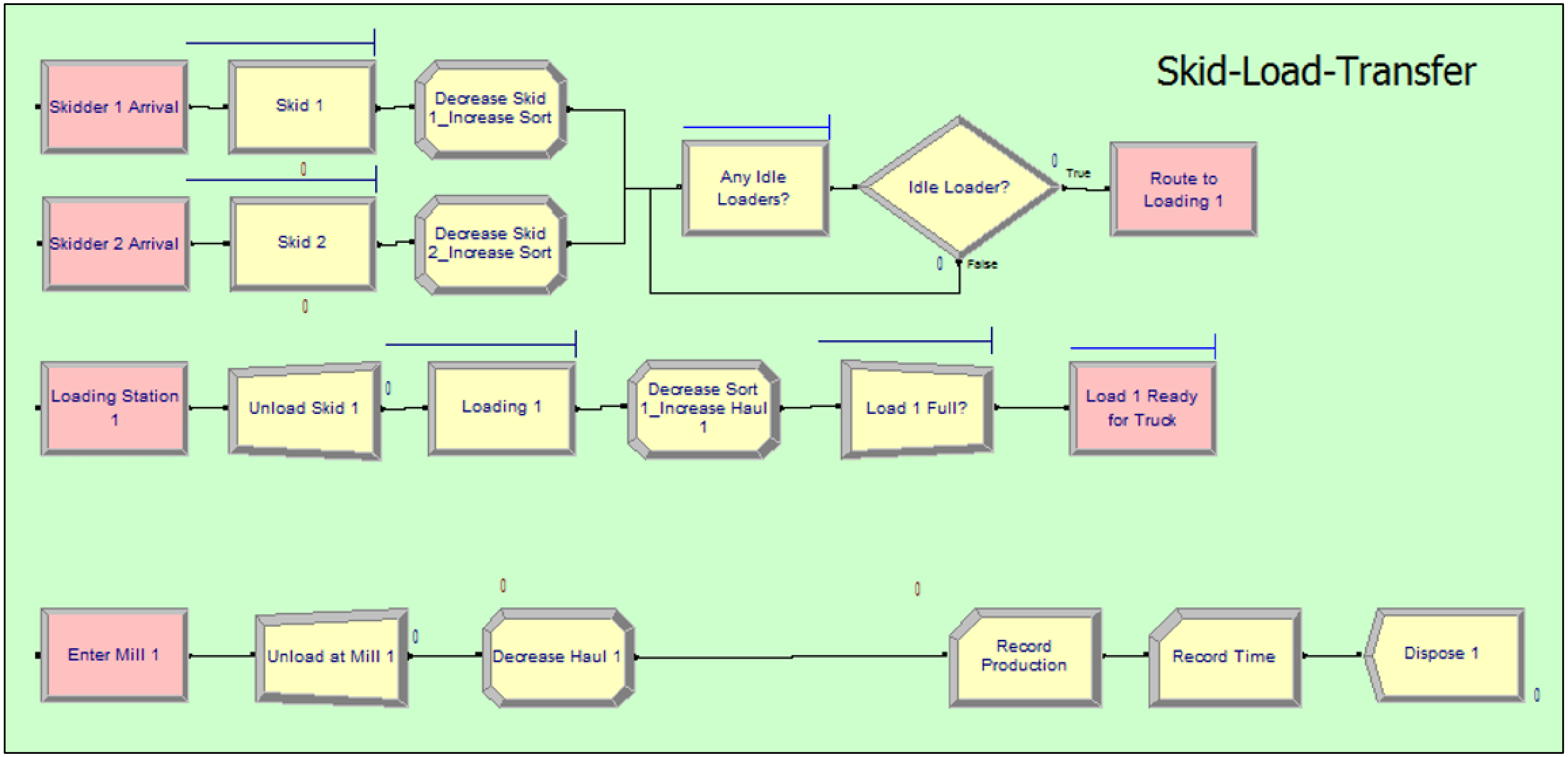

Figure 11: Skid-Load-Transfer Operations Segment.

Skid-Load-Transfer Operations

The skidding, loading, and trucking activities all take place in this segment of the model. Resources that can be utilized during this segment are 2 skidding resources, 1 loading resource, and 6 log truck resources. In the early stages of this segment, skidding resources "arrive" to the skid pile and the batch is seized, processed, and released. The processing time during the skid is exponential with a mean time of 6 minutes for every batch. After the skidding resource releases the entity, the skid pile is decreased and a sort pile is

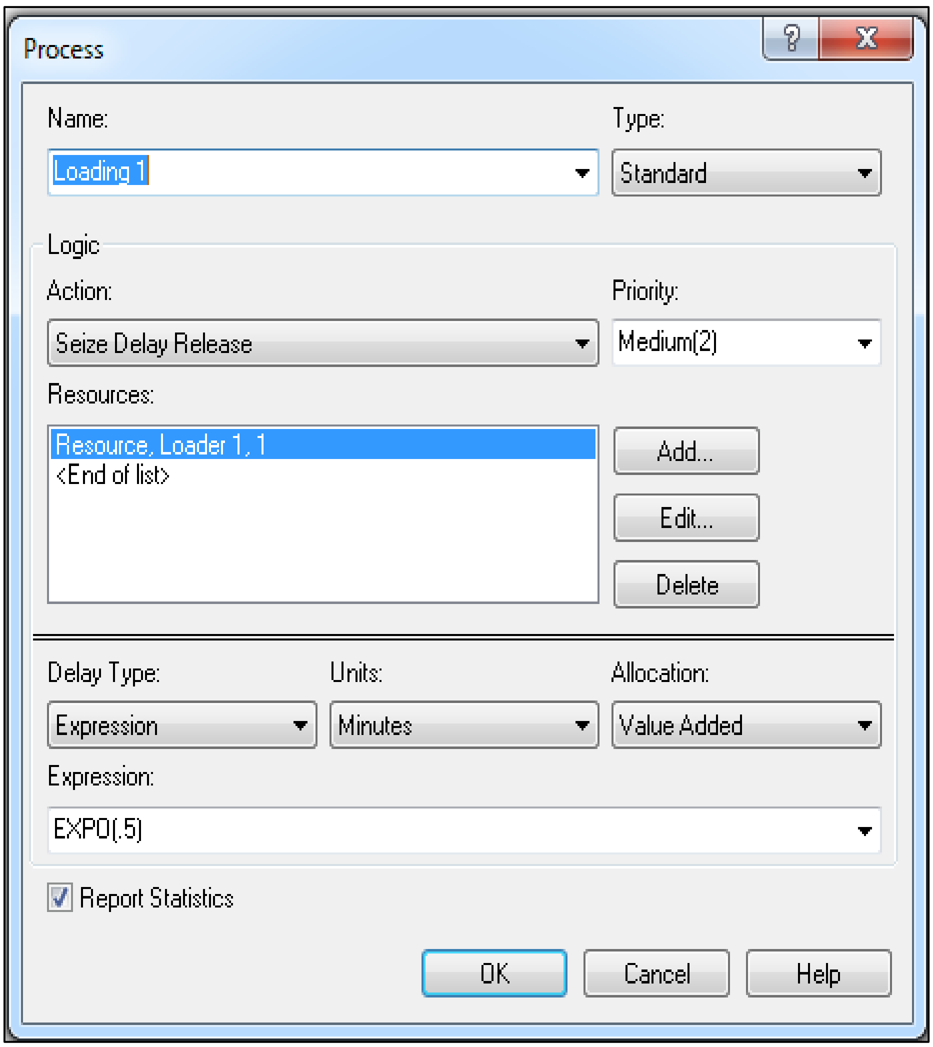

Figure 12: "Process" Module for Loader Resource Productivity.

increased by the batch amount. In the same way the system scans for idle felling and skidding resources, the system again scans to see if the loader is available or unavailable. If the loader is unavailable, the batches are queued until the loader is idle again. Once a loader is scanned as being idle, the batch moves to “Loading Station 1” via the Route module and comes to the “Unload Skid 1” Separate module. Here the batches are separated back into single-ton entities in preparation for the loading process.

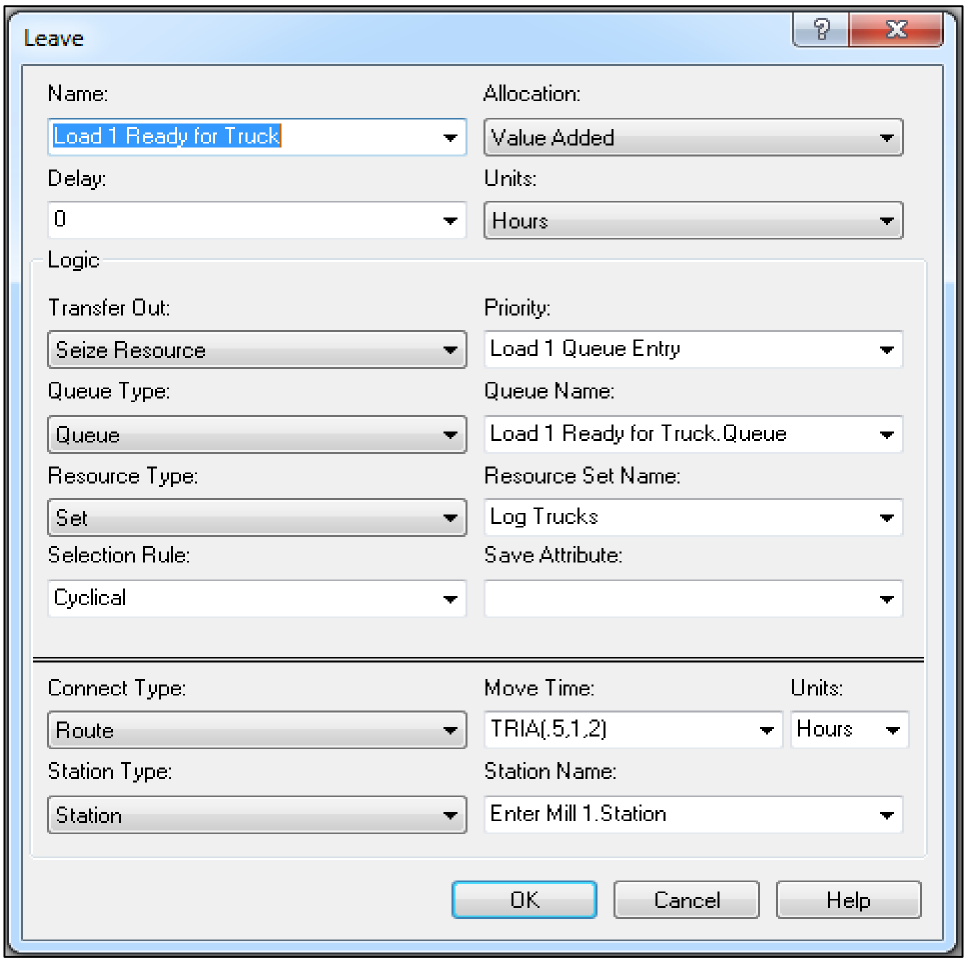

Figure 13: “Leave” Module for Log Truck Resource Times.

Similar to other processes in the simulation, when the entity enters the “Loading 1” Process module it is seized by the available loading resource, delayed by the appropriate process time, and released to continue progressing through the simulation. The processing time for the loader in the simulation is exponential with a mean loading time of 30 seconds. Once the loader resource releases the entity, the sort pile is decreased and the haul load is increased by one ton each. Entities then enter the "Load 1 full?" Batch module where they are grouped into sizes that represent a typical log truck load in North Carolina. Current weight regulations in North Carolina allow for log trucks to haul loads of up to 25 tons. For this reason, entities are batched in sizes of 25.

When the "load" reaches 25 tons (25 entities), a signal is sent to the log truck resource that the batch is full via the "Load 1 Ready for Truck" Leave module. The "load" or batch seizes the first available log truck from the set of 6 log truck resources. Once fully loaded and ready to begin transport, the log trucks follow a triangular distribution of travel times with 30 minutes the minimum time, 1 hour the most likely value, and 2 hours the maximum value.

When the log truck resource "arrives" at the mill the batched load is separated again from one batch size of 25 entities to 25 separate entities. After separation, the haul load is decreased by each entity and a count of each entity is recorded. Because this model is not concerned with entities once they reach their respective mills, each entity leaves the system through the Dispose module and the simulation path is completed.

Simulation Reports and Results

Reports are generated once the simulation is complete and provide information on entities, processes, resources, and other user defined statistics. Entity statistics include value-added and non value-added time in the system, transfer time in system, and overall time spent between start and finish. Arena is also able to report utilization percentages on resources used within the system. This particular measurement is fundamental in analyzing the productivity of a harvesting operation. Cost components can also be tracked and reported as the simulation occurs which could allow future studies to analyze the cost of each harvesting activity and the productivity associated with those costs. Because this is a study of logging production and capacity, entity statistics will play a key role in understanding how processes are defined and resources are utilized in the simulation.

It's important to make the distinction between the denominations used in this model and the denominations in a real-world harvesting operation. Field observations are often made at harvesting sites and are sometimes recorded in terms of a single stem or group of stems. For example, the productivity of a loader is usually measured by how many single stems it

Table 1: Entity Throughput Statistics Report

Replication 1 Start Time: 0.00 Stop Time: 49.00 Time Units: Hours

Entity

Time

VA Time	Average	Half Width	Minimum	Maximum
Tons	0.06364528	0.003168227	0	0.7054

NVA Time	Average	Half Width	Minimum	Maximum
Tons	0	0.000000000	0	0

Wait Time	Average	Half Width	Minimum	Maximum
Tons	0.2753	0.019889372	0	1.6895

Transfer Time	Average	Half Width	Minimum	Maximum
Tons	0.5678	0.036354989	0	1.8786

Other Time	Average	Half Width	Minimum	Maximum
Tons	0	0.000000000	0	0

Total Time	Average	Half Width	Minimum	Maximum
Tons	1.8135	0.080793243	0.7303	3.1353

processes per minute or hour. A skidder can be evaluated in the field by how many stems it can transport in each cycle. However, the denominations used in this study are strictly on a per ton basis.

Table 2: Resource Utilization Statistics Report.

Resource Detail Summary

Usage

	Inst Util	Num Busy	Num Sched	Num Seized	Sched Util
FB 1	0.54	0.54	1.00	1,427.00	0.54
Loader 1	0.23	0.23	1.00	1,422.00	0.23
Skidder 1	0.78	0.78	1.00	359.00	0.78
Skidder 2	0.69	0.69	1.00	354.00	0.69

From the above report, we can see that each entity, or ton, spends about 0.0636 hours (about 3.8 minutes) in value-added activities such as felling, skidding, and loading. Wait times such as queues associated with waiting for an idle resource or waiting for a batch to be filled are on average 0.275 hours or 16.5 minutes. An important measure of productivity is how long each ton spends in the harvesting system. We can see above that each ton spends on average 1.81 hours (108.6 minutes) in the entire system.

Table 3: Auburn Harvest Analyzer Equipment Utilizations.

Function	Utiliz%
Felling	54
Skidding	70
Loading	26
Hauling	90

Crucial to a study of logging productivity are the relative productivities of each unit of equipment. Arena provides instantaneous utilizations for all simulated harvesting machines in their “Resource Detail Summary” report. Capital utilization rates are displayed below and are compared against utilization rates for equipment provided by the Auburn

Harvesting Analyzer (AHA 2007) for a generic harvesting tract. In our simulation, the feller buncher was busy 54 percent of the time, one skidder was busy 78 percent of the time while the second was busy 69 percent of the time, and the loader was busy 23 percent of the time. When looking at the utilization rates in the Auburn Harvest Analyzer model, we see that felling is also utilized 54 percent of the time. This matches our simulation

Table 4: Weekly Entity Production

Key Performance Indicators

System	Average
Total Cost	0
Number Out	2,810

utilization rate for the feller buncher. AHA's utilization rate for the skidding function is 70 percent. The skidding resources used in the simulation are busy on average 73.5 percent of the time, a difference of 3.5 percent. The loading procedure is utilized 26 percent of the time according to AHA's model. In the simulation, the loading resource is busy 23 percent of the time, a difference of 3 percent. These utilization differences are assumed to be trivial and support the processing times programmed into each harvesting operation used in the simulation.

After aligning the utilization rates between the simulation and the Auburn Harvest Analyzer, we can obtain production levels for the simulated system. The simulation was run for two time periods to authenticate short-term and long-term production levels. To define a week in terms of hours worked, we used Hahn's (2015) logging survey respondents in eastern North Carolina who reported an average of 49 hours worked per week. According to the survey, loggers in eastern North Carolina produce 2,960 tons of roundwood per week. After running the simulation for 49 hours, 2,810 tons were produced, a difference of 150 tons per week. In terms of softwood and hardwood production, 2,136 tons of softwood are produced and 674 tons of hardwood are produced.

Table 5: Annual Entity Production (tons)

Key Performance Indicators

System	Average
Total Cost	0
Number Out	147,097

In order to define a year in terms of hours worked, we will use Hahn's logging survey again. Respondents in eastern North Carolina reported working on average 50 weeks out of the year. At 49 hours per week, we can calculate that a typical logging crew works 2,450 hours per year. According to Hahn's (2015) survey which provides average weekly production and average weeks worked during a year, a logging crew in eastern North Carolina produces 147,975 tons per year. When we run the simulation for 2,450 hours, the harvesting model produces an annual total of 147,097 tons, a difference of 878 tons per year. When we categorize production by species, the model produces 111,793 tons of softwood and 35, 304 tons of hardwood on an annual basis.

In constructing and verifying the model, the simulated equipment utilization rates and processing times have been supported using the Auburn Harvest Analyzer. Production levels have been simulated and contrasted against Hahn's (2015) logging questionnaire in eastern North Carolina. Simulation results appear to also be supported by Hahn's findings for weekly and annual wood production. We can say with reasonable confidence that on average harvesting crews in the coastal plains produce about 147,000 tons each year.

Next, a logging capacity dashboard is presented which includes production estimates from the above simulation model. These production levels along with historical timber output reports, harvest distributions, employment metrics for the logging industry, and market forecasts for timber demand growth will be used to analyze and answer our logging capacity question.

CHAPTER 5: Logging Capacity Dashboard

Timber Output in North Carolina Coastal Plains

North Carolina is made up of 3 physiographic regions: Mountains, Piedmont, and Coastal Plain. The coastal plain is further divided into northern and southern coastal plain. The following logging capacity dashboard will assess potential logging production levels in both coastal plains.

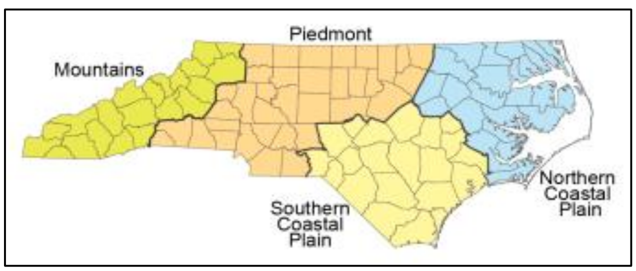

Figure 14: Physiographic Regions of North Carolina.

Actual harvest output levels are available from the U.S. Forest Service Southern Research Station. The most recent timber production data for North Carolina was released in 2011. The 2011 timber product output (TPO) report provides harvest production outputs by county, product, and species group. The counties were narrowed down to display only coastal plain counties and are displayed below. In the northern coastal plain, pine is harvested significantly more in Beaufort county while hardwood was harvested most

Table 6: North Carolina Timber Product Output for the Northern Coastal Plain (cubic feet).

NORTHERN COASTAL PLAIN	**All products**	
County	**Pine**	**Hard**
Beaufort	28,958,000	2,309,000
Bertie	16,946,000	1,361,000
Camden	1,385,000	350,000
Carteret	4,577,000	573,000
Chowan	1,009,000	73,000
Craven	15,056,000	1,592,000
Currituck	2,361,000	751,000
Dare	77,000	0
Edgecombe	4,446,000	1,581,000
Gates	8,940,000	604,000
Halifax	12,631,000	3,722,000
Hertford	4,269,000	738,000
Hyde	5,606,000	234,000
Martin	13,173,000	1,519,000
Nash	3,438,000	1,966,000
Northampton	11,236,000	2,006,000
Pamlico	8,691,000	709,000
Pasquotank	1,625,000	118,000
Perquimans	1,870,000	267,000
Pitt	12,037,000	1,932,000
Tyrrell	1,810,000	35,000
Washington	2,327,000	505,000
Wilson	7,897,000	1,083,000
All counties	**170,365,000**	**24,028,000**

heavily in Halifax county. In the southern coastal plain, pine was harvested the most in Brunswick, Columbus, Jones, and Moore county while hardwood harvested the heaviest in

Table 7: North Carolina Timber Product Output for the Southern Coastal Plain (cubic feet).

SOUTHERN COASTAL PLAIN	All products	
County	**Pine**	**Hard**
Bladen	10,947,000	2,870,000
Brunswick	12,614,000	1,976,000
Columbus	12,874,000	2,515,000
Cumberland	5,166,000	1,327,000
Duplin	6,288,000	2,394,000
Greene	3,780,000	1,002,000
Harnett	2,934,000	1,061,000
Hoke	3,252,000	158,000
Johnston	3,244,000	1,517,000
Jones	12,552,000	961,000
Lee	2,266,000	1,368,000
Lenoir	3,271,000	1,433,000
Moore	12,309,000	2,050,000
New Hanover	441,000	64,000
Onslow	11,149,000	999,000
Pender	9,584,000	2,158,000
Richmond	10,566,000	614,000
Robeson	8,499,000	2,198,000
Sampson	5,492,000	2,427,000
Scotland	3,272,000	237,000
Wayne	2,253,000	788,000
All counties	**142,753,000**	**30,117,000**

Bladen county. This correlates with reports from the Forest Inventory Data Online (FIDO) database for average annual harvests for growing stock timber shown in Figure 15.

Timber output is reported by the U.S. Forest Service in volume (cubic feet) and must be converted to weight (US tons). We can use the Log Rule and Weight Equivalents (TMS 2007) table provided by Timber Mart-South to make this conversion. This allows

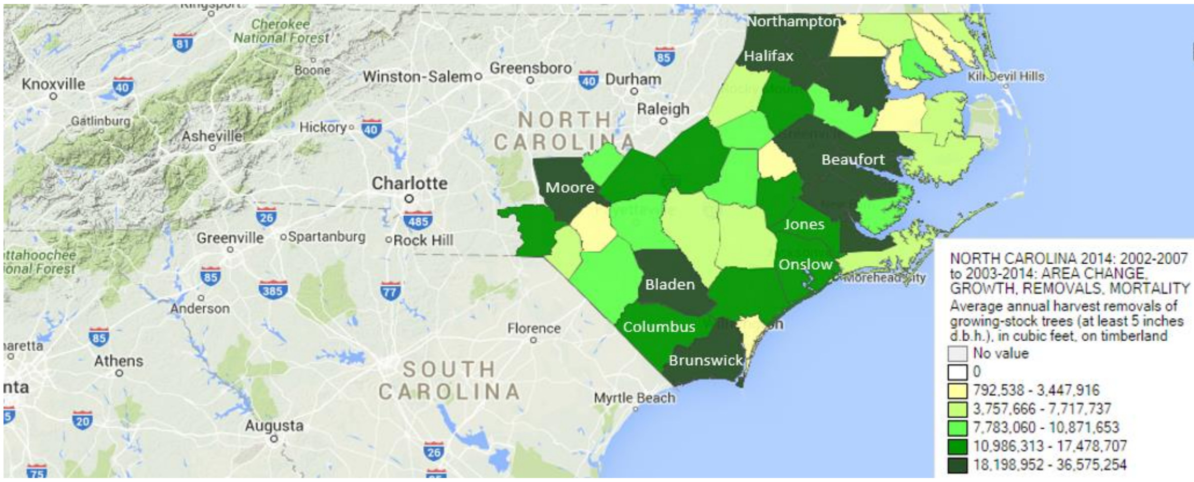

Figure 15: FIDO Average Annual Harvest Levels in the Coastal Plains, 2014 (cubic

This allows conversions to be made between cubic feet and standard cords of solid wood, cubic feet and standard cords of solid wood and bark, cubic feet and cubic meters, and between cubic meters and short tons (2,000 lbs) of wood and bark. For our purposes, harvest levels above will be converted from cubic feet to cubic meters, and again from cubic meters to short tons. According to Timber Mart-South, 35.315 cubic feet is the equivalent of 1 cubic meter. Further, 0.822 cubic meters of southern pine and 0.787 cubic meters of

Table 8: Timber Product Output Weight Equivalents, Coastal Plains total

			COASTAL PLAIN TOTAL OUTPUT							
			**From TPO data & TMS Weight Equivalents							
	in Cubic Feet									
	All products		Sawlogs		Veneer logs		Pulpwood		Other industrial	
	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard
All counties	313,118,000	54,145,000	125,012,000	14,433,000	27,115,000	5,810,000	146,942,000	32,762,000	14,049,000	1,140,000
	Cubic Meters (m^3)									
	All products		Sawlogs		Veneer logs		Pulpwood		Other industrial	
	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard
All counties	8,866,431	1,533,201	3,539,912	408,693	767,804	164,519	4,160,895	927,708	397,820	32,281
	Short Tons (2000 lbs)									
	All products		Sawlogs		Veneer logs		Pulpwood		Other industrial	
	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard	Pine	Hard
All counties	10,786,412	2,241,439	4,306,463	582,836	934,068	231,580	5,061,916	1,382,549	483,965	44,475
Other industrial: Includes composite panels, poles, posts, mulch, log homes, industrial fuelwood, and all other industrial products.										
Total Pine & Hard (tons)	13,027,851									

mixed hardwood are equivalent to 1 short ton. Below are the weight equivalents for the harvest volumes reported by the 2011 TPO report. From the table we can see that 313.1 million cubic feet of southern pine is the equivalent to 8.86 million cubic meters and 10.78 short tons. 54.1 million cubic feet of mixed hardwood is equivalent to 1.53 million cubic meters and 2.24 million short tons. Total timber output in both coastal plain regions sums to 13,027,851 pine and hardwood tons. When we compare the species distribution of harvested wood between 2011 TPO levels (after conversion to tons) and what is reported by FIDO, we find that about 83 percent of all harvests were pine according to the TPO report and about 76 percent of harvests were pine according to FIDO.

Logging Employment and Crew Size

The forest products industry is divided into four major sectors by the U.S. Department of Commerce. The four sectors are Forestry & Logging, Wood Product Manufacturing, Paper Manufacturing, and Furniture & Related Product Manufacturing. According to Mitchell (2013), the Forestry & Logging sector accounted for 2,900 jobs in North Carolina's forest products industry. According to Eddie Reese of North Carolina's Forestry Association, there are 1491 members registered as NC ProLoggers. ProLoggers can include both loggers and consulting foresters.

To find employment levels specifically for loggers North Carolina's forest products industry, we can retrieve quarterly employment tables from the Bureau of Labor Service. In the fourth quarter of 2014, employment in the northern coastal plains' logging industry (NAICS 113310) totaled to 380, up from 236 in 2012. Conversely, logging employment in the southern coastal plain (NAICS 113310) was 344 during the fourth quarter of 2014, down from 372 in the first quarter of 2012. Labor force totals for the logging industry in the coastal plains equal 724, up from 608 in the first quarter of 2012. We can compare BLS logging employment levels with similar levels reported by Mitchell (2013). In 2013, Mitchell reports that the forestry & logging sector accounts for 2,900 jobs in North Carolina, while the BLS reports 2,587 logging employees for the same year. It is unknown whether Mitchell's estimate accounts for forestry consultants, which could explain the slight difference in employment levels. According to Hodges et al. (2011), BLS employment levels for the logging industry can be underestimated due to the number of independent contractors that are not reported.

Logging crew compositions vary among geographic regions. To gain an estimate of "in-woods" crew sizes, we have consulted previous studies and logging surveys. According to Hahn's (2015) logging survey, the average number of total employees per logging firm in North Carolina is 16 with a minimum of 2 and a maximum of 30. Baker and Greene's (2007) study of changes in Georgia's logging force between 1987 and 2007 found an average "in-woods" crew size of 6.8 employees. Barrett et al. (2010) analyzed logging firm characteristics that harvested biomass in the piedmont of Virginia and reported an average crew size of 3.3. Baker et al. (2015) utilized mailed surveys and face-to-face interviews across the US South and found average crew sizes to be 4 and 4.2 employees via surveys and face-to-face interviews respectively. Finally, Barrett et al. (2012) surveyed logging operations in Virginia's coastal plain and found average crew sizes to be 4.2 employees. Because our study is exploring logging capacity in the coastal plain region, we will use Barrett et al.'s (2012) average crew size of 4.2 employees.

Logging Capacity and Labor Requirements

Our simulation provides estimated annual production levels of a typical crew operating in the coastal plains of North Carolina. Using the latest available timber product output data for both coastal plain regions, we can approximate how many logging crews it would take to produce TPO harvest levels for eastern North Carolina.

Coastal plain timber output levels in 2011 total to 13,027,851 pine and hardwood tons, after being converted from volume to weight. If we use our simulation results of 147,097 tons to represent annual production levels of a typical logging crew in eastern North Carolina, then in 2011 it would have taken approximately 89 crews to supply TPO levels of wood. At 4.2 employees per crew, we estimate that 372 logging employees supplied the total production output for the coastal plains in 2011. If we use Barrett et al.'s (2010) estimation of 3.3 "in-woods" employees per crew, we find that 292 workers supplied 2011 levels of timber output. Using Baker et al.'s (2007) larger crew size of 6.8, "in-woods" logging employment increases to 602 workers.

We further estimate how many loggers and logging crews will be necessary to meet new demand growth for timber as the market recovers from its recessionary lows. European energy regulations have also spurred the demand for wood pellet production, resulting in pellet production facilities beginning operations in North Carolina. This new and sustained growth for wood fiber will also demand additional capacity to harvest timber.

The Southern Forest Futures Project (Wear et al. 2015) analyzes timber markets and trends in timber supply and demand. Based on their research of supply and demand relationships, they forecast future timber demand growth over a 40-year period. Under one demand scenario, the project assesses a revival of demand growth in the US South. This "Expanding Demand" scenario forecasts an expansion of timber demand at a rate of 10 percent per decade. We approximate that decadal change by assuming increased timber output of 1 percent per year beginning in 2011.

Since 2011, timber demand growth has been partially attributed to a recovery in the housing market and a return of demand for construction-grade lumber. Growth in timber demand is also due to European regulations for more environmentally-friendly energy production. The US South has seen an increase in pellet production capacity to meet this demand. In late 2011, Enviva opened a wood pellet mill in Ahoskie, NC with an annual capacity of 407, 855 short tons (370,000 metric tons). In May 2013, they began operating in Northampton, NC with a 551,156 ton capacity pellet mill (500,000 metric tons). In

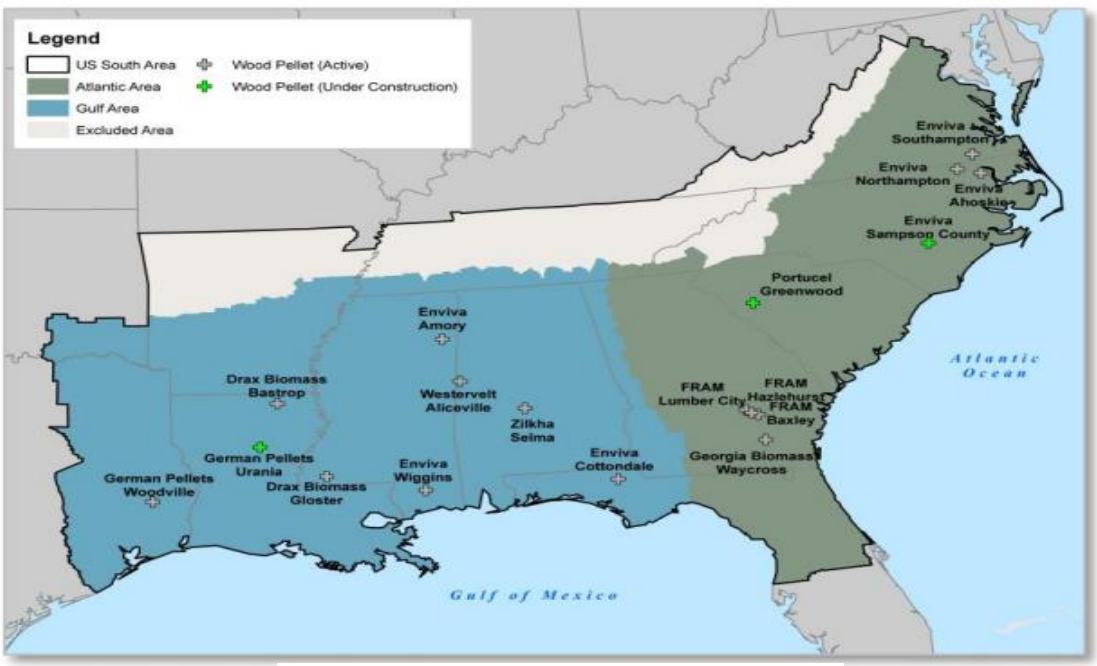

Figure 16: Wood Pellet Facilities in the US

spring of 2016, Enviva plans to begin pellet operations in Sampson, NC with another 551,156 ton (500,000 metric tons) capacity pellet mill. This demand for wood fiber necessitates the need for additional harvesting capacity. This timber demand is added to our estimate of timber output increases. Table 9 shows our projected average growth in timber output based on Southern Forest Futures Project demand forecasts as well as the addition of wood pellet plants in North Carolina since 2011. Three linear growth scenarios

Table 9: Timber Product Output Growth based on Demand Forecasts.

	Growth rate (avg)			Additional Crews needed (Arena)			Additional Loggers needed (4.2 per crew)			
	+1.2M/yr	+1.289M/yr	+1.378M/yr	+1.2M/yr	+1.289M/yr	+1.378M/yr	+1.2M/yr	+1.289M/yr	+1.378M/yr	
2011 TPO	13,027,851	13,027,851	13,027,851	-	-	-	-	-	-	**Enviva Plant-Ahoskie, NC**
2012	14,232,135	14,317,334	14,405,924	8.19	8.77	9.37	34	37	39	
2013	15,436,419	15,606,816	15,783,996	8.19	8.77	9.37	34	37	39	**Enviva Plant-Northampton, NC**
2014	16,640,704	16,896,299	17,162,069	8.19	8.77	9.37	34	37	39	
2015	17,844,988	18,185,781	18,540,141	8.19	8.77	9.37	34	37	39	
2016	19,049,272	19,475,264	19,918,214	8.19	8.77	9.37	34	37	39	**New Enviva Plant-Sampson, NC**
2017	20,253,556	20,764,746	21,296,286	8.19	8.77	9.37	34	37	39	
2018	21,457,840	22,054,229	22,674,359	8.19	8.77	9.37	34	37	39	
2019	22,662,124	23,343,711	24,052,432	8.19	8.77	9.37	34	37	39	
2020	23,866,408	24,633,193	25,430,504	8.19	8.77	9.37	34	37	39	
2021	25,070,692	25,922,676	26,808,577	8.19	8.77	9.37	34	37	39	

were used to analyze the sensitivity of the logging workforce to different rates of growth. The first scenario represented an additional 1.2 million ton growth in timber output, or 0.5 percent. In scenario 2, timber output increased by 1.289 million tons annually, or 1.0 percent. The third scenario increased at 1.5 percent per year, or 1.378 million additional tons annually.

Under a 0.5 percent growth rate in timber output, an average of 8.2 additional logging crews or 34 logging employees will be needed each year to produce this level of output. At a 1.0 percent growth rate, an average of 8.77 additional crews per or 37 loggers will be needed each year to meet growth in production. Under a 1.5 percent growth rate in timber production, an additional 9.37 crews or 39 logging employees on average will be required each year over the 10 year period. Finally, to provide a "loggers required per million tons" metric, we estimate that an additional 29 "in-woods" employees (6.8 crews) are required each year to produce an additional 1 million green tons.

CHAPTER 6: Discussion

Simulation utilization rates for harvesting machinery were compared and supported by utilization rates taken from the Auburn Harvest Analyzer. Annual production levels produced by the simulation were further supported by Hahn's (2015) survey of logging crew production in North Carolina. Using production levels of 147,097 tons produced by the simulation and utilizing an average crew size of 4.2 employees, we calculated that the logging force in both coastal plains amounted to 372 logging employees.

According to the BLS, 593 employees were listed as employed in the logging industry (NAICS 113310) in the first quarter of 2012. The BLS defines employment in their quarterly census as "the number of workers who worked during, or received pay for, the pay period that included the 12th day of the month" (BLS 2014). Employment includes "most corporate officials, executives, supervisory personnel, professionals, clerical workers, wage earners, piece-workers, and part-time workers" (BLS 2014). This definition indicates that employment reported by the BLS in the logging industry includes all logging production workers as well as administrative employees.

In order to estimate how many total logging employees are "in-woods" production workers, we will consult a previous logging survey. Baker et al. (2015) collected 23 face-to-face interviews from contractors across 6 states in the US South. Contractors were asked to disclose how many total employees worked in their firm as well as how many of those employees worked in the woods. The average company had 18 employees, 10 of which worked in the woods (Baker et al. 2015). For this study we will assume that 55 percent (or

10 out of every 18) of employees in the logging industry work in the woods. Using this measure we estimate that 329 out of the 593 logging employees are "in-woods" workers. Comparing this figure to the 372 employees estimated by our simulation study, we find a difference of 43 employees.

Production per employee (in-woods) hour for the simulation comes out to 14.3 tons/hour where production per employee (in-woods) hour using BLS employment levels in 2012 becomes 16.2 tons/hour, a difference of 1.9 tons/hour. From this we can conclude that the simulation could be a fair representation of logging crew productivity in the coastal plain. When comparing production results from this simulation with previous logging survey studies, we find this study to be within an acceptable range of crew production levels. Barrett et al.'s (2010) study found that the most productive crews in the Virginia Piedmont harvested as much as much as 2500 tons per week. Baker et al. (2015) interviewed 22 logging firms across the South and reported average weekly production among those firms to be 4,197 tons. In Hahn's (2015) survey, the average logging firm produced 2,960 tons per week. We acknowledge that surveys are subjective by nature but prove useful in this study as a verification of feasibility for simulated results. We also know that the simulation did not account for every inefficiency associated with a typical harvesting operation. Inefficiencies such as mechanical breakdowns and year-to-year weather patterns can heavily impact crew productivity but are difficult to model.

Equipment compositions in logging operations can vary among small and large firms. The composition in this study used one feller-buncher, 2 skidders, and 1 loader. This equipment mix may not be suitable for all logging firms as machine-line balancing principles may dictate other combinations of equipment. Future research could analyze the sensitivity of timber output to different equipment compositions and its impact on logging production capacity. Included in the appendix are five supply chain networks for the forest products supply chain. Each network maps different levels of vertical integration and wood flow pathways. A focus for future studies could also be to estimate relative production capacity for each wood supply system and isolate their respective bottlenecks in wood flow.

Logging costs are also important to analyze when assessing the health of logging firms. Adding a cost component for each logging activity to the simulation could expand its utility for decision makers. The Auburn Harvest Analyzer is a useful tool for measuring logging costs and machine productivity but is strictly deterministic in its functionality and does not account for variability that occurs during harvesting. Because randomness is inherent in stochastic models such as simulation, this study could provide a more accurate measure of harvest system costs and production.

Concerns have previously been raised about the sustainability of the forest products supply chain and the ability for loggers to supply adequate wood levels. These concerns range from aging equipment, an aging workforce, lack of new entrants to the logging sector, and a lack of trust in business relationships between loggers and mills. However, manufacturing mills have never run out of wood. Incentives offered by mills or government agencies to logging firms could prove useful in attracting loggers back to the workforce.

CHAPTER 7: Thesis Conclusions

The housing market collapse of 2008 led to 50-year lows for housing starts in the US. The consequent effects to the lumber and plywood industry led to depleted demand for timber in the US South. The forestry & logging, wood manufacturing, and paper manufacturing sectors lost 322,805 jobs between 2005 and 2009 (Woodall et al. 2011). Only logging firms that were healthy enough were able to survive the diminished conditions. Growth in the logging sector has also been hampered by an aging workforce and a paucity in recruitment into the forest products industry (Greene et al. 2013). Other recessionary effects include restrictive standards for obtaining credit on capital investments. Taylor (2012) notes that financial institutions are requiring higher down payments on equipment as high as 20 to 30 percent. Taylor (2012) also states that during a time where profit margins have been trimmed, financial institutions are also requiring profit/loss statements from firms for major loans regardless of past credit history.

However, market conditions have improved somewhat-housing starts have more than doubled since their 2009 lows signaling a return to business-as-usual for lumber and plywood markets. The surge in wood pellet demand in Europe has provided an avenue of growth for pellet production firms such as Enviva Biomass and a new source of wood fiber demand. For logging firms to supply adequate levels of wood, they must increase either labor inputs or capital inputs. We do not expect major increases in efficiency because logging crews have reached near-full mechanization in their operations.

This study explored the production capacity of wood suppliers in the coastal plain regions of North Carolina in response to a recovering timber demand market. In order to determine if the logging industry is prepared for a market rebound, simulation software was utilized to estimate the annual timber production of a logging crew operating in the northern and southern coastal plain regions of North Carolina. Based on the simulation results and historical timber production data for the coastal regions, we were able to approximate labor demands in the industry based on expert forecasts on timber demand in southern forests.

Using timber demand forecasts from the Southern Forest Futures Project as well as additional fiber demand from wood pellet mills in the state, 3 labor demand scenarios were developed to anticipate increases in timber demand. Depending on the optimism of each scenario, this study estimates that average annual increases in labor requirements range from 8.19 crews (34 employees) to 9.37 crews (39 employees) per year. A useful metric for industry professionals is "loggers needed per additional million tons." Using the same methods, we estimate that an added 29 "in-woods" employees per year are required to produce an additional 1 million green tons. The results appear to be a fair representation of harvesting crews in the coastal plains of North Carolina. The simulated production levels are within an acceptable range of other production capacity studies in the US South. Demand for wood fiber in the U.S. South is recovering towards pre-recession levels. But additional labor is likely to be required if this additional demand is expected to be met in North Carolina.

Finally, areas of future research could include (1) analyzing the effect of vertical integration in the supply chain on timber output based on networks provided in the appendix, (2) estimating the sensitivity of production capacity to different equipment compositions using simulation and (3) adding a cost component to the simulation used in this study to provide more accurate analysis for logging firm decision makers.

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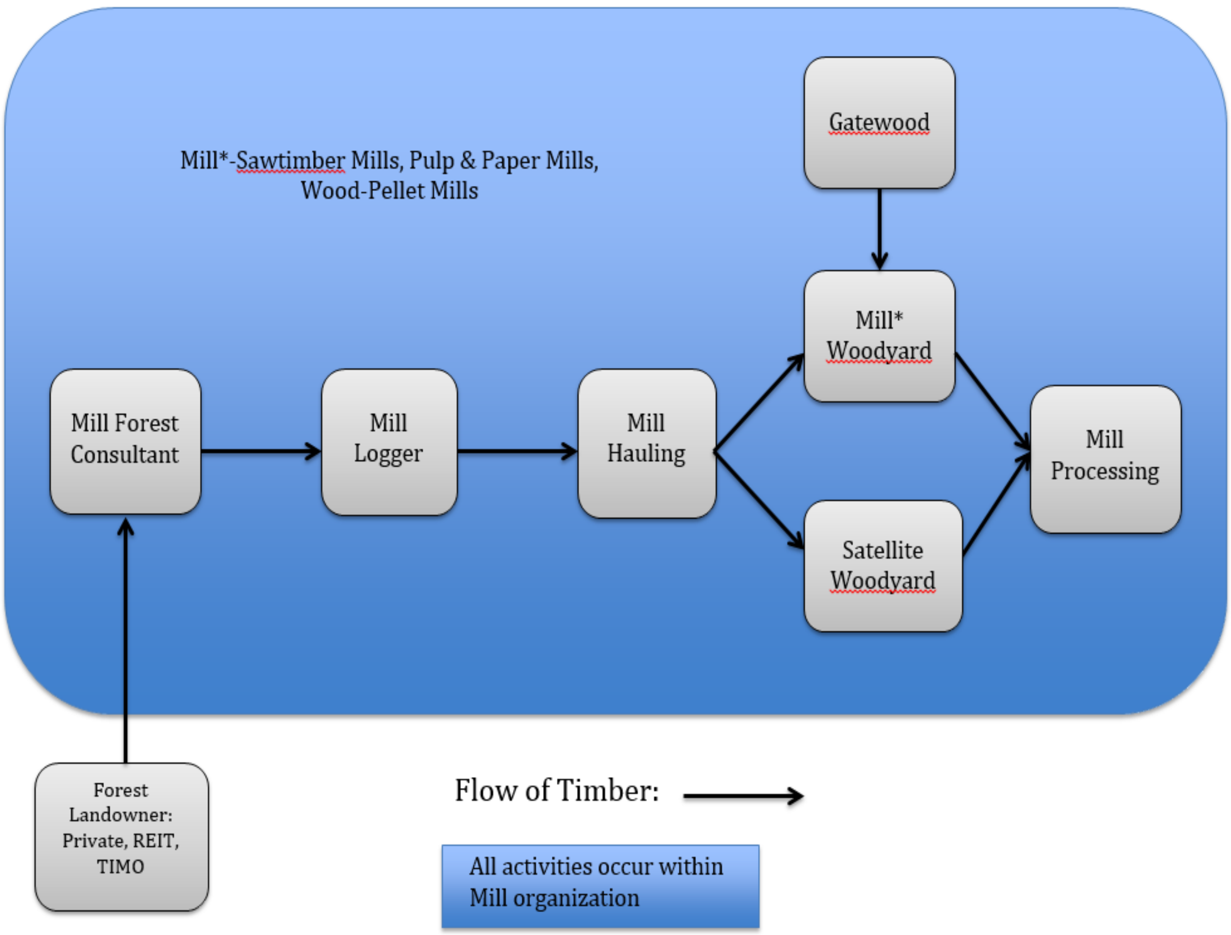
Appendices

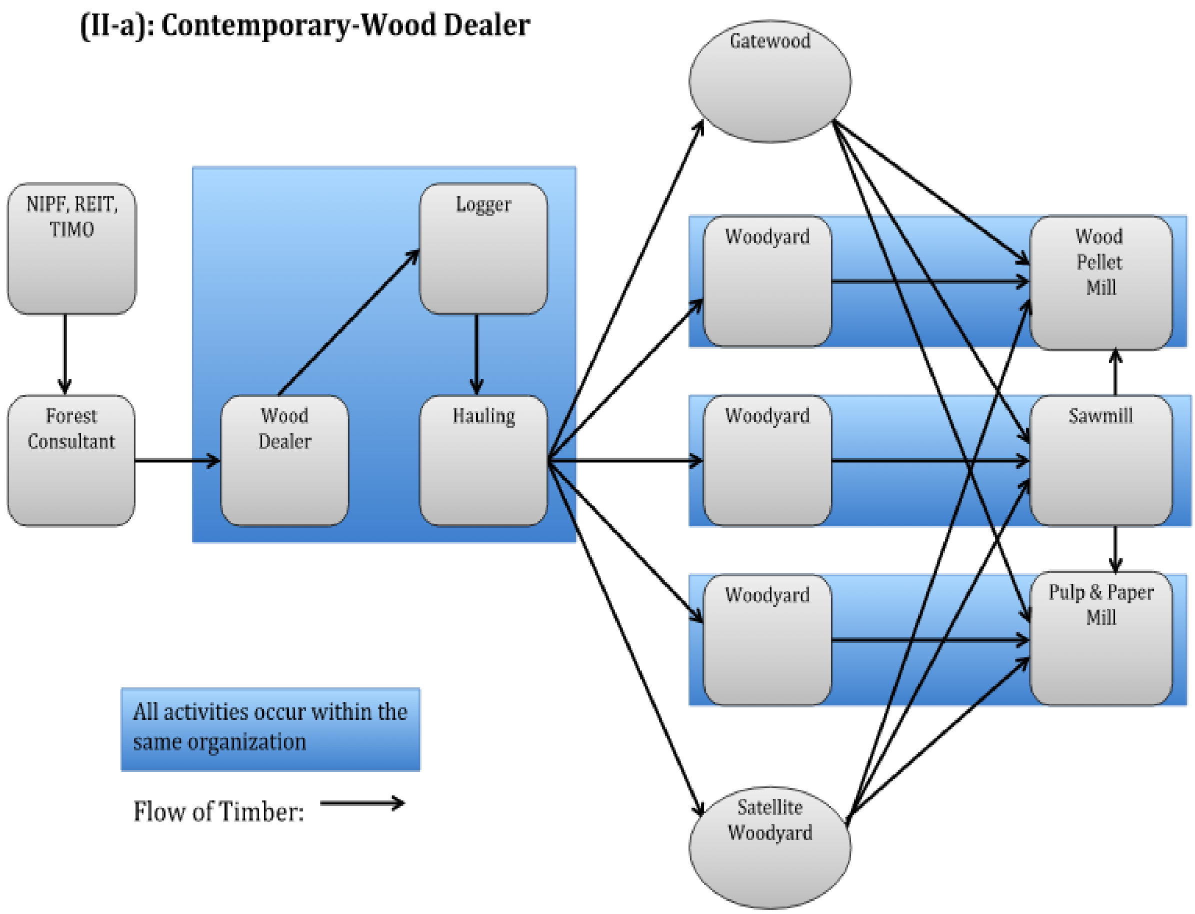
Appendix A: Supply Chain Network Adaptations

Several types of procurement systems exist. We will try to model and analyze the key variations ranging from direct mill purchases to complete reliance on a dealer network.

(I): Mill-Full Procurement



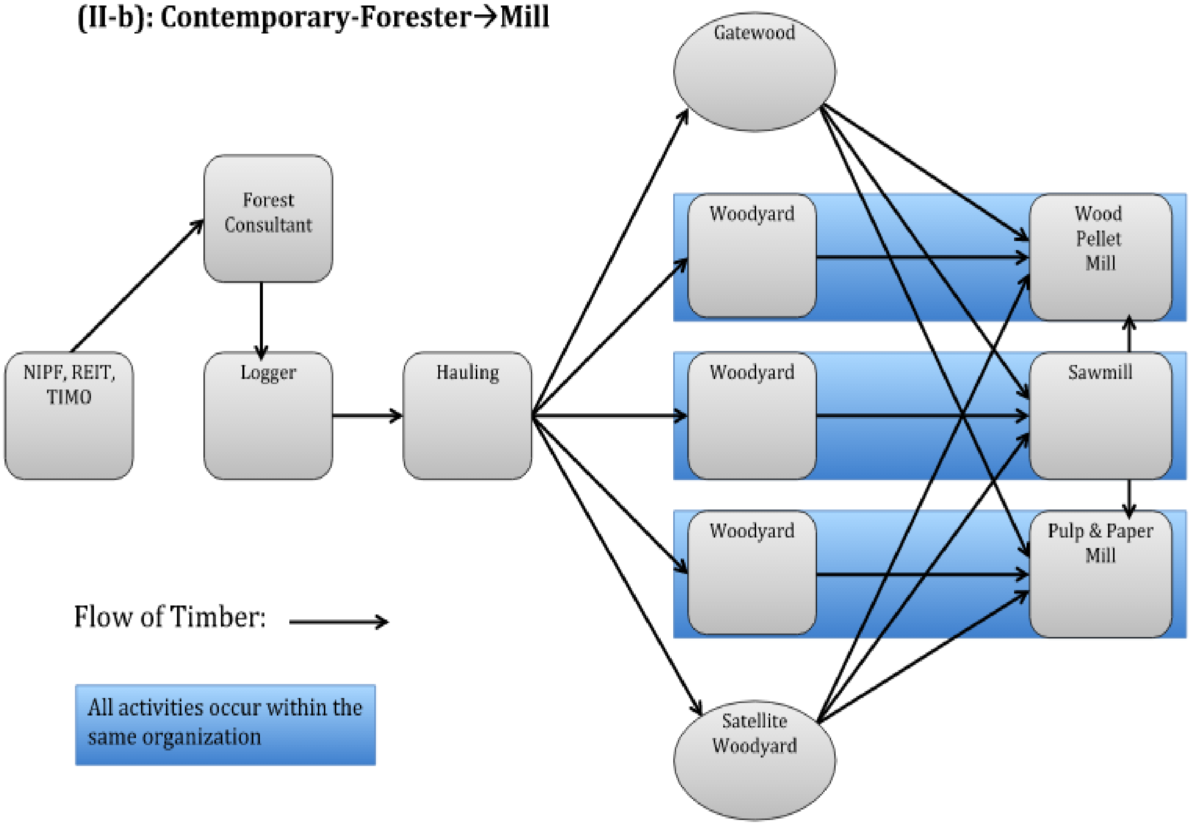
In one version of the forest products supply chain, the mill is fully integrated across all functions and procures wood fiber independent of external contractors. Supply chain integration provides numerous benefits as described by Akkerman et al. (1999) such as cooperation, collaboration, information sharing, trust and shared technology. In this case, the mill employs its own staff foresters and harvesting crews, and operates its own harvesting and hauling equipment. Staff foresters purchase timber directly from landowners. Timber is hauled to a woodyard at the mill or to an intermediate satellite woodyard.



The wood dealer adaptation of the supply chain is well represented in the forest products industry and is partially integrated. The wood dealer is best described as a “middle man” between consuming mills and the landowner. In this system, a landowner initiates a sale or hires a forest consultant to initiate a timber sale per usual. When the sale is advertised, a wood dealer bids on the sale (as opposed to mill procurement personnel bidding on sales in the Mill-Full Procurement adaptation). Dealers also contact landowners directly and make negotiated sale purchases.

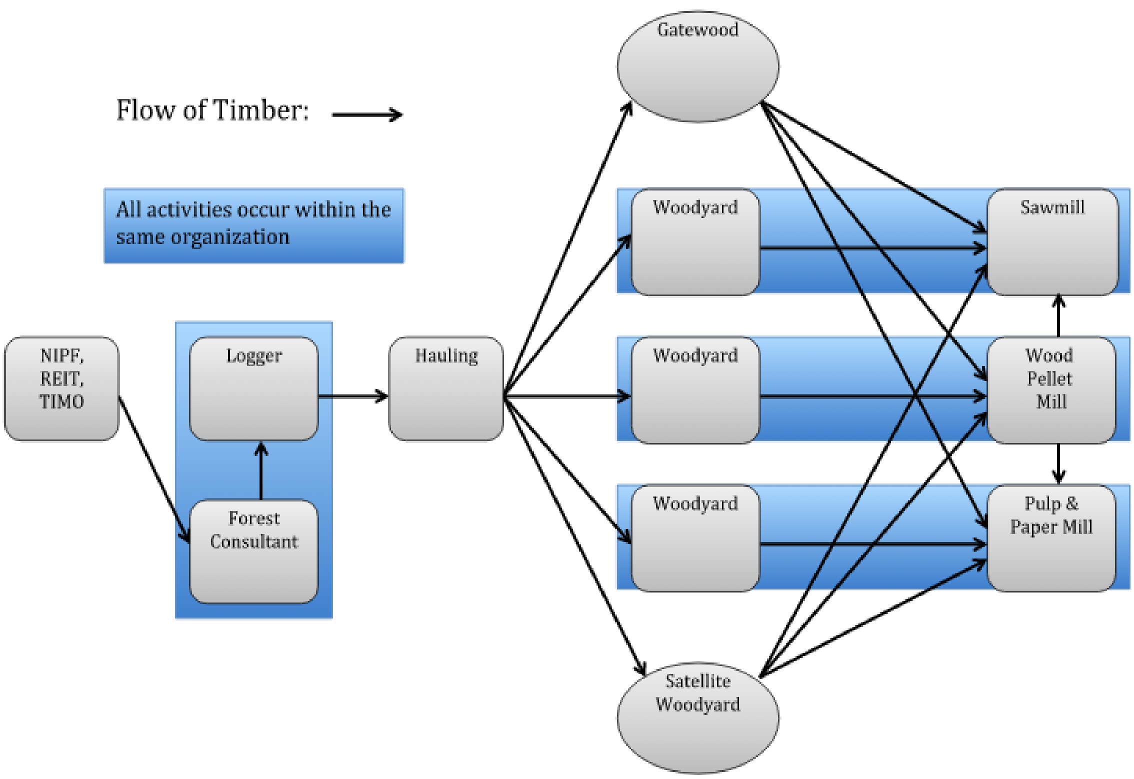
Wood dealers then used contracted logging crews and transportation crews to harvest and haul timber to consumer mills to fulfill their timber supply agreements. Timber is hauled to a woodyard at the mill, to an intermediate satellite woodyard, or hauled to the mill as gatewood. Timber volumes to be hauled to mills as well as delivered prices to the mill are predetermined in timber supply agreements between suppliers and consuming mills.

(II-b): Contemporary-Forester→Mill



The "Forester to Mill" supply chain is the most disintegrated of the mapped supply chains yet it is still used. Each function of the supply chain is performed by a separate entity. The forester is hired by the landowner who values the timber to be sold and initiates the timber sale. Harvesting crews bid on the sale and when the sale is agreed, the winning bidder begins harvesting activities. Once the timber is harvested and initially sorted at the landing, it is loaded and hauled. In this case, the transportation is contracted out by the harvesting crew. Timber is hauled to a woodyard at the mill, to an intermediate satellite woodyard, or hauled to the mill as gatewood. Timber volumes to be hauled to mills as well as delivered prices to the mill are predetermined in timber supply agreements between suppliers and consuming mills.

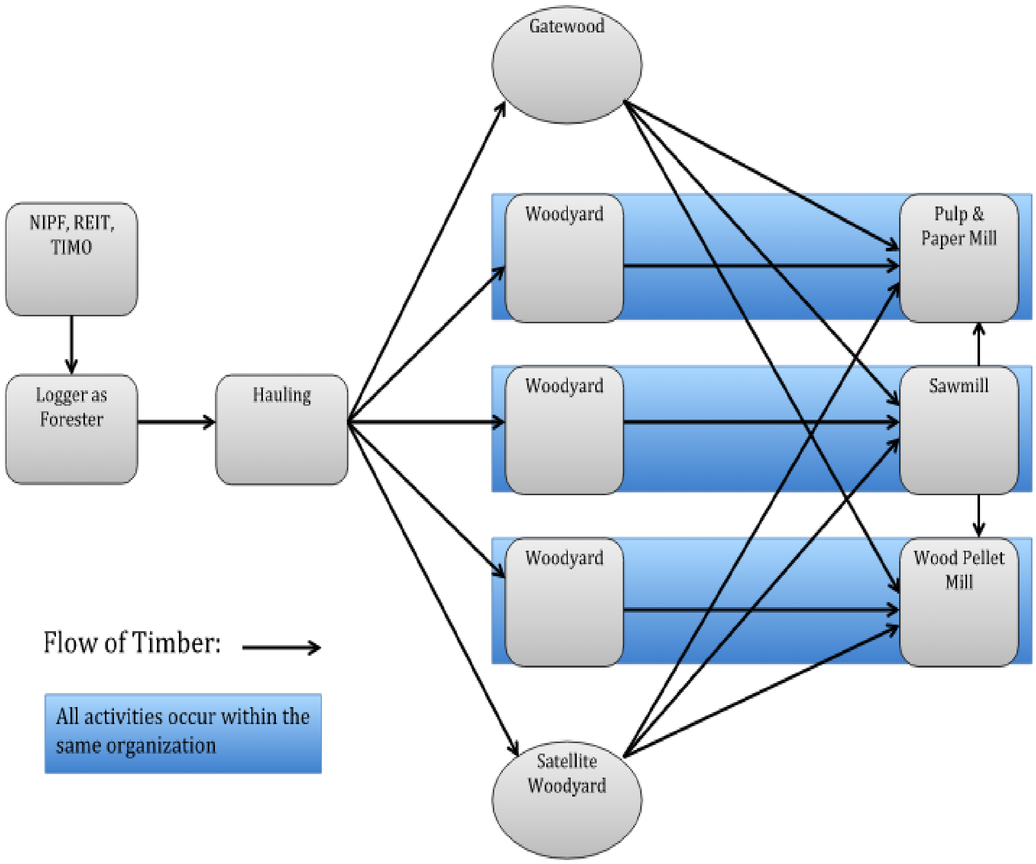
(III-a): Traditional-Logger/Forester Partnership



A modified version of the supply chain portrays a partnership between harvesting firms and forest consultants that is traditionally seen in smaller firms and is partially integrated.

Per usual, the forester is hired by a landowner and values the merchantable timber to be sold. In this case, the forester is partnered pre-contract with a specific harvesting firm who will perform harvesting activities. This supply chain adaptation provides added security for harvesting firms that may experience possible insecurity in other networks. Once the timber is harvested and initially sorted at the landing, it is loaded and hauled. Hauling activities are contracted to a transportation firm who hauls the timber to a woodyard at the mill, to an intermediate satellite woodyard, or to the mill as gatewood. Timber volumes to be hauled to mills as well as delivered prices to the mill are predetermined in timber supply agreements between suppliers and consuming mills.

(III-b)-Traditional: Logger as Forester



The last supply chain network is similar to the Logger-Forester partnership in that the consulting and harvesting functions are integrated. Whereas before the forester and harvesting firm were partnered, here the harvesting firm does not partner with another entity but performs the consulting duties internally. The harvesting firm therefore prepares a sale estimate of the merchantable timber to be sold and begins harvesting once the estimate is completed. Once the timber is harvested and initially sorted at the landing, it is loaded and hauled. Hauling activities are contracted to a transportation firm who hauls the timber to a woodyard at the mill, to an intermediate satellite woodyard, or to the mill as gatewood. Timber volumes to be hauled to mills as well as delivered prices to the mill are predetermined in timber supply agreements between suppliers and consuming mills.