Improving efficiency in logistics operations of the wood fiber supply chain

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ABSTRACT

There is a gap in the research regarding applications of Lean tools in the wood fiber supply chain. A Value Stream Map (VSM) tool that focused on identifying Lean waste in logistic operations was developed and applied to three case study firms: a paper mill, a sawmill, and a logger. Using the VSM tool an absence of structured methods to select and assess suppliers was found, which promotes a fluctuating environment for suppliers. Therefore, a tool that implements a hierarchy system to categorize suppliers was developed, verified and validated.

Through the use of the VSM implementation the author found a lack of information sharing between supply chain stakeholders, which causes a reactive environment for the industry. Improvements in wood flow planning, tract allocation, truck scheduling, and communication were projected as a future state of the system. The annual potential savings by implementing the projected improvements in the total cost were as follows for the paper mill, the sawmill, and the logger respectively: $306,232, $312,085, $756,504.

As a result of the findings obtained through the VSMs, a supplier selection model was designed. The tool was implemented into software for the wood industry. The tool was then verified and validated. The verification process consisted of comparing the output through previously known results and was performed through seven interviews with different stakeholders. The appropriate application of the supplier selection tool improves the way in which companies in the wood industry select and assess their suppliers and guarantee that the best alternatives are selected.

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PUBLIC ABSTRACT

In the wood fiber supply chain, integration between different parties within a supply chain has proven to be a difficult task. An innovative lean-logistics tool value-streamed map (VSM) was developed to evaluate the current and future state of a supply chain Once the tool was developed it was used to map the wood fiber supply chain, determine and measure key performance metrics, calculate the cost of logistics operations, and identify potential sources of waste.

Three case studies representing common wood fiber supply chains were conducted to develop three current VSMs for selected value streams. The lack of communication between supply chain partners was determined to be the most significant source of waste in all three cases. Lack of communication could lead to idle equipment, unnecessary waiting times, excessive inventories, overproduction, and excessive transportation and movement.

As a result of the findings obtained through the VSMs, which revealed the absence of structured methods to select and assess suppliers, a supplier selection model was designed. The tool was implemented into software for the wood industry. The tool was then verified and validated. The verification process consisted of comparing the output through previously known results and was performed through seven interviews with different stakeholders.

The appropriate application of the supplier selection tool improves the way in which companies in the wood industry select and assess their suppliers and guarantee that the best alternatives are selected, thus increasing the chance of a successful relationship and increasing the value that the company gets from its supplier base.

DEDICATION

I dedicate this thesis to my mother Hannia Fallas Valverde, for all her unconditional love,

support, and sacrifice.

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1. Introduction

1.1 Overview

The U.S forest products market has been emerging from a recession. The nature of domestic and international markets has changed. Currently the nature of domestic and international markets is becoming more diverse and interconnected than ever. Market opportunities for U.S forest products have expanded for traditional and emerging products, but traditional forest products have increased competition from alternatives to wood-base materials (Goergen, Harding, Owen, Rey, & Scarlett, 2013). "Domestic wood products manufacturers have lost market share to low-cost producers, overseas, with some sectors, such as household furniture and flooring, particularly affected" (Espinoza & Smith, 2015).

Recent market dynamics such as the economic recession of 2008, the decline in the housing market, and market share loss to steel, plastic, and concrete have adversely affected the forest products industry. The paper industry has also faced challenges. The increase in electronic communications has caused a reduction in demand for fiber. Between 2005 and 2009 the U.S hardwood and softwood lumber shipments have dropped by more than 40%. The impact on the forest products industry has repercussions in the gross domestic product (GDP); for example, in North America the total contribution of roundwood, wood processing, pulp and paper industries to the GDP was of 1.4%, and by 2006 it had decreased to 1% (see Table 1). Therefore, the health of the forest products industry has repercussions on the health of the U.S economy. During December of 2007 to June of 2009, job losses in the forest products sector are estimated to be in the hundreds of thousands, with harsh effects on small business and rural communities (Espinoza & Smith, 2015).

Table 1. Gross Value Added in Forestry (Shahriari, Hessami, Jadidi, & Lehoux, 2015)
(FAO Corp, 2012)

Region	Roundwood US$ billion		Wood Processing US$ billion		Pulp and Paper US$ billion		Total US$ billion		Contribution to GDP (%)	
	1990	2006	1990	2006	1996	2006	1996	2006	1996	2006
Africa	6	9	2	2	3	3	11	14	1.7	1.3
Asia and the Pacific	29	33	21	30	40	56	90	119	1.4	1.0
Europe	27	25	57	57	74	60	159	142	1.4	1.0
Latin America and the Caribbean	13	21	6	7	11	12	30	40	2.0	1.9
North America	21	27	35	53	73	67	129	147	1.4	1.0
Western and Central Asia	2	2	1	1	2	2	5	5	0.5	0.3
World	98	118	123	150	202	201	424	468	1.4	1.0

The challenges over the last two decades justify the need for increased competitiveness in the industry, but waste in the U.S wood fiber supply chain is still a barrier. Waste in the U.S wood supply chain has been documented in literature. Waste affects the U.S wood industry and stakeholders (i.e. loggers, transport companies, sawmills, etc…). Considering the amount of global competition from the world's major industrial wood suppliers (Western Canada, Brazil, Sweden, and Australia) (Greene , et al., 2006), change in current practices must be taken, for the U.S. to remain competitive.

The wood fiber supply chain is a foundation of the forest products market. Supply chain effectiveness is of crucial importance to the U.S forest products industry to remain competitive. Although global competitors have higher delivered prices they still compete with the southern U.S. on final product basis (Greene , et al., 2006). Current inefficient supply chain practices can affect the cost of the final product, because costs associated with the creation of the product increase. "Inefficiencies in the supply chain, such as parts shortages, underutilized plant capacity, excessive inventory, or runaway transportation costs, are caused by inaccurate or untimely information and can waste as much as 25% of operating costs" (Universidade do Porto, 2017). If costs increase in the upstream supply chain, costs can also increase on the final product or downstream supply chain. Therefore, cost competitiveness is at risk with non-value added activities in the wood fiber supply chain.

Research conducted by the Wood Supply Research Institute on unused logging capacity estimated a loss of $400 million per year, which is approximately equivalent to two dollars per ton in 2004 (Greene D. W., Mayo, Cornelis, & Egan, 2004). Updating this dollar value for 2018, it equals

$2.68 per ton. Literature over the past two decades has indicated that the reduction of waste in the wood fiber industry can be accomplished by managing a number of factors, therefore providing stronger, more reliable supply chains (Rodgers, Visser, Shaffer, & Gallagher, 2002; Greene, et al., 2002; Taylor, 2012; Barynin & Taylor, 2013; Guatam, Lebel, & Beauddoin, 2013;Penfield, Germain, & Smith, 2014).A major opportunity exists within the wood supply process or a wood procurement system (WPS). "A WPS includes upstream processes and actors in the forest-products supply chain, responsible for procuring and delivering raw materials from the forest to the mill" (Gautam, Lebal, & Beaudoin, 2013). "Current planning in the wood supply process is primarily reactive rather than proactive. This is due in part to the high degree of uncertainty in today's business practices among the forest and logging industries that can introduce inefficiencies in the wood supply chain" (Rodgers B. , Visser, Shaffer, & Gallagher, 2002). In 2012 loss of production was attributed by suppliers to break-downs in the consumer/supplier relationship. These breakdowns refer to unfulfilled negotiations. Problem solving such breakdowns could potentially save 2.6 million tons of wood fiber loss annually, equaling 15% of production. Such losses due to ineffective interactions between suppliers and consumers has a significant impact on overall productivity affecting the efficiency of the supply chain and its cost (Taylor, 2012).

Economic and production data support evidence that the weakest link in the wood fiber supply chain may be the logging workforce. Challenges for the loggers include: rising prices of fuel, and parts and equipment costs. With the cost of new logging equipment, the lack of long-term contracts and other factors, financing has been harder to secure. In 2010, 50% of logging companies reported a loss, or were at best breaking even. (Goergen, Harding, Owen, Rey, & Scarlett, 2013). The WSRI Wood Supply Chain report raises concerns over the capacity of suppliers to replace their equipment, and an accelerated rise in log demand. These are alarming figures, considering that massive logging and trucking capital investments will be required to meet the projected harvest demand (Barynin & Taylor, 2013). Proposals across body of literature seem to develop around rebuilding relationships that minimize wood disruptions, fortifying relationships, and information sharing between procurement mangers and suppliers (Barynin & Taylor, 2013; Rodgers, Visser, Shaffer, & Gallagher, 2002; Taylor, 2012; Greene, et al., 2002; Penfield, Germain, & Smith, 2014).

Reduction of waste and improvement of relationships are necessary to maintain competitiveness of the industry. The efficiency of a supply chain has been consistently associated with a company's competitiveness (Arif-Uz-Zaman & Ahsan, 2014). Gartner Group provides examples of companies such as Ford and Procter & Gamble that have benefited from utilizing their supply chains as a core strategy. The constant reengineering of their supply chains benefits them when demand is weak or when a new business opportunity is presented (Gartner Group as cited by (Penfield, Germain, & Smith, 2014).

Adequate supply chain management is vital to reduce waste in the wood fiber supply chain. However, there are many challenges that the wood fiber supply chain must overcome to improve current supply chain efficiency and reduce costs. Current literature has focused diagnosing current status, and providing generic recommendations on:

1. Trucking Operations
2. Supply chain aspects such as efficiency, supplier consumer relationship, supplier production capacity, inventory management, and agile capabilities.

This thesis focuses on filling the gap within the body of literature, focusing on developing and validating tools that can help the wood fiber supply chain overcome current supply chain management challenges. The three objectives of this study are:

1. To introduce a Lean manufacturing tool in the wood fiber supply chain to identify and reduce waste by developing and implementing a lean logistics value stream map. The specific focus is the upstream supply chain for three different industry sectors: a paper mill, a sawmill, and a logging company.
2. To introduce a structured supplier selection model and computational tool into the wood fiber supply to prioritize suppliers.
3. To verify and validate the supplier assessment and supplier selection computational tool in order to determine that the model as implemented prioritizes suppliers.

The first objective captured the current state of the system of the three different industry sectors. The current state of the system is documented through a framework that provides insight through visualization and simplification of the selected processes. The application of the framework provided insight through visualization and simplification of the selected processes. The results of objective one lead to the creation of the second and third objective of this research. Supply chain disruption and poor communication within consumers and suppliers, were amongst the results for the first objective. Therefore, a tool that encouraged selecting suppliers in an orderly and structured manner was the purpose of the second objective. The structured approach aimed at encouraging order and prioritization when selecting suppliers in an effort to promote proactive planning amongst suppliers and consumers. The third objective verifies and validates the tool. The following section comprehends the literature review.

2. Literature Review

2.1 Supply Chain Management

Supply chain management is defined as the effective integration and management of the supply chain (Westcott R. , 2013, p. 490). It encompasses all activities related to the flow and transformation of goods, from the stage of extraction of the raw material to the final customer, as well as related information flows. Materials and information flow upstream (in the first supplier direction) and downstream (in the final customer direction) in the supply chain (Ballou, 2004, p.5). "Supply chain management (SCM) is the active management of supply chain activities to maximize customer value and achieve a sustainable competitive advantage. It represents a conscious effort by the supply chain firms to develop and run supply chains in the most effective and efficient ways possible. Supply chain activities cover everything from product development, sourcing, production, and logistics, as well as the information systems needed to coordinate these activities" (NC State University, 2017).

The supply chain management approach necessitates a change in thought regarding production. In past years, the traditional way of producing was make to stock. However, in an information-age economy, production is a response to customers' demand (Russel, 2007). In recent years, the study of the supply chain has increased its relevance in modern business environments seeking efficient supply chain management as a key to business continuity (Cabral, Grilo, & Cruz-Machado, 2012). Competition at the international level and globalization of markets pressure firms to reduce their costs, while demanding a more reactive operational response for the customer (Tinham, 2005).

Supply chain management seeks to maximize performance in commerce by synchronizing supply and demand at all levels to reduce product development cycles, reduce order cycle time, replace stocks with flows, meet precise customer requirements, and maximize customer satisfaction. Because the supply chain transcends the boundaries of the company, good relationships both with suppliers and customers are essential to guarantee transparent information flow across the chain. Decisions concerning the collaboration between the firm and key partners are made in the context

of mutual gain. These relationships should not be interpreted as a single relationship between two businesses, but rather as a network of multiple businesses and relationships (Russel, 2007).

Proper supply chain management is closely related to supply chain performance measurement (SCPM). The link between the two is the management and the manipulation of information in order to become more competitive. Information is vital for supply chain performance and information technology helps to hold the supply chain together by establishing a flow of information across functional areas of the company and business partners, for whom accuracy, speed, relevance and accessibility are critical for successful performance (Russel, 2007).

2.2 Supply Chain Performance Measurement

Over the last ten years there has been a steady stream of research regarding supply chain performance measurement. It has been portrayed as "an indispensable management tool and the vehicle to achieving success. Performance measurement enables supply chain to strategically manage and continuously control achieving of objectives. It provides the necessary assistance for performance improvement in pursuit of supply chain excellence" (Agami, Saleh, & Ramsy, 2012). In essence, a performance measurement system consists of a number of individual performance measures or metrics. "The term "metric" refers to the definition of the measure, how it will be calculated, who will be carrying out the calculation, and from where the data will be obtained" (Gunasekaran and Kobu, 2007 as cited by Arzu Akyuz & Erman Erkan, 2010).

Supply chain performance measurement is important because competitive advantage has been associated with the alignment of an organization's activities with its strategies (Hanson & Melnyk, 2011). Performance measurement and management systems can measure the state of alignment because of their dual function of communicating strategy and controlling performance (Melnyk et al., 2004; Magretta and Stone, 2002 as cited by (Hanson & Melnyk, 2011). Performance measurement and management system (PMMS) enables the set of tools and the system for management to fulfill three functions, listed in Table 2.

Table 2. Functions of PMMS

Communication	Because of the system's formality, universality, and the rewards or sanctions, the PMMS communicates: • What has to be done and what does not have to be done • What is important and what is unimportant • What is satisfactory and what is not (what needs to improve)
Information	PMMS aids in the identification of performance variations. It shows where there is need for intervention and improvement, but it does not identify why the problem exists.
Control	Rewards and sanctions selectively influence the performance of those areas under control.

These three functions can also be extended to a performance measurement system's purpose as listed below (Gunasekaran and Kobu 2007 cited by Arzu Akyuz & Erman Erkan, 2010).

- Identifying success
- Identifying customer needs are met
- Better understanding of process
- Identifying bottlenecks, waste, problems and improvement opportunities
- Providing factual decisions
- Enabling progress
- Tracking progress
- Facilitating more open and transparent communication and co-operation

An effective SCPM system needs to comply with a set of characteristics (see Table 3). These characteristics strengthen a supply chain by ensuring that separate participants have an understandable and reliable commonality to measure performance. Numerous studies state that PMMSs play a key role in strategy, communication, and management processes, generating organizational capabilities that enable success in an organization (Arzu Akyuz & Erman Erkan, 2010).

Table 3. Characteristics of an Effective SCP (Agami, Saleh, & Ramsy, 2012)

Effective SCPM	
Inclusiveness	Covers all aspects and processes of a supply chain.
Universality	Allows comparison under different operating conditions

| Measurability | Output is quantitative and can be measured |
| Consistency | Metrics are compatible with supply chain goals |

The functions of a PMMS and the purpose of these systems justify the need for such tools in the wood fiber supply chain. Although the goal of a collaborative relationship between supplier and consumer is ambitious, it is necessary to reduce waste and improve efficiency. PMMS is a tool that can facilitate or aid in changing cultural practices in the industry by encouraging information sharing. "The integrative philosophy of supply chain management monitor eliminates the boundaries of the single firm and puts emphasis on the effectiveness of the supply chain as a whole" (Bowersox and Closs, 1996; Chan et al., 2003 as cited Papakiriakopoulos & Pramatari, 2010).

2.3   Logistics

Logistics are the activities required to effectively meet the customer's need for products in the proper time and place. They are the link between manufacturing and the consumption of a product or between suppliers and production, all separated by distance and time (Kazandijan & Norton, 1999). Goldsby & Martichenko (2014) rephrase the significance of logistics into the movement of inventory, whether this is hard or soft goods, materials, people or information. This movement includes upstream and downstream management of inventory.

Logistics are embedded in a supply chain and provide the management of inventory and how interactions involving inventory occur. Within a supply chain, logistics operations comprehend planning, implementation, and controlling of the goods, services, and related information. These logistic operations are responsible for the an efficient and effective flow from the point-of-origin to the point-of-consumption to meet the customer's requirements. (The Council of Supply Chain Management, 2002). Outstanding supply chains have a set of characteristics that define them according to Blanchard 2010:

- Clear supply chain strategy as their foundation. Deep understanding of the company's business strategy.

- Adaptable and quick.

- Transparent: Have clearly stated performance expectations, and culture of accountability to their customers.

- Focused on continuous improvement throughout the supply chain and aim at peak-to-peak performance.

- Recognize strengths and weaknesses, and participate in benchmarking activities.

- End to end perspective, focusing on the supply chain activities of plan-buy-make-move-store-sell.

- They have global, rather than regional, focus.

These characteristics can be summarized in a holistic supply chain that extends from the customers' customer to their suppliers' suppliers and all that is in between. Figure 1 shows the relationship between the main elements of a supply chain as considered in this report.
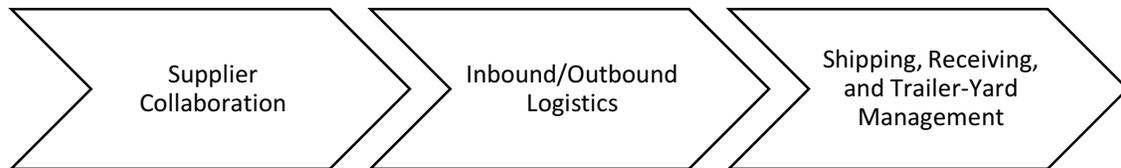
Figure 1. Areas in a Fulfillment Stream (Martichenko & von Grabe, 2010)

The sections portrayed in Figure 1 are explained below.

2.3.1 Supplier Collaboration

Supply chain collaboration has been defined as "two or more chain members working together to create a competitive advantage through sharing information, making joint decisions, and sharing benefits which result from greater profitability of satisfying end customer needs than acting alone" (Togar & Sridharan, 2002, p.19). A term distinction is necessary to distinguish the difference between collaboration and cooperation. Collaboration is a higher level of strength in a relationship than coordination and cooperation, which occur at a lower degree of strength. Table 4 shows different supplier collaboration definitions.

Table 4. Supplier Collaboration (Singh & Power, 2009)

Strategic suppliers involved in processes of value definition in organizations.	(Dyer, Cho, & Chu, 1998)
Key suppliers can be expected to provide high quality standards	(Verma & Pullman,

of products and services.	1998)
A communication system between organization and supplier that guarantees transparency of information to aid suppliers in improvement in quality and responsiveness.	(Garcia-Dastugue & Lambert, 2003)
Suppliers involved in new product development to guarantee fairness and that benefits obtained are shared between interacting partnerships.	(Ireland, 1999) (Ballou, Gilbert, & Mukherjee, 2000)
Collaborative problem solving and planning translate to levels of trust and with firm performance.	(Claro, Hagelaar, & Omta, 2003)

2.3.2 Inbound/Outbound Logistics

Inbound logistics is the movement of inventory to and from an organization. The inbound logistics refers to the shipment of raw material or finished inventory (Martin & Osterling 2014)(Martichenko & von Grabe, 2010).

2.3.3 Shipping, Receiving, and Trailer-Yard Management

This section of the supply chain refers to the management of warehouses or activities related to the organization's receipt of raw materials, their handling, and how they prepare the final product for shipment. Warehouse activities include receiving, put-away, storage, order picking, packing, marking, staging, and shipping. (Varila, Seppanen, & Soumala, 2007). The function of a warehouse in the supply chain "is to provide the utility of time and place to customers, both retail and individual. The warehouse bridges the gap and enables both parties, manufacturer and customer, to operate within their own spheres" (Sharp, 2007).

2.4 Overview of Research within the Wood Fiber Supply Chain Related to Logistics and Upstream Wood Fiber Supply Chain

Major research efforts about logistic operations within the wood fiber supply chain have been limited to the diagnosis of the current situation and recommendations in different areas such as trucking operations, evaluation of current wood supply chains in various dimensions, or in supply chain relationships and information sharing. Relevant research is listed in Table 5.

Table 5. Research Related Logistics or Supply Chain Management in the Wood Fiber Supply Chain

Areas of Research		Publication Name and Authors
Trucking Operations		1. Compensation Indices for Logging & Trucking Occupations (Baker & Mendell, 2016) 2. How to Improve Transportation Efficiency and Cost. (Gallagher, Smidt, McDonald, & Tuffs, 2004) 3. Investigation of Roundwood Truck Turn-Time Cost Penalties to the Wood Supply System (Deckard, Newbold, & Vidrine, 2001)
Supply Chain	Efficiency	1. Assessing the Supply Chain Efficiency of Hardwood Sawmills in New York State though Case Study Analysis(Penfield, Germain, & Smith, 2014) 2. Wood supply chain efficiency and fiber cost (Siry, et al., 2006)
	Supplier Consumer Relationship	1. Supplier/Consumer Relationship Study Southeastern Region Report (Taylor D. , 2012) 2. Planning and Communication: State of the Forest Industry and Opportunities for Improvement in the Wood Supply Chain (Rodgers B. , Visser, Shaffer, & Gallagher, 2002)
	Supplier Production Capacity	1. Wood Supply Chain Analysis: Special Market Analysis Study (Barynin & Taylor, 2013) 2. Causes and Costs of Unused Wood Production Capacity (Greene D. W., et al., 2002).
	Inventory Management	1. Simulation of Woodyard Inventory Variations Using a Stochastic Model and Total Inventory Manager (LeBel & Carruth, 1997).
	Agility Capabilities	1. Agility Capabilities in Wood Procurement Systems: A literature Synthesis (Gautam, Lebal, & Beaudoin, 2013)

Table 5 shows the literature consulted relating to logistic operations. Two major areas identified were trucking operations and upstream wood fiber supply chain in the United States. Trucking operations have been evaluated to determine employment conditions and how to improve truck

load assignation. Baker & Mendell (2016) researched the compensation for logging occupations and occupations competing for the same employee pools. Gallagher et. al (2004) elaborated a logistics simulation that evaluated the rules used when assigning a driver to a load. Deckard et. al., (2001) addressed both the time-of-day and the delivery day-of-week and the effect of these varaibles on the total turn-time.

Wood fiber supply chain literature reviewed focuses on diferent areas related to supply chain. These areas are efficiency, supplier/consumer relationships, supplier production capacity, and inventory management. Penfield et., al. (2014) identified the characteristics of the supply chain specific to hardwood sawmills that contribute to efficiency. Both the efficiency of the hardwood sawmills and the hardwood sawmill's supply chain were calculated. Data envelopment analysis (DEA) was utilized to determine the relative efficency of the hardwood sawmills studied. A survey tool was utilized to calculate the hardwood sawmills' supply chain efficiency.

Siry et., al. (2006) performed a comparison of the supply chain cost between the U.S. wood fiber supply chain and its foreign competitors. How the supply chain could be modified to improve competitveness was analyzed. The scope of operational differences between the southern U.S. and the examined countries included logging systems, truck payloads, scheduling and dispatching, contract hauling, cooperative maintenance, and logging contracts.

Supplier/consumer interactions have been evaluated using different categories. Taylor (2012) evaluted the working relationship between suppliers and consumer mill procurement. The catergories of the interactions were: negotiations, joint-planning, feedback, and problem solving/communications. Similarly, Rodgers et., al (2002) assessed the current state of planning and communication in the industrial wood supply process and identified opportunities for improvement.

Supplier production capacity, inventory management, and agility capabilities have also been researched. Barynin and Taylor (2013) evaluated the current regional harvesting capacity and quantified supply chain capabilities to meet future round wood consumption. Greene et., al. (2002) identified the causes and costs of unused logging capacity in the southern U.S. and Maine.

Inventory management in a reactive environment was approached by Lebal & Carruth (1997). A simulation of a paper mill's need for a constant fiber supply in a variable procurement environment was performed under the requirement of maintaining wood yard inventory within desired levels. Inventory management is closely related to agility, which is the capability of a firm to acknowledge change and efficiently react to it. Guatem, et., al. (2013) performed a literature synthesis of agile capabilities in wood procurement systems.

Key areas of the upstream wood fiber supply chain have been addressed by diverse research. The literature consulted uncovers important challenges that are characterized by waste. The major challenges and sources of waste within the scope of this research are found in the next section.

2.5   Challenges in the U.S. Wood Fiber Supply Chain

The wood fiber supply chain is full of opportunities for improvement. Benchmarking supply chain practices with international competitors helps identify the effectiveness of better practices. Research shows that international community practices may work best to increase supply chain effectiveness. Major differences between the southern U.S. and competitor regions* include different logistics related operations and supply chain management. Trucking in major competing regions allows larger truck payloads than the U.S. (i.e. Brazil allows 55-66 tons while the U.S. only allows 25-28 tons). Practices such as on-board scales ensure reduced variability or uniform loading in comparison to the U.S. "This permits cost-effective trucking over larger distances and provides a considerably lower trucking cost at similar distances compared to the United States" (Greene , et al., 2006). Competitors have better scheduling and dispatching systems which can help eliminate truck wait time while loading and unloading. "It is not uncommon to observe trucks moving smoothly with no wait lines to load or unload" (Greene , et al., 2006). According to Greene, et al., this is, in part, due to the fact that trucking contractors are independent from wood harvesting operations. In the U.S. there has been a negative response to such initiatives. The reason for reluctance is related to loggers' economic self-interest. "The greatest impediment to incorporating advanced logistics into log transport is the unwillingness of loggers to surrender control of trucking operations to a central dispatcher" (Gallagher, Smidt, McDonald, & Tuffs, 2004).

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* Western Canada, Brazil, Sweden, and Australia

Regarding supply chain practices, a major difference between the U.S. and global competitors is that forest management, logging, and manufacturing operations are closely managed. This integration is provided by contracts or ownerships. Therefore, logging enterprises benefit from logging contracts of one or more years. The result is a stable planning horizon which facilitates financing in their operations. Larger scale operations and integration aid in planning and scheduling. This greatly contrasts with operation in the southern U.S. where such operations are not coordinated, tract sizes are decreasing, short-term contracts are the norm, and little to no scheduling of deliveries is found (Greene , et al., 2006).

The body of literature supports this claim. "In evaluating both the health and integrity of the current supply chain, there is a critical predicate—the individual links in the supply chain are as independently controlled today as they have ever been in history" (Goergen, Harding, Owen, Rey, & Scarlett, 2013).The result is that there are no fully integrated forest products manufacturing corporations. This brings unsettling consequences. No industry segment of corporate entity controls the entire manufacturing supply chain. No longer are there economic subsidies provided from one element (link) to another to provide supply chain integrity. "Consequently, the strength of each link is subject to separate variables" (Goergen, Harding, Owen, Rey, & Scarlett, 2013). Strong evidence suggests that there is little knowledge within an individual link of the challenges faced by the rest of the chain (Goergen, Harding, Owen, Rey, & Scarlett, 2013; Taylor, 2012; Rodgers, Visser, Shaffer, & Gallagher, 2002; Siry et al., 2006).

The industry faces a highly disintegrated supply chain, where there is a clear necessity to change current operating practices in order increase competitiveness. There are many challenges associated with the implementation of improvements. A significant barrier is the limited access to well- funded consistent research efforts in the U.S. in comparison to competitors such as Sweden, Western Canada, and Australia (Greene , et al., 2006). Therefore, research initiatives in the current research line are of vital importance to the industry.

2.5.1   Waste Identification in the U.S Wood Fiber Supply Chain

The body of literature is consistent in problems still to be overcome that introduce waste into the wood fiber supply chain. These wastes or perpetuating actions are presented in Table 6.

Table 6. Important Opportunities for Improvement Identified in Present Report and in Literature Review

Problematic Identified	Literature or Identified in Present Study
Overcapacity of Suppliers	• Simulation of Wood Yard Inventories (LeBel & Carruth, 1997) • Causes and Costs of Unused Logging Capacity (Greene D. W., et al., 2002) • Lean Logistics Framework in the Wood Fiber Supply Chain (Fallas-Valverde, Quesada, & Bond, 2018)
Loss of Production Due to Market Factors	• Causes and Costs of Unused Logging Capacity (Greene D. W., et al., 2002) • Supplier/Consumer Relationship Study Southeastern Region Report (Taylor D. , 2012) • Lean Logistics Framework in the Wood Fiber Supply Chain (Fallas-Valverde, Quesada, & Bond, 2018)
Current Planning Process is Primarily Reactive Rather than Proactive	• Simulation of Wood Yard Inventories (LeBel & Carruth, 1997) • Planning and Communication: State of the Forest Industry and Opportunities for Improvement (Rodgers B. , Visser, Shaffer, & Gallagher, 2002) • Supplier/Consumer Relationship Study Southeastern Region Report (Taylor, 2012) • Lean Logistics Framework in the Wood Fiber Supply Chain (Fallas-Valverde, Quesada, & Bond, 2018)
Recognition of Impact of Consumer Actions	• Planning and Communication: State of the Forest Industry and Opportunities for Improvement (Rodgers B. , Visser, Shaffer, & Gallagher, 2002) • Supplier/Consumer Relationship Study Southeastern Region Report (Taylor, 2012) • Lean Logistics Framework in the Wood Fiber Supply Chain (Fallas-Valverde, Quesada, & Bond, 2018)

2.5.2   Overcapacity of Suppliers

Forest harvesting operations are always highly susceptible to wet weather. In a 1993 study it was reported that logging contractors could lose as much as 20% of their logging capacity to weather related factors alone. Stock risk at a wood products manufacturing facility is unacceptable, due to

the high cost associated with downtime, in some cases, in facilities that would like to run 24 hours per day 365 days per year, for economic reasons. This risk can lead to an overcapacity of suppliers. Greene et. al (2002) documented significant overcapacity, presented reasons for it, and estimated its cost to the supply system. Twenty years later the industry still faces the issue of how to define the appropriate logging force needed for a given procurement area. Therefore, it is still common to see companies, including dealers and large woodland owners, contracting their logging operations to large numbers of suppliers. In an industry that involves multiple sourcing, no one supplier can satisfy the demand. Two critical decisions must be made. Which are the best suppliers, and what quantity is to be purchased from each supplier selected? (Ghodsypour & O'Brien, 1996). These decisions can help to reduce waste caused by inefficiency.

2.5.3   Loss of Production Due to Market Factors

How wood fiber consumers handle their supplier-consumer relationships affects the loggers. Market causes discussed within the body of this study control the receiving mills, wood dealers, and logging firms in the wood supply system (Greene et al., 2002). Wood order constraints continue to provide a threat to lean in the wood fiber supply chain. The supply stream is stressed due to the reactive market environment. Low and variable quotas affect the financial status of loggers and their capacity to keep their businesses afloat. Loggers that consistently face a constrained market environment, face real hardships. In a 2002 study, market factors were the most recurrent cause of lost production. Market factors were divided into three causes; quota, mill handling, and mill closures (Figure 2). Quota refers to supply amounts imposed by the consumer company or wood order constraints. Mill handling refers to inefficient unloading or handling of product. Mill closures is used to describe the unplanned or short-notice of receiving mill. The study found that there were approximately 3.5 loads of missed production per week (an estimated 26m^{3}per load). Quota losses contributed to 1.9 loads, mill handling and mill closures respectively assigned 1 load and 0.6 loads (Greene et al., 2002).
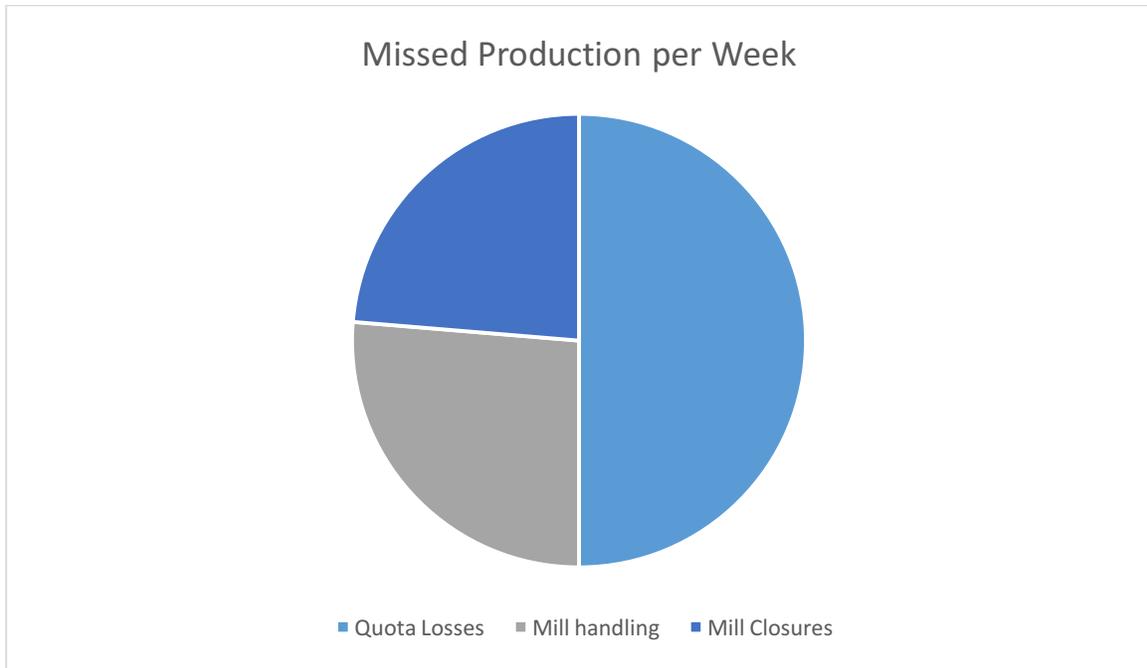
Figure 2. Missed Production per Week (Greene D. W., et al., 2002)

A decade later the Supplier/Consumer Relationship Study Southeastern Region Report again identified the loss of production due to break-downs in the consumer/supplier interaction. Breakdowns refer to unfulfilled negotiations, joint-planning, feedback or communications-problem solving. This could potentially represent 2.6 million tons annually or a loss of 15% of production. Ineffective interactions between supplier and consumers have an impact on overall productivity affecting the efficiency of the supply chain and its cost (Taylor, 2012).To recognize the importance of stability to the loggers, and how situations above can affect the economic stability Greene et al., demonstrated how sensitive a logger's break-even level can be. One day of missed production is capable of dropping a crew below break-even level.
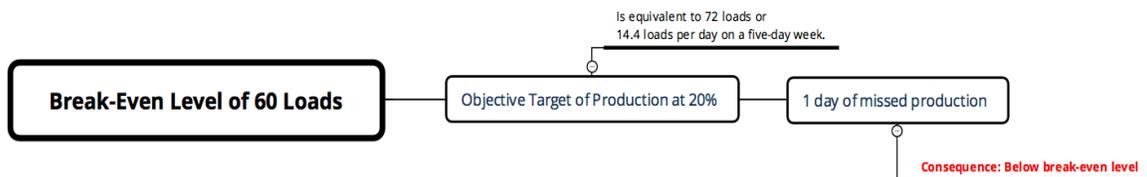
Figure 3. Example of Break-Even Level (Greene et al., 2002)

Figure 3 explains that if one day of production is missed, the crew can fall below break-even level. For example, if the production target in a 5 day week is 72 loads (20% above break-even point),

not working one day (daily production is 14.4 loads) places the crew below break-even point (72-14=58 loads) (Greene et al., 2002).

2.5.4 Wood Supply Planning

Planning and Communication: State of the Forest Industry and Opportunities for Improvement Rogers et al. (2002) states that "current planning in the wood supply process is primarily reactive rather than proactive." The reactive environment is due in part to the high degree of uncertainty facing the forest and logging industries in today's business practices that can introduce inefficiencies in the wood supply chain." This reactive environment can be explained by the unpredictable situations that the industry faces, but traditional business practices also contribute. In 2002 more than 75% of contract loggers claimed being informed less than one week in advance of the location and characteristics of the next tract, and 37% indicated that they received poor or bad information on expected demand (Rodgers, Visser, Shaffer, & Gallagher, 2002).

The re-direction of loaded transport vehicles, continues to promote waste in the supply chain. The short notice given to haul distances that exceed what the transportation system is designed for is another example waste. The re-direction of loaded transport vehicles was seen throughout this study and found in literature. WSRI's Supplier/Consumer Relationships Study also identifies the practice of suppliers having to drive further distances, which incrementally increased logistics costs due to a cultural practice in the industry that introduces inefficiencies to the system (Taylor, 2012). The wasteful scenarios discussed previously regarding the reactive environment that suppliers face can be augmented by the absence of firm and longer-term wood orders, which was a major issue identified by Taylor (2012). This practice provides small or no planning horizon for the suppliers. Table 7 lists examples of consequences that affect the industry of a reactive planning process. The examples clearly demonstrate that reactive planning affect different sectors of the supply chain understudy. These are likely to propagate and introduce inefficiency to other sectors.

Table 7. Examples of Consequences of Reactive Planning Processes (Rodgers B. , Visser, Shaffer, & Gallagher, 2002)

Examples of Consequences of Reactive Planning Processes
• Loggers may not plan capital expenditures or resources efficiently.
• Consumer's ability to coordinate volumes according to inventory levels is compromised.

> • Fragmented communication not only impacts tract allocation (mismatch of production capacity to tract), but also introduces inefficiencies for transportation.

2.5.5   Recognition of Impact of Consumer Actions

Before strategies to combat the present issues can be designed and implemented, consumers must understand these issues. In 2002, consumers still had not recognized the importance of a strong supply chain. Many of the consumers interviewed did not see the advantage of having a logging contractor that was profitable, much less one that had adequate cash reserves to 'wait out' a rain event (Rodgers et al., 2002). In 2012, the number one issue identified by southeastern suppliers was the lack of recognition of conditions that were having an economic impact on the suppliers at the time (inflation and rising fuel costs) (Taylor, 2012). Both findings demonstrate the opportunity to strengthen relationships between consumer and supplier to protect the wood supply chain from inefficiencies that cause waste.

 Recently wood fiber supply chains are controlled more independently than they ever have been. There no longer exists a fully integrated forest products manufacturing corporation. Practices such as economic subsidies, from one link to another, to maintain supply chain integrity no longer exist. Therefore, the withstanding of each supply chain element or link is subject to separate variables. "Moreover, there is strong evidence to suggest that those who reside within individual links are largely unaware of the challenges faced by the rest of the chain" (Goergen, Harding, Owen, Rey, & Scarlett, 2013). The lack of supply chain integrity causes different elements within a supply chain to be unaware of the challenges faced by other elements in the supply chain. Current research related to efficiency in the fiber supply chain focuses mainly on the identification of causes of inefficiency or the current operating state of the system in the wood fiber supply chain. There is no existing literature on tools or methodologies that can be applied to increase supply chain collaboration and cooperation. Furthermore, there is no research on the impacts of information sharing or methodologies and tools to promote information sharing within a supply chain (see Table 6).

2.6   Lean Logistic Applications in the Wood Fiber Supply Chain

2.6.1   What is Lean Thinking and Why it Can Benefit the Wood Fiber Supply Chain

Value refers to the transformation or processing of raw materials or semi-finished products into goods and services to satisfy the needs of customers. In a perfect world, all activities performed to provide these goods and services are "value adding" (VA) from the perspective of the customer. In reality, some and oftentimes many of these activities are non-value adding (NVA) and considered "waste". The goal of lean thinking is continuous waste reduction to maximize flow goods and services that are truly VA activities. Therefore, understanding what adds value and identifying which activities "get in the way" (NVA or waste) are the most important steps in effective lean implementation. Once NVA activities and their causes are identified, continuous efforts can begin toward effective improvement. Complicating improvement efforts, wasteful activities can also include necessary but non-value adding (NVA). These necessary NVA activities are wasteful but very difficult to avoid under current practice or technological constraints. The seven most common wastes according to Toyota Production System (see Table 8) are overproduction, waiting, transport, inappropriate processing, unnecessary inventory, waste of motion, and defects (Hines, Rich, & Esain, 1999; Hines & Rich, 1997).

Hines et al. (1999) explains that Womack popularized the term lean. The term lean "has become the universally accepted term for increasing value and reducing waste" (Quesada & Buehlmann, 2011). Hines et al. also defines lean as a system that obtains outputs with fewer inputs but offers more choices to the end customer. Gjeldum, Veža, & Bilić (2011) and Cookson, Read, Mukherjee, & Cooke (2011) explain that lean is a management principle that is known to be very effective in productivity, continuous improvement, product quality, and time delivery to customers. It also serves an effective purpose when identifying waste with tools like value stream mapping. The value chain is intimately entwined with lean. The final consumer motivates these chains because it is he/she who allocates value to the product or service. This concept is related to directing attention to the processes needed to create the product or provide the service (Quesada & Buehlmann, 2011). Figure 4 shows the four basic concepts of lean thinking.
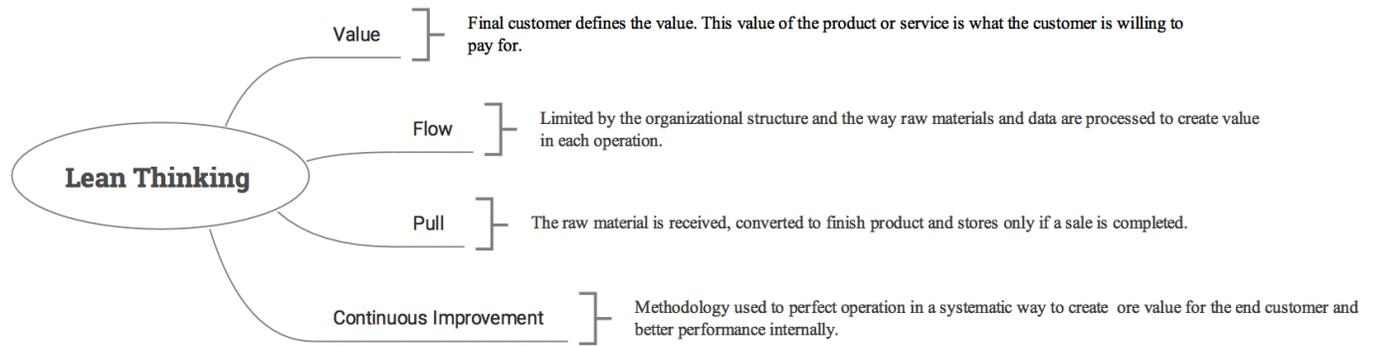
Figure 4. Lean Thinking: Four Basic Concepts (Quesada & Buehlmann, 2011)

Lean thinking translates into increasing customer satisfaction, creating a positive impact financially. This challenges traditional views of formulating prices as the sum of cost and dividend but reestablishes it as dividend equals price minus cost (Quesada & Buehlmann, 2011). Benefits of lean thinking include, but are not limited to (Chavez et al., 2015; Nawanir, Lim, & Othman, 2013; Panwar, Nepal, Jain, Rathore, & Lyons, 2017):

- Lot size reduction

- Lower inventories

- Improved quality

- Reduced rework

- Increased productivity

- Flexibility

- Reduced space requirements

- Lower overheads

- Decreased production costs

- Reduced lead-times

The benefits of the application of lean in logistics and supply chain management has been recognized in the literature. The application of lean in supply chain management is a force that enhances product quality and business performance (Jaiprakash & Kuldip, 2014). Table 8 shows

the main types of waste, as defined by lean thinking, and the connection with specific waste examples in the wood fiber supply chain.

Table 8. Types of Wastes in Lean Thinking (Flinchbaugh & Carlino, 2006; Quesada & Buehlmann, 2011)

Types of Waste in Lean Thinking		
Type of Lean Waste	Definition	Examples in Wood Fiber Supply Chain
Overproduction	Production exceeding customer needs or what the production order indicates. Increase in finished products inventory and holding costs.	• Demand at consumer mills is fulfilled, but the logger continues to harvest wood • Excessive harvesting, to take advantage of good weather conditions
Transportation	Avoidable transportation of goods, parts, or information.	• Truck redirection to another drop location • Excessive transportation distances
Inventory	Excess raw material, work in process, and finished goods inventories are seen as waste, since the money invested is put to rest.	• Partially cut tracts waiting to be finished, because there is no quota for what is left standing • Excess inventory in the log yards • Purchasing of stumpage that exceeds demand forecasts
Movement	Movement by people that is not applied to a value adding activity.	• Crews that are not assigned to tracts that fit their machine capability may result in additional movements while working • Poor visual control in log yards cause unnecessary movements
Waiting	Downtime spent waiting for material, information or people. Idle equipment or operators.	• Excessive truck turn time also incurs an increased waste. This wait applies, although the time is spent in queue • Idling of logging crews and their equipment, due to decreased demand
Over-processing or Incorrect Processing	Doing more than the customer requires to a process or product. Incorrect processing increases cost that is not associated with any value.	• Harvesting of wrong trees, because they were not correctly marked • Harvesting wood when weather is good but there is no actual demand • Information on harvesting sites is incorrect
Defects	Process, product, or service errors. Defects are considered whether or not they reach the customer.	• Harvested wood does not meet specifications • Harvested wood is damaged during transportation or handling in log-yards
Unused employee creativity	Wasting employee potential that could otherwise be utilized in improvements and opportunities.	• Lack of collaboration between the consumer mills and the loggers • Ignoring feedback from loggers • Not including all personnel in the strategic decision-making process

2.6.2 Lean Logistics

The concepts previously presented are all related to lean logistics and a combination of these concepts transform into the significance of lean logistics. Lean logistics breaks the formal perception that lean may only be applied to manufacturing. Feng et al (2013) describes that lean logistics' core is to eliminate waste, including stock, to achieve cost reduction. Chun & Wu (2005) describe that the link between critical functions and transportation is vital in reducing waste in the form of inventory. This link reduces the cost and ultimately increases productivity. Therefore, the combination of waste reduction in logistics activities develops into lean logistics.

Lean has an important impact on logistics, because traditional methodologies do not have a holistic approach to the fulfillment of product or service, whereas lean thinking does. The lack of visualization diminishes efforts made in specific processes that do not significantly impact the performance of the value chain; they just optimize the focal points (Quesada & Buehlmann, 2011). The main objective of lean in logistics "is to eliminate waste, decrease work in-process inventories, and, in turn, decrease process and manufacturing lead times, ultimately increasing supply chain velocity and flow" (Goldsby & Martichenko, 2014, p.5). Waste is defined as "anything other than the minimum amount of equipment, materials, parts, space, and human capital time which are absolutely essential to add value to a product or service (Burnham, 1987; Inman & Mehra, 1991; Canel, Rosen, & Anderson, 2000; (Ugarte, Golden, & Dooley, 2016).

 The seven common wastes in the TPS are overproduction, waiting, transportation, inappropriate processing, unnecessary inventory, unnecessary motion, and defects (Hines & RIch, 1991). Feng et al. justifies and relates the integration of the supply chain that Jones et al. exposed to value concept. "Manager needs draw up logistics solution with value stream according to the principle of uninterrupted, no backflow, wait-free and no waste. The goal of perfection will be achieved by striving for eliminating any logistics link which causes waste" (2013, p. 2490). In order to eliminate any logistics link that causes waste there needs to be cohesion in logistics operations.

Lean is meant to be customer centered. The concept of value in lean practices is defined and decided by the customer. A key feature development was that "value was linked to customer requirements" (Hines et al., 2004, p. 995). This concept of customer value does not limit operations

to use cost reduction as the only way to compete in a demanding market, but lets other features increase competiveness. Value is increased with additional features, even if this may not mean an additional cost, for example a shorter delivery cycle, which means an increase in customer value (Peter Hines et al., 2004). This conception of value can be found in the pull system that is used in lean logistics.

Pull logistics revolves around customers and their needs. This converts into shorter logistics cycles with reduced inventory whichincreases customer satisfaction (Feng et al., 2013). Fen et al., and Urgate et al., agree that a pull system is high in customer satisfaction. The fact that the pull supply chain strategy is used for waste reduction disguises it as increasing customer satisfaction. Another positive aspect is that it contributes to productivity. "The introduction of lean manufacturing strategies into logistic operations has brought benefits such as reduced costs and product waste while improving productivity" (Ugarte et al., 2016)

Lean logistics presents the opportunity to change the way logistics has functioned, turning to more sustainable practices. This depends on how the supply chain is managed. When improving various processes in an organization these reduce inputs, reducing waste significantly. Suarez-Barraza et al. suppports this postion. For example, the collaboration betweeen two supply chains demanding strategic changes can result in carbon emission reductions of 54% combining road and rail transport(Pan, Ballot, & Fontane, 2013).

2.6.3   Value-Streamed Mapping (VSM)

The VSM is a tool that is utilized in lean thinking. Martin & Osterling (2014) describe the value stream as the series of activities that fulfill a customer request, where material and information flows are considered. These activities involve the design, production, and delivery of a product or service. A value stream reflects the fundamental flows of a product; the production flow from raw materials to the customer, and the design flow that extends from concept to launch. These activities are all classified as non-value adding or value adding (Rother & Shook, 1999) activities. The goal of the value stream map is to identify and communicate where non-value adding activities occur and how they impact the overall value adding functions. A value stream map (VSM) is a visual

tool that aids in analyzing and redesigning the production and supply chain process. It includes both material and information flow in order to identify waste that should be eliminated. Value stream mapping is divided into two sections. The first is the current state map, which represents the present process flow. The second is the future state, which represents the future vision of how the value stream should look after the company makes improvements.

Value stream mapping uses simple visualization to represent the value stream and enables gathering, analyzing, and presenting information. This tool allows all stakeholders, from the newest collaborators to the highest ranked collaborators, a graphic way to visualize a process, making it easier to understand (Nash & Poling, 2008). It also serves as an effective way to benchmark a current process's effectiveness; this is done by removing realistic wastes and showing how the process may look, if waste is removed (Hines, Rich, & Esain, 1999).

Value-stream mapping is a tool that relies on simplicity to uncover waste, but there are instances where its use might not be effective. For example, VSM is weak in mapping multiple products with different routings. Additionally, VSM is better fit for production processes that are repetitive. Matt (2014) has also indicated that VSM is hard to apply in complex manufacturing processes that have merging flows (Matt, 2014). However, a single value stream can be chosen to implement VSM when there are multiple products or routings. A VSM is a simply tool that aids in analyzing and redesigning the production and supply chain process. Since it is meant to reduce waste across different operations (internal or external) it can help the fragmented supply chain that literature review supports.

2.6.4 Symbols and Metrics Used in Value Stream Mapping

Table 9. Important Considerations in Value Stream Mapping (Sources: Rother & Shook (1999), Martin & Osterling (2014); and Ruiz-de-Arbulo Lopez, Fortuny-Santos, & Cuatrecasa-Arbós (2013))

Metric	Visual Representation Symbol	Definition
Process Box		Indicates a process in which material is flowing. It includes one area of material flow. It stops when flow stops and another process box is added.

Push Movement		Movement of production material by push.
Finished Goods		Movement of finished goods to customer.
Electronic Flow		Electronic flow of information.
Inventory		This triangle signals the location of inventory and must be used multiple times if there is more than one location in the process.
Go see		The action of going to see something visually (observation).

Table 9 shows a compilation of the VSM symbols that integrate both lean and logistics. Table 10 shows specific lean metrics designed to measure the perfect-order execution in lean logistics. Table 10 shows the individual logistics metrics that are used in determining the perfect order execution metric. The perfect execution metric is the multiplication of all the metrics. If all are not available, the remaining are multiplied.

Table 10. Logistics Metrics (Martichenko & von Grabe (2010), Chun & Wu, (2005), Dörnhöfer, Schröder, & Günthner (2016), Wongrassamee, Simmons, & Gardiner, (2003), and Yang et al. (2010))

Metric	Description
Right Quantity	The right quantity of product received at each point of the VSM. For example, the right number of loads received from supplier.
Right Product/Part	Right product sent to the next recipient. For example, the right species of softwood being delivered to the consumer.
Right Place	The product sent to the right place. The loads are delivered to the mill that requested the quota and not diverted to other markets.
Right Time	The product received at the right time. For example, the supplier transporting the logs at the required time.

Right Quality	Material/ product/ part/ how often material is sent with perfect quality to the next recipient. Right quality information is also included in this metric
Right Cost	How often is the planned price paid.
Right Service	How often the expected service is received.

2.6.5 Inventory Carrying Costs

Wilson (2007) states that carrying costs are the expenses that come from holding goods in storage. This storage may be in a shipping container, trailer, or railcar in the forest products industry this may also occur in the forest floor, or wood/log yard. The carrying cost may be divided into four areas: interest, warehouse, inventory risk and inventory service.

Interest refers to the cost of opportunity of the money invested in inventory that could be earning interest. This cost depends on the volume of inventory and the interest rate utilized. Warehouse refers to the cost that is associated with storing goods either in public or private warehouses; this includes those in manufacturing plants. Inventory risk and inventory service these cost comprehend several categories that are stated on Figure 5 Inventory risk and inventory service together represent 62% of carrying costs.
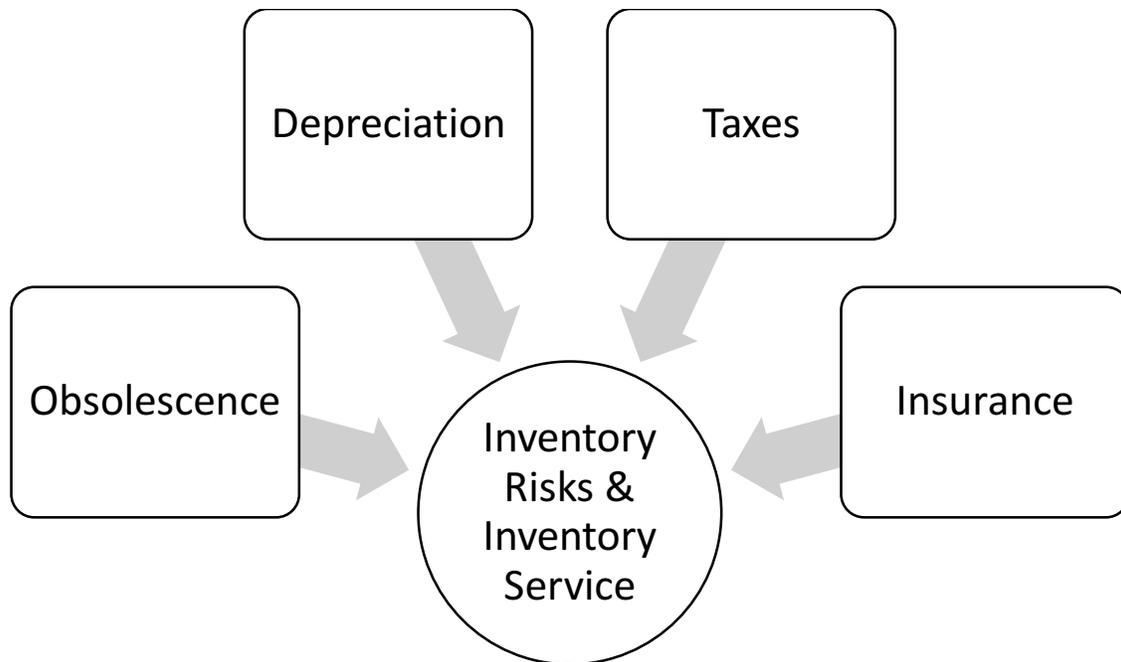
Figure 5. Components of Inventory Risks & Inventory Service (Wilson, 2007)

Obsolescence is the term designated to damages, shrinkage, or stolen inventory. Inventory that was not sold also falls under this category. Depreciation is presented in inventory as a decline in replacement prices. Taxes are the contribution to state revenue; these will vary depending on inventory volume. Insurance is defined as "the use of contracts to reduce and redistribute risk. In an insurance contract, the insurer accepts a fixed payment, or premium, from the insured, and in return makes payments if certain events occur" (Oxford Reference, 2016). In most instances, inventory levels are a key metric that can be used as a proxy to detect waste in a value stream. When there is excessive overproduction, excessive waiting times, miscommunication, defective products, and excessive transportation and movement, the amount of inventory is often increased to protect a company against low productivity and higher variability in the supply chain. However, this practice likely leads to higher inventory carrying costs. Inventory carrying costs can be quantified as a percentage of the value of the inventory but determining this percentage could be a difficult task because of the amount of information that must be gathered and analyzed. Martichenko & von Grabe (2010) indicate that using a percentage of the value of the inventory to estimate the carrying inventory cost is a common and acceptable practice in supply chain management.

2.7 Important Considerations for Lean Thinking Implementation in Wood Fiber Supply Chain

There is a vast amount of research and information available on lean thinking. This management approach incorporates a series of principles and practices to decrease waste (Czabke, Hansen, & Doolem, 2008). Lean thinking is still not widely applied to the forest products industry, although companies in this industry are aware of the methodology. In a survey conducted in 2010 targeting primary and secondary wood products industries in Virginia, findings showed that the majority of industries surveyed were aware of lean (72%) and that a lesser fraction (42%) had implemented lean initiatives (Fricke & Buehlmann, 2012).

A study developed in Harwood Sawmills in New York evaluated the relative efficiency of various supply chains. The research showed that lean thinking implementation was not widely applied. Forecasting methodologies where only applied in one sawmill in the entire sample. None of the sawmills were utilizing software to analyze shipping and transportation costs. Excessive handling and movement of materials was noted. This was not a surprising finding, as lean and Six Sigma was applied in only one sawmill (Penfield, Germain, & Smith, 2014).

The resistance of the U.S. forest products industry towards lean can be explained by the fact that small companies tend to be reluctant to accept new business trends because of the lack of funds, and because they are more prone to short term planning rather than long-term planning (Westhead & Storey, 2006). This resistance comes with a cost as there are significant internal and external factors impacting the competitiveness of the U.S. forest products industry, such as foreign competition and higher production costs. Lean thinking could be a good strategy to overcome the lack of competitiveness of U.S. forest products (Czabke et al., 2008).

Implementing lean and sustaining lean is not easy (Fricke & Buehlmann, 2012), as is reflected in the U.S. forest products industry. The low implementation rates of lean thinking in the U.S. forest products industry could translate to missed opportunities to mitigate risk from competition and to generate competitive advantages (Espinoza, Smith, Lyon, Quesada-Pineda, & Bond, 2012).

Key aspects for successful implementation of lean thinking are top management involvement and support, and employee training. When implementing lean thinking, gaining the support and engagement of management is vital (Chappell, 2002). This is especially important when obstacles and difficulties arise in the implementation process, as only the determination of managers could steer the organization towards success (Fricke & Buehlmann, 2012). Top management involvement could lead to employee training in lean aspects. Without the support from the top end of the organization this initiative wouldn't be possible.

According to Czabke et al. (2008), successful implementation of lean thinking can be reached if all employees are well educated with the lean strategy. Investing in people is recognized as beneficial, since an educated workforce can achieve higher productivity and innovation levels (Watson, Galwey, O'Connell, & Russell, 2009). Training and education on lean thinking can also help to overcome challenging aspects, such as resistance to change and communication. "Communicating, understanding, and believing in the new vision proved to be difficult, not only for employees, but also for management" (Czabke et al., 2008).

2.8 Supplier Selection in the Wood Products Industry

The overcapacity of suppliers is evident in the body of literature and seen during the application of the lean logistics VSM in three case study companies in Objective 1. This current supply chain challenge is closely related to the decision of selecting suppliers. Supplier selection is a vital portion of supply chain activities. Appropriate supplier selection is discussed in the following section.

2.8.1 Why is a Supplier Selection Model Helpful for the Wood Products Industry?

In today's competitive environment, characterized by thin profit margins, high consumer expectations for quality products, and short lead times, companies are forced to take advantage of every opportunity to optimize their business processes. To reach this goal, academics and practitioners have concluded that for a company to remain competitive, it must work with its supply chain partners to improve the chain's total performance. The purchasing function is gaining

increased importance, since it is the main process in the upstream chain and affects all areas of an organization (Yadav & Sharma, 2016).

Supplier selection and evaluation are two of the most critical functions for the success of an organization (Bhutta & Huq, 2002), given that a company's ability to handle purchasing has a profound impact on its competitiveness and profit-generating capacity (Gadde, Hakansson, & Persson, 2010). In addition, adding value to the supply chain is a crucial aspect that must be emphasized when selecting and evaluating suppliers to achieve competitive advantage (Bhutta & Huq, 2002).

Yadav and Sharma (2016) also argue that it is impossible to successfully produce low-cost, high-quality products without appropriate vendors. Thus, one of the most important purchasing activities is the selection of a competent group of suppliers. A suitable supplier may become cooperative and develop a long-term partnership, which can help the growth of a company and can be crucial to the success of the business. Hence, a systematic and effective procedure or method to select the most appropriate suppliers is important.

A report on the wood supply chain in the United States by Barynin & Taylor (2013) found that supplier-consumer relationships within the wood industry are currently tense. There is a need to rebuild business relationships to minimize disruptions in the wood flow throughout the chain. In their recommendations, these authors urged both wood suppliers and wood consumers to address their business strategies and relationships to achieve successful marketplace performance.

For these reasons, a structured supplier selection system model can be useful to help practitioners in the wood industry improve their procurement practices and their relationships with suppliers.

2.8.2   Supplier Selection Criteria

The supplier selection problem is multi-criteria. It is necessary to make a trade-off between conflicting factors, both tangible and intangible (Ghodsypour & O'Brien, 2001). A review of twenty articles in the literature revealed sixteen criteria proposed by five or more authors in previous supplier selection studies. A list of those criteria is shown in Table 11.

Table 11. Sixteen Most Mentioned Criteria in the Literature

Criteria	Related Work
Quality	(El Mokadem,2017) (Percin,2006) (Kumar & Pani,2014) (Sharma & Yadav,2016) (Aivaz & Kusakci,2016) (Kumar,2014) (Govindan & Sivakumar,2015) (Chen & Chao,2012) (Oliveira, Osorio, & Palma,2017) (Anjomshoae et al., 2015) (Amiri, Ghorabaee, Turskis, & Zavadskas, 2016) (Dehnavi & Mirmousa, 2016) (Acar, Gumus, Gurel, & Onden, 2015) (Haq & Kannan, 2007) (Hsu, Kannan, Leong, & Tan, 2006) (Zak, 2015) (Ávila, Bastos, Mota, Pires, & Putnik, 2012) (Gargeya & Su, 2016)
Cost	(El Mokadem,2017) (Kumar & Pani,2014) (Sharma & Yadav,2016) (Aivaz & Kusakci,2016) (Kumar,2014) (Govindan & Sivakumar,2015) (Chen & Chao,2012) (Kasirian & Yusuff,2012) (Anjomshoae et al., 2015) (Amiri, Ghorabaee, Turskis, & Zavadskas, 2016) (Hätönen & Roukonen, 2010) (Dehnavi & Mirmousa, 2016)(Haq & Kannan, 2007) (Hsu, Kannan, Leong, & Tan, 2006) (Zak, 2015) (Ávila, Bastos, Mota, Pires, & Putnik, 2012) (Gargeya & Su, 2016)
Delivery	(El Mokadem,2017) (Percin,2006) (Kumar & Pani,2014) (Sharma & Yadav,2016) (Aivaz & Kusakci,2016) (Kumar,2014) (Govindan & Sivakumar,2015) (Chen & Chao,2012) (Kasirian & Yusuff,2012) (Oliveira, Osorio, & Palma, 2017) (Anjomshoae et al., 2015) (Amiri, Ghorabaee, Turskis, & Zavadskas, 2016) (Dehnavi & Mirmousa, 2016) (Haq & Kannan, 2007) (Zak, 2015) (Gargeya & Su, 2016)
Financial Position	(El Mokadem,2017) (Percin,2006) (Kumar & Pani,2014) (Kumar,2014) (Chen & Chao,2012) (Hätönen & Roukonen, 2010) (Dehnavi & Mirmousa, 2016) (Haq & Kannan, 2007) (Hsu, Kannan, Leong, & Tan, 2006) (Zak, 2015) (Ávila, Bastos, Mota, Pires, & Putnik, 2012)
Long-term Relationship	(El Mokadem,2017) (Percin,2006) (Sharma & Yadav,2016) (Chen & Chao,2012) (Hätönen & Roukonen, 2010) (Acar, Gumus, Gurel, & Onden, 2015) (Hsu, Kannan, Leong, & Tan, 2006) (Ávila, Bastos, Mota, Pires, & Putnik, 2012)
Flexibility	(El Mokadem,2017) (Percin,2006) (Sharma & Yadav,2016) (Chen & Chao,2012) (Amiri, Ghorabaee, Turskis, & Zavadskas, 2016) (Dehnavi & Mirmousa, 2016) (Hsu, Kannan, Leong, & Tan, 2006)

Ease of Communication	(Kasirian & Yusuff,2012) (Oliveira, Osorio, & Palma, 2017) (Amiri, Ghorabaee, Turskis, & Zavadskas, 2016) (Dehnavi & Mirmousa, 2016) (Acar, Gumus, Gurel, & Onden, 2015) (Hsu, Kannan, Leong, & Tan, 2006) (Gargeya & Su, 2016)
Reputation	(El Mokadem,2017) (Percin,2006) (Anjomshoae et al., 2015) (Dehnavi & Mirmousa, 2016) (Hsu, Kannan, Leong, & Tan, 2006) (Zak, 2015)
Technical Capability	(Percin,2006) (Aivaz & Kusakci,2016) (Kumar,2014) (Chen & Chao,2012) (Amiri, Ghorabaee, Turskis, & Zavadskas, 2016) (Haq & Kannan, 2007)
Customer relationships	(Aivaz & Kusakci,2016) (Chen & Chao,2012) (Hätönen & Roukonen, 2010) (Dehnavi & Mirmousa, 2016) (Haq & Kannan, 2007) (Ávila, Bastos, Mota, Pires, & Putnik, 2012)
Services	(El Mokadem,2017) (Sharma & Yadav,2016) (Anjomshoae et al., 2015) (Dehnavi & Mirmousa, 2016) (Haq & Kannan, 2007) (Ávila, Bastos, Mota, Pires, & Putnik, 2012)
Logistics Cost	(Sharma & Yadav,2016) (Govindan & Sivakumar,2015) (Acar, Gumus, Gurel, & Onden, 2015) (Hsu, Kannan, Leong, & Tan, 2006) (Ávila, Bastos, Mota, Pires, & Putnik, 2012)
Manufacturing Capability	(El Mokadem,2017) (Percin,2006) (Kumar & Pani,2014) (Kumar,2014) (Ávila, Bastos, Mota, Pires, & Putnik, 2012)
Continuous Improvement Programs	(Percin,2006) (Chen & Chao,2012) (Oliveira, Osorio, & Palma, 2017) (Acar, Gumus, Gurel, & Onden, 2015) (Hsu, Kannan, Leong, & Tan, 2006)
Geographical Location	(Percin,2006) (Anjomshoae et al., 2015) (Amiri, Ghorabaee, Turskis, & Zavadskas, 2016) (Hsu, Kannan, Leong, & Tan, 2006) (Ávila, Bastos, Mota, Pires, & Putnik, 2012)
Order Fulfillment Lead Time	(Kasirian & Yusuff,2012) (Acar, Gumus, Gurel, & Onden, 2015) (Haq & Kannan, 2007) (Zak, 2015) (Gargeya & Su, 2016)

The top five criteria are quality, cost, delivery, financial position, and long-term relationship. Quality is defined by the Project Management Institute as "the degree to which a set of inherent characteristics fulfill requirements," that might belong to a product, a process or a system. One important consideration about quality is its counter entropic nature, meaning that it is not the natural order of things, or a naturally occurring event, but rather a result of never ending deliberate hard work regarding planning, contributing elements and disciplined process tools applications

(Rose K. , 2014, p. 6). In operational terms, low quality materials and services directly affect the output of an organization (Athawale, Mukherjee, & Chakraborty, 2009), Therefore, if a supplier is known to have an effective quality control system for their products, then the purchasing company can reduce the testing process for the raw material entering the process (Westcott R. , 2013, p. 490).

Selecting the right supplier has the potential to reduce the costs and strengthen the company's performance in the market place. Different authors define cost in different ways. Cost could refer to purchasing, transportation, inventory, operations, maintenance, energy, inspection, delivery, security, ordering, holding and others (Ghodsypour & O'Brien,2001). Delivery refers to the ability of the supply chain to provide the right product, at the right time, place, amount, in good condition, and packaging. Date of delivery, the accuracy in filling order and the percentage of items eventually shipped complete are parameters used to assess delivery success (Cirtita & Glaser-Segura, 2012),which has become critical to satisfy the customer's demands for suppliers, and contributes to the effective management of the supply chain (Klassen & Vachon, 2002).

Long-term relationships allow businesses to overcome barriers and develop performance-based contracting by negotiating and agreeing on performance targets established in contract clauses (Mouzas, 2016). Coordination can be achieved between supply chain parties, if they develop a long-term ongoing relationship (Ren, Cohen, Ho, & Terwiesch, 2010).The criteria selected to evaluate the suppliers is also affected according to the impact that the raw material provided by the suppliers has in the production processes of the company. If the item purchased does not have a critical impact on the company's performance, then price and availability may be all that needs to be considered. However, if the products and services purchased will have a significant impact on performance, then this simple view does not apply (Westcott, 2013, p.492. Therefore, a trade-off among all considered criteria should be weighed when selecting the best suppliers in any given situation (Athawale, Mukherjee, & Chakraborty, 2009).Ghodsypour & O'Brien (1998) propose selecting the evaluation criteria according to the level of integration desired with the suppliers. For this, they establish five levels of integration, as shown in Table 12.

Table 12.Important Criteria for the Supplier Selection Process According to the Level of Integration (Ghodsypour & O'Brien, 1998)

Level of Integration	Important Criteria
1. No Integration assumed	Price and quality
2. Logistical Integration	Logistical performance: reliability, flexibility, supply lots, lead time
3.Operational Integration	Supplier's process capability: set up time, lot size, lead time and number of quality inspections
4.Process and Products Integrated with Suppliers	Supplier's human resources: design involvement, management ability, culture
5.Business Partnership	Supplier's strategic direction: human and technological resources, direction of business.

2.8.3   Multi-criteria decision-making models

The pros and cons of an alternative can be described in a logical framework as part of a procedure and a defined set of rules that contribute to guide a decision maker in choosing the most appropriate option (Rogers, Bruen, & Maystre, 2000). To address the problem of making decisions using contradictory criteria, multiple-criteria decision-making methods (MCDM) have been developed. These methods allow decision makers to make decisions using several criteria or attributes (Kasirian & Yusuff, 2013). Each of these methods have different aggregation philosophies, structures, algorithms and processes for integrating multiple decision maker's viewpoints on multiple criteria regarding selection or evaluation problems (Mahjouri, et al., 2017). The criteria selected to address a problem of this kind is one to the most crucial steps of the process (Sultana, Ahmed, & Azeem, 2015).

An important aspect of the multi-criteria decision- making methods to consider is that the models do not attempt to compute an optimal solution, but to determine, via several ranking procedures, a ranking of the alternatives to select the best option with respect to several criteria (Triantaphyllou, 2000). Although several MCDM models have been developed, all of them follow the same basic steps, as shown in Figure 6.
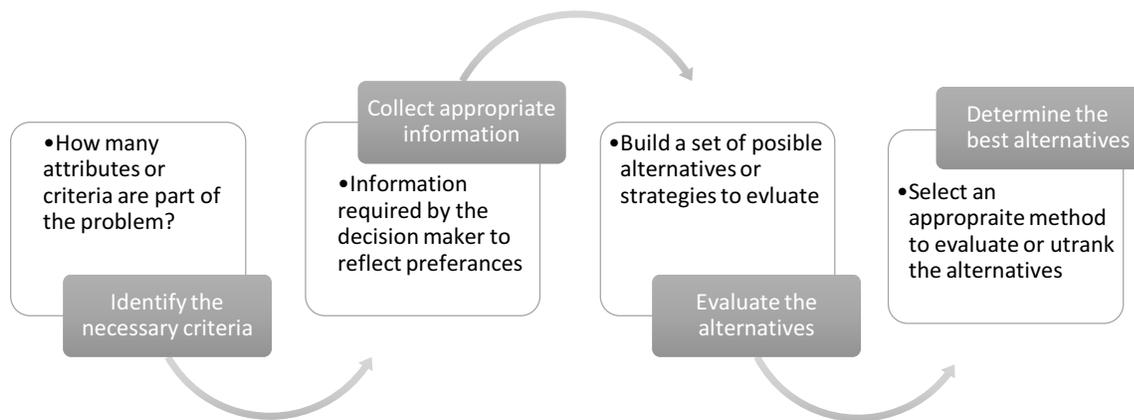
Figure 6.Steps to Deal with Multiple Criteria Decision-Making Problems (Tzeng & Huang, 2011, p. 1)

2.9 Methods Selected for Supplier Weighting and Ranking

2.9.1 The Analytic Network Process

The analytic network process is a multi-criteria theory of measurement utilized to give relative priority scales by using absolute numbers from individual judgments or actual measurements. The judgments represent the relative influence of one or two elements over the other in pairwise comparison process on a third element with respect to an underlying control criterion (Saaty T. , Fundamentals of the analytic network process-dependance and feedback in decision-making with a single netwrok., 2004).

Contrary to the AHP, the analytic network process (ANP) does not assume independence between levels of criteria or between criteria within the same level, and establishes a network without levels, which means that some criteria might influence other criteria. Networks in the ANP model generally include clusters, elements, and interactions may occur between and within them. All influences must be considered when using this method (Kasirian & Yusuff, 2013).

In ANP, not only is the importance of the alternatives determined by the importance of the criteria, but the importance of the criteria is determined by the importance of the alternatives themselves. The main structural difference between AHP and ANP is that while AHP is constructed in a top down manner, a network in ANP spreads out in all directions, involving cycles between clusters and loops within the same cluster (Saaty & Vargas, Decision Making with the Analytic Network Process, 2013, p. 7).
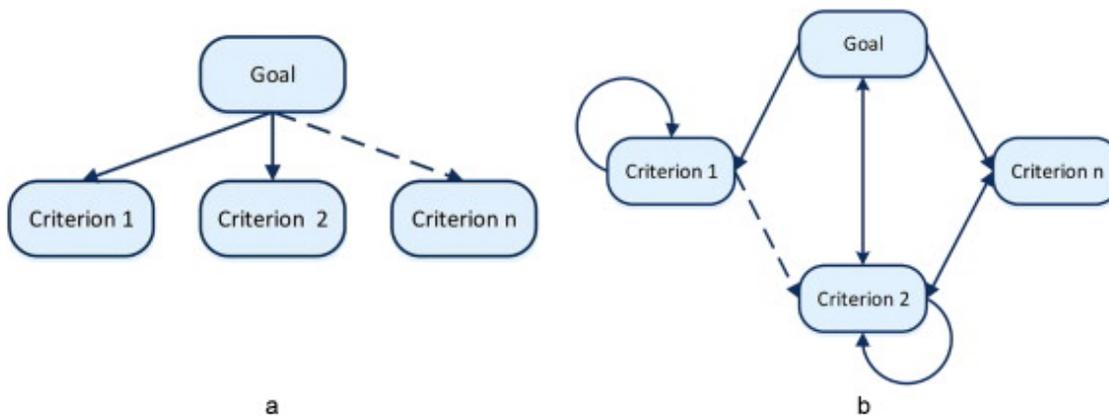
Figure 7. AHP and ANP Structure (Hashemi, Kamiri, & Tavana, 2015)

Figure 7 represents the structural difference between the AHP and ANP methods. The ANP is a generalization of the AHP. It could also be said that AHP is the simple and special case of an ANP network (Hashemi, Kamiri, & Tavana, 2015). In this ANP structure, any element can be a source, an origin of a path of influence, or a sink, the destination of a path of influence (Bottero, Comino, & Riggio, 2011). A general methodology to apply the ANP is shown in
Table **13**.

Table 13. General Methodology for the Analytical Network Process (Bottero, Comino, & Riggio, 2011)

Step	Name	Description
I	Structure Development	Structure is the first main objective defined. This objective is divided into groups (clusters) that are made of elements (nodes) and alternatives. This step also deals with the relationships between different parts of the network.

II	Pairwise Comparisons	Pairwise comparisons are made to determine the relative importance of elements with respect to particular components in the network. Components within the same level with interdependencies are controlling components to each other. Pair matrixes are created as a product of the judgments at each level of the network. Then the weighted priority vector is obtained by pairwise comparisons between elements.
III	Super Matrix Formation	A portioned matrix where each sub-matrix is constituted by a set of relationships between and within levels. This initial super matrix has all priority vectors derived from the pairwise comparison matrixes. The priority vector that results from a cluster comparison with respect to the control criterion is applied to the initial super matrix as a cluster weight, which results in a weighted super matrix.
IV	Final Priorities	The weighted super matrix is made to converge to obtain a stable set of weights. The super matrix is then raised to a limiting power to get a matrix where all columns are identical, and each gives the global priority vector.

2.9.2 Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS)

As a multi-criteria decision-making method, TOPSIS is a relatively easy way of ranking alternatives. The best alternative, according to this method, is the nearest to the positive ideal solution, one that maximizes the benefit criteria and minimizes the cost criteria, and the farthest from the negative ideal solution. The best values attainable from the criteria are part of the positive solution while the opposite is true for the negative solution (Sultana, Ahmed, & Azeem, 2015).

An important advantage of this method is that the ranking methodology is relatively simple, due to its systematic procedure. Several applications have been developed using this method and the results are satisfactory (Mahjouri, et al., 2017). The TOPSIS method is the one that produces the fewest rank reversals when compared to simple additive weighting, using four versions of the analytical hierarchy process, and ELECTRE (Zanakis, Solomon, Wishart, & Dublish, 1998). A rank reversal occurs when a new alternative is added to the original set of alternatives and the order relation on the old set of alternatives changes (Brunelli M. , 2015, p. 13). Pairwise comparisons are not necessary, which makes it easier to work with large numbers of criteria, as compared to methods like AHP, an unlimited number of criteria can be included and the model allows for interactions and trade-offs between criteria to take place (Savadogo & Shanian, 2006). Abd Manaf,

Ghoddusi, Halimoon, Ishak & Mahjouri (2017) mention that TOPSIS is a method with sound logic that can use linguistic or experimental variables and is easy to program. Its main weakness is its inability to provide consistency checking for the decision-making process, which is a crucial feature for the group decision making process (Kalbar & Karmakar, 2013). **Figure 8** shows the flow of the TOPSIS procedure.
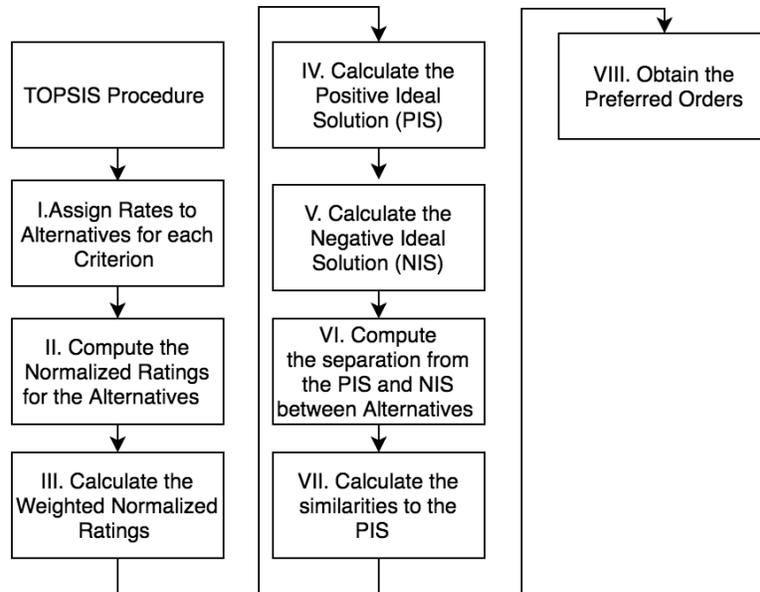
Figure 8.TOPSIS Method (Tzeng & Huang, 2011, pp. 69-71)

The first step in the TOPSIS procedure is to create a matrix with the ratings given to each criterion for all alternatives considered. Then, a normalized matrix is computed using the elements of the initial matrix in order to get the normalized weighted matrix using weights previously established. The core of the method is the positive ideal solution (PIS) and the negative ideal solution (NIS), which are necessary to calculate the separation between both with the alternatives using the Euclidean distance approach. Finally, the similarities to the PIS are computed and, based on them, the preferred orders are obtained according their descending order for choosing the best alternatives (Tzeng & Huang, 2011, p. 70).

2.10 Total Cost of Ownership Supplier Selection Methods

The total cost of ownership refers to all the costs related to a purchase, starting with the purchase itself and through the entire value chain of the company (Shank & Govindarajan, 1992). This means that the method goes beyond minimizing the purchase price, taking into account all the costs that take place during the item life cycle, which includes service, quality, delivery, administration, inventory holding, communication, and defects, among others. In order to visualize and quantify these costs, the activity based cost methodology (ABC) is helpful, which is not an optimization tool, but provides accurate input for the optimization (Degraeve, Labro, & Roodhoft, 2005). Kanagaraj, Ponnambalam & Jawahar (2016) considered three fundamental cost elements as part of the TCO model, starting with procurement cost, which is related to the costs associated with the purchase and the application to the operation. Replacement cost represents the cost of replacing a failed component during the intended product lifetime. The downtime cost represents the cost incurred due to non-availability. The suppliers selected are those that give the company the least value of total cost of ownership. Figure 9 shows the relationship between those main costs cited above and the product cost and reliability.
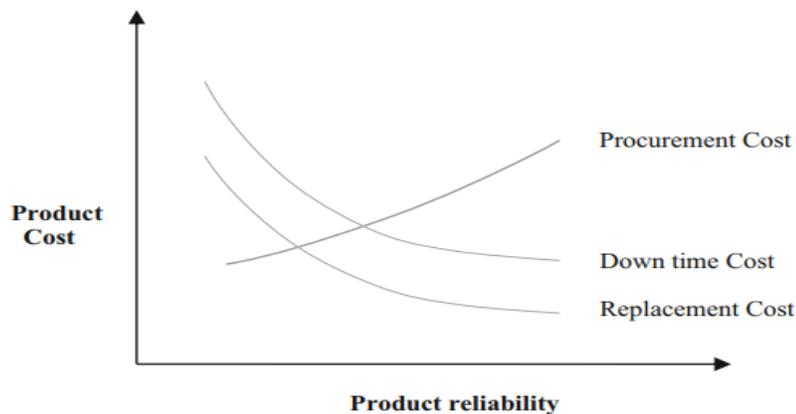
Figure 9.Product Cost-Reliability Relationship (Kanagaraj, Ponnambalam, & Jawahar, 2016)

The core of a supplier selection process using the total cost of ownership approach considers cost as the final measurement of suppliers, which are a consequence of the supplier's performance (Dogan & Aydin, 2011). The greatest strength of the model is to use the same model to select and to evaluate suppliers across the board, identifying the best option according to the lowest transaction cost. However, the model is unable to take into account qualitative criteria and work, in an environment where subjective assessments are needed in comparing factors (Bhutta & Huq, 2002).

2.11 The Supplier Relationship

The main benefits of logistics alliances are that they allow the outsourcing company to concentrate on the core competence, increase the efficiency, improve the service, reduce the transportation cost, restructure the supply chains, and establish the market place legitimacy (Hertz & Alfredsson, 2003; Skjoett-Larsen, 2000; Bhardwaj, Gupta, & Sachdeva, 2010). The relationship between a company and its suppliers is important for an effective supply chain system because its effects on the chain's competitiveness lasts once the supplier becomes a part of the chain (Chen & Lin, 2006).

The supplier relationship management goes beyond supplier selection and evaluation, encompassing areas like purchasing strategies, supplier collaboration and supplier development. Therefore, it is important to have a holistic approach when dealing with this kind of relationship. A framework for supplier relationship management is shown in Figure 10.

```
┌──────────────┐   ┌──────────────┐   ┌──────────────┐   ┌──────────────┐
│ Shaping the  │   │   Supplier   │   │ Collaboration│   │   Supplier   │
│  Purchasing  │ → │   Selection  │ → │  (Supplier   │ → │ Assessment   │
│  Strategies  │   │              │   │ Involvement) │   │ and          │
└──────────────┘   └──────────────┘   └──────────────┘   │ Development  │
                                                          └──────────────┘

┌─────────────────────────────────────────────────────────────────────┐
│                      Continuous Improvement                           │
└─────────────────────────────────────────────────────────────────────┘
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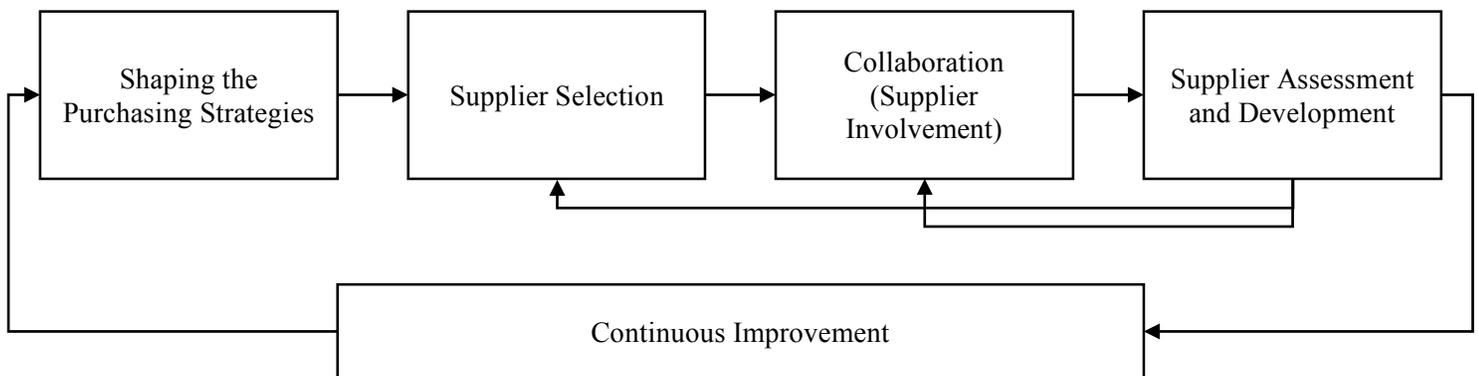
Figure 10.Integrative Framework for Supplier Relationship Management (Park, Shin, Chang, & Park, 2010)

The main goal of any business is to make money. To achieve this, a company must accomplish long-term stability and profitability by producing the highest quality product at the lowest possible cost. The procurement department is responsible for developing a supplier base that is in line with the main objective. In technical terms, the foundation of a supplier partnership strategy is to provide incentives to the supplier to provide high quality products and services, and mutually beneficial policies (Bossert J. , 2004).

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2.12 Model Validation & Verification

A tool needs to be properly verified and verified in order to determine if it functions as it was initially intended during the design phase. **"**Model verification and validation are the primary processes for quantifying and building credibility in numerical models" (Thacker, et al., 2004). Verification determines if a model implementation portrays the intended conceptual description of the model and its solution (American Institute of Aeronautics and Astronautics, 1998). Feigin (2016) defines verification as "the process of confirming that the model as implemented in software does what the model designer intends". Validation determines to what degree the model is an accurate representation of the real world within the scope of the intended uses of the model (American Institute of Aeronautics and Astronautics, 1998). "Validation is the process of confirming that the model is a reasonable representation of the real-world system being modeled" (Feigin, 2016). Figure 11 shows the detailed model development, verification, and validation process.
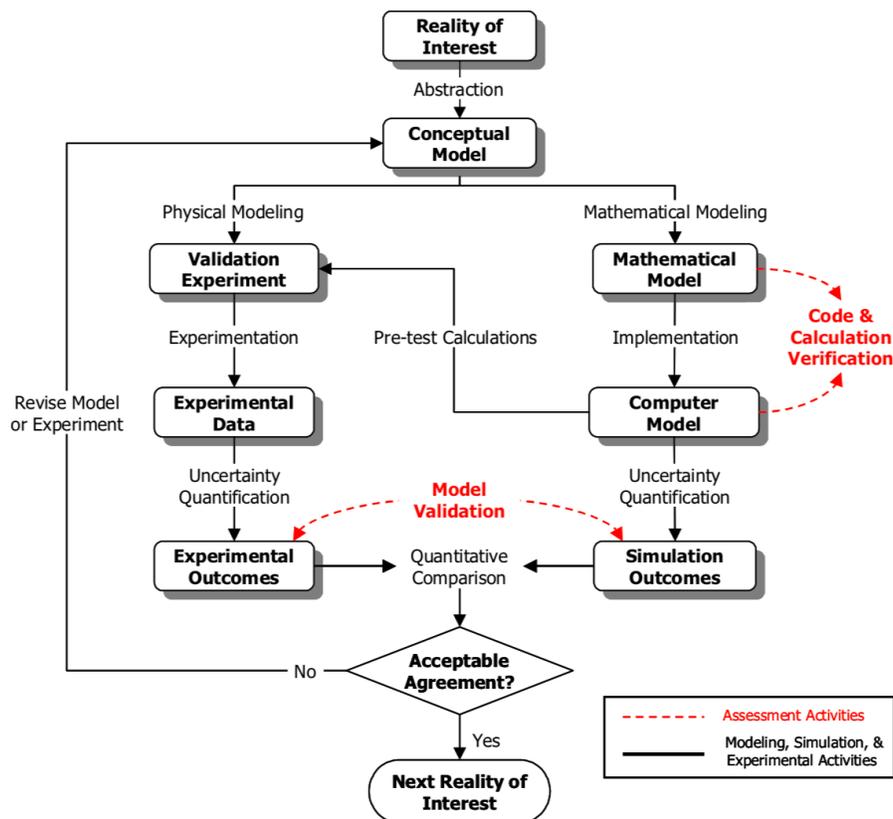
Figure 11. Detailed Model Development, Verification, and Validation Process (Thacker, et al., 2004)

"Mathematical modeling can be thought of as the activity involved in finding a solution to a real-life problem by working with a mathematical structure that captures the important characteristics of the situation" (Hirst, 2013). The conceptual framework may be presented as a research guide, providing a visual representation of theoretical constructs and variables of interest (National Center For Postsecondary Improvement, 2013). When developing a conceptual model, various components must be identified: the computational objective, the required level of agreement between the experiment and simulation outcomes, the domain of interest, all important physical processes and assumptions, the failure mode of interest, and the validation metrics.

The mathematical modeling and the mathematical formulation of a problem is a one of the first key steps in creating the computer model, but not the computer model itself. The next major step is the process of taking a mathematical model and implementing it into a useful software program (Feigin, 2016). Code and calculation verification assessments are performed on the computer model. This is done to identify and eliminate: errors in programming, insufficient grid resolution, solution tolerances, and finite precision arithmetic (Thacker, et al., 2004). "Software verification provides objective evidence that the design outputs of a particular phase of the software development life cycle meet all of the specified requirements for that phase (U.S. Department Of Health and Human Services Food and Drug Administration Center for Devices and Radiological Health Center for Biologics Evaluation and Research, 2002). Although the insertion of a mathematical model into a computer model and the verification are significant steps, the most important consideration in a computer model is the data needed to populate it, because without adequate data the computer model is just an abstraction (Feigin, 2016). The validation experiment in Figure 11 refers to a physical experiment. The purpose of the experiment is to provide the information needed to validate the model. Once the information is obtained, it is utilized to determine if the model's results are in acceptable agreement with the experiment. The acceptable agreement is a decision that evaluates the comparison between the experimental outcomes and the simulation outcomes (Thacker, et al., 2004). To perform a validation a commonly used method is to identify one or more base cases, which are scenarios or model instances, which describe the real system. Examples of these base cases are data obtained from past periods (Feigin, 2016). "If the

agreement between the experimental and simulation outcomes is unacceptable, the model and/or the experiment can be revised" (Thacker, et al., 2004).

3. Goals and Objectives

The literature review provides strong evidence of the critical problems affecting the wood fiber supply chain related to waste. The literature consulted explains why these critical problems exist, what the consequences are, and generic recommendations. Therefore, the diagnoses and analysis of the current state of the problem exist. However, there is a gap in the literature regarding tools or methodologies to help forest products companies identify their own waste and diagnose their current status, opportunities for improvement, and what areas need reinforcing. Tools that introduce lean thinking practices or structured ways to perform supply chain management activities are currently missing. The main research question is: *Can the implementation of lean manufacturing tools such as a VSM and a supplier selection model be used to reduce waste between suppliers and consumers within the wood fiber supply chain?*

The main hypothesis statement of this research is: 1) *The introduction of Lean manufacturing tools such as VSM can be used to identify and potentially reduce waste in the wood fiber supply chain: 2) The introduction of a structured supplier selection model and tool will provide the baseline needed to prioritize suppliers; 3) The prioritization will help consumer companies identify the suppliers that add value to their operations and encourage a proactive planning process between suppliers and consumers.* This research aims to provide validated tools that can help the wood fiber supply chain overcome current supply chain management challenges. Respectively aligned with the hypotheses, the three objectives of this study are as follows:

1. To introduce a Lean manufacturing tool in the wood fiber supply chain to identify and reduce waste by developing and implementing a lean logistics value stream map. The specific focus is the upstream supply chain for three different industry sectors: a paper mill, a sawmill, and a logging company.
2. To introduce a structured supplier selection model and computational tool into the wood fiber supply to prioritize suppliers.
3. To verify and validate the supplier assessment and supplier selection computational tool in order to determine that the model as implemented prioritizes suppliers.

4. Methodology

This research involves three individual case studies. The case studies performed in this research are based on a descriptive qualitative study. Yin's definition of a descriptive case study is an intervention or an occurrence in its real-life-context (2009). A case study approach was selected, since it uses experience or observation to investigate a contemporary phenomenon in depth and within real life context. The contextual conditions surrounding the phenomenon and the boundaries between the two are not clearly evident (Yin, 2009). A case study provides information which is only intended to describe the specific group. (Hancock & Algozzine, 2006).

The unit of analysis is defined by Yin as what the "case is" (Yin, 2009). The case studies throughout this thesis represent the abstraction of different processes of the upstream wood fiber supply chain from supplier to consumer, specifically: logistic operations and the supplier selection process, both within the context of wood fiber supply chain. The first objective includes three different case studies which focus on a supply chain representing three different industry sectors: a paper mill, a lumber sawmill, and a logging company. The second objective studies interviews performed with wood product industry stakeholders and wood science professors. The third objective includes seven interviews with company representatives. There are three interviews with three different loggers, two interviews with two different sawmills, and two interviews with two different paper mills. This research involves single-case studies since there are no other cases available for replication. An inconvenience of a single-case design is its inability to provide a generalized conclusion (Zainal, 1997).

There are multiple ways of collecting data for this research. Sources of evidence include documents, archival records, interviews, and direct observation. The selection of multiple sources of data is intended to support a qualitative case study approach, since it aids in the exploration of an occurrence throughout multiple data sources. This would translate into the phenomenon being captured from different perspectives (Baxter & Jack, 2008). Multiple sources of evidence contribute to the triangulation in order to develop converging lines of inquiry (Yin, 2009).In the interest of procuring a high-quality research design three tests have been applied (see

Table **14**).

Table 14. Quality Research Design (Yin, 2009)

Tests	Case Study Tactic Applied
Construct Validity	Multiple sources of evidence have been collected to enhance data credibility Chain of evidence conducive to conclusions Review of case study report by key informants
External Validity	Analytical generalization The models developed are intended to be generalized to other similar processes
Reliability	Case study protocol Documentation of procedures

4.1 Objective 1

Objective 1: To introduce a Lean manufacturing tool in the wood fiber supply chain to identify and reduce waste by developing and implementing a lean logistics value stream map. The specific focus is the upstream supply chain for three different industry sectors: a paper mill, a sawmill, and a logging company.

4.1.1 Task 1: To Determine the Lean Metrics for a Lean Logistic VSM for the Wood Fiber Supply Chain Processes from Stumpage to Log Yards.

4.1.1.1 Description of Activities and Methods:

Value stream mapping is a lean manufacturing or lean enterprise technique that was used as a basis. The value stream map included the major inventory points from stumpage to log yard. The major inventory points are supplier's inventory, inventory transported, and the inventory at the consumer's log/wood yard. The lean logistics metrics that were considered in the framework came from the literature review. Existing metrics that could be used as lean logistic metrics were extracted from the existing VSM technique. New metrics were also aggregated to the existing group of metrics. The metrics enable an adequate measurement of lean logistics operations and the evaluation of the current state of the system. Table 15 shows the main metrics utilized, the description, and the units.

Table 15. Main Metrics

Metric	Description	Units
Order to Shipment/ Transit Time	Order to Shipment: The period of time when an order is executed to when it is ready for shipment. Transit Time: The time the shipment takes to be delivered from the harvesting operation to the consumer's wood/log yard.	Days
Lead Time/Total Lead Time	In the VSM, the lead time is the sum of the order to shipment and transit time. The total lead time is the lead time and the inventory days on average.	Days
Process Time	Process time is the amount of time that the supplier needs to deliver raw material. Case Study 1: The number of days, on average, that it takes a logger to harvest. Case Study 2: Theoretical time the loggers with quotas have to bring in loads. Case Study 3: Timeframe between receipt of an order by the sawmill to completion of harvesting operations.	Time Units
Inventory	In the value stream, inventory is: • The wood carried at stumpage. • The logs harvested and transported (this is inventory within the transportation portion of VSM). • The wood at the wood/log yard.	Days
Average Days on Hand(ADOH)	Tons of the inventory at the wood yard or standing, based on average consumption of the VSM mills.	Days' Supply
Minimum Order Quantity (MOQ)	The minimum amount of material moved.	An Average Truckload
Cost of Fulfillment	The cost of logistics activities that are required to move wood from stumpage to wood/log yard, which includes the following costs: • Wood Yard Cost • Material Ordering • Harvesting Cost • Inbound Logistics • Supplier Collaboration • Inventory Carrying Costs	Dollars ($)
Carrying Cost	Carrying costs are the expenses that come from holding goods in storage.	Dollars ($)

The specific lean logistics metrics that where measured in each case were:

• Operational metrics, inventory levels, travel distances, transit times, batch sizes, minimum order quantities, total lead time, and current demand. Table 16 shows sample data collected for the operational metrics.

Table 16. Operational Metrics Sample Data

Inventory Levels	Travel Distances	Transit Times	Batch Sizes	MOQ	Total Lead Time	Current Demand
Historical information of inventory levels	Average distance from suppliers in selected value stream	Distance and average truck speed	Average Truck Size		ADOH and transit time	Average of current demand of value stream selected

• Cost of fulfillment data, transportation costs, inventory carrying costs, and material handling costs (from suppliers and consumers). Table 17 shows the sample information for the cost of fulfillment.

Table 17. Sample Information for Cost Fulfillment

Material Ordering	Transportation Costs	Inventory Carrying Costs	Log Yard
• Personnel: Quantity and salaries	• Number of Incoming Tons Daily • Days worked per year • Cost per ton loaded per mile	• Average inventory at each point of interest • Value of inventory per unit • Demand	• Number of people working and specific salary Material handling: • Specification and number of machines utilized at log/wood yard • Operating and fixed costs of machines were determined with information provided by the company and input from literature

• Fulfillment-stream performance data using perfect-order execution metrics such as: time, quantity, quality, place, product, supplier, cost, and service. The metrics were calculated using the historical reports solicited or by asking the contact person in each company. The information for this metrics was provided from historical information solicited from the case study companies. The data collected was then compared with results from similar literature† to ensure its validity and reliability.

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† (Rodgers, Visser, Shaffer, & Gallagher, 2002)(Gallagher, Smidt, McDonald, & Tuffs, 2004)(Greene , et al., 2006)(Greene, et al., 2002)(Greene, Mayo, Cornelis, & Egan, 2004)

4.1.2 Task 2: To Apply a Lean Logistic Value Stream Map (VSM) to a Selected Value Stream in Three Case Studies within the Wood Fiber Supply Chain.

4.1.2.1 Description of Activities and Methods:

A formal interview request was sent via e-mail to thirteen consumer companies and eleven logging companies. The companies targeted were current members of the Wood Supply Research Institute that were either loggers or consumers. Three companies confirmed their participation. The case study firms who participated were a paper mill, a logging company, and a sawmill. The case studies are representative of the upstream wood fiber supply chain because the logging company, the paper mill company, and the sawmill company belong to sectors that significantly impact the forest products industry. The largest segments of the forest products industry in the United States are industrial roundwood and sawnwood. Industrial roundwood accounts for 38.5% of the industry's total value, and sawnwood accounts for 37.6% of the industry's total value (MarketLine Industry Profile, 2017). Sawmills, millwork, and treating account for 625 manufacturing facilities, which is the largest fraction of total wood products (American Forest & Paper Association , 2017).

Pulp, paper, and paperboard mills represent the second largest number of manufacturing facilities (343 facilities) in the paper manufacturing sector of the industry. The largest manufacturing facilities are the converted paper products, but these facilities (4,047 products) are not part of the upstream wood fiber supply chain. The third case study is part of the logging and forestry sector which represents the supplier portion of the upstream wood fiber supply chain selected. One unstructured interview was conducted with each company and their management personnel. The meeting goals were:

- Direct Observation: The overall logistics and production processes were observed to understand the major operations of the case study firm and identify potential value streams for the project.
- General Project Scope: Timeframe, purpose, expected input from the company, and expected output from the project was established. The expected input was the time commitment, and an overview of the type of information required. The expected outputs were the deliverables to the company, which was the VSM map with a respective analysis.

- Selection of the value stream under study: The current value streams of the company were discussed with procurement personnel to select one value stream that would involve the major inventory points in the upstream supply chain: supplier(s)'s inventory, transportation inventory, and the company's inbound inventory (log/wood yard).

- Data Collection: The data needed to fulfill the lean metrics extracted from the literature review was discussed with the company. Historical reports of interest were solicited. Historical reports solicited for consumers and the supplier included information on quota distribution and fulfillment per supplier, the mill's forecasted demand and actual demand, the hauling distance averages for each supplier, standard timber quantity across time, the estimated stumpage value per ton for each supplier, and the average inventory at the consumer company's inbound inventory site (log/wood yard). These historical reports were of interest because relevant information could be extracted and measured.

- Follow up procedure: Once the historical information from each company had been analyzed and the metrics that could be measured with the historical reports obtained had been identified, the remaining metrics were obtained from direct consultation with the main point of contact, who would obtain the information from key collaborators within the company.

The interview results, documentation analysis, process observation, and metrics collected in tasks 1 and 2 were used to implement a VSM to a particular value stream with each company. The current VSMs were a visual representation of the material and information flow process from the supplier to the wood/log yard in each case.

4.1.3 Task 3: To Identify Potential Sources of Waste from Each Lean Logistic VSM in the Selected Value Streams.

4.1.3.1 Description of Activities and Methods:

In lean thinking there are eight different types of wastes that could impact productivity, customer service, quality, cost, and the general performance of the value stream. The eight categories of waste were identified in common practices within the wood fiber supply chain. The identification of this type of waste was determined through: the interview at each process site done in Task 2,

analysis of the current lean logistic VSM, provided historical reports, and direct observation of the operations. Results from waste identification in the wood fiber supply chain from the literature review‡ were used to cross-validate the results.

Finally, the analysis of the current VSM and the different sources of waste were used to make recommendations to decrease or eliminate waste in each case. This analysis was critical to establish a baseline for a future VSM that could be used as a strategic tool for the companies. Results were disseminated through a report explaining the main principles behind lean thinking and how to apply the VSM to a wood fiber supply chain.

4.2   Objective 2

Objective 2: To introduce a structured supplier selection model and computational tool into the wood fiber supply to prioritize suppliers.

4.2.1   Task 1: Identify Qualitative and Quantitative Criteria for Supplier Selection to be Implemented in a Structured Model.

4.2.1.1   Description of Activities and Methods:

Figure 12 shows an overview of the steps taken to obtain the list of assessment and selection criteria. First, a literature review of supplier selection in other industries was performed. The result was the extraction of the most relevant knowledge on the subject. A list of metrics for supplier selection was created. The criteria included both qualitative and quantitative dimensions.

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‡ (Rodgers, Visser, Shaffer, & Gallagher, 2002)(Gallagher, Smidt, McDonald, & Tuffs, 2004)(Greene , et al., 2006)(Greene, et al., 2002)(Greene, Mayo, Cornelis, & Egan, 2004)
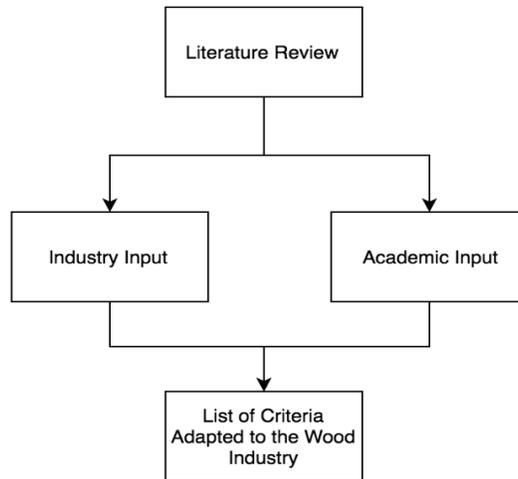
Figure 12. Steps to Obtain the List of Criteria

After the literature review was performed, semi-structured interviews were conducted with both industry and academia to understand current industry practices regarding supplier selection. Interviews were selected because qualitative research explores and describes the "quality" and "nature" of how people behave, experience, and understand (Brown, 2001). Performing interviews offers the opportunity to obtain or uncover information that may not be accessible with other methods such as questionnaires and observation (Blaxter, Hughes, & Tight, 2006). The interviewees were purposely solicited from industry and from academia to obtain different perspectives on the subject. The interviewees were contacted through email.

To complement the literature review and maintain a similar structure to industry practices, current methods in the industry for supplier selection were also researched. In the interviews performed a question was designed to help determine and understand current methods used for supplier selection in the industry (see Table 18). Four interviews were conducted from August 2017-December 2018. The interviewees were selected based on their availability and willingness to perform the interview, and their experience related to the topic. Two interviews were conducted with industry. One interview was conducted with a District Manager of Woodlands, and another was conducted with a strategic management collaborator from a company that owns two sawmills (see Figure 13).
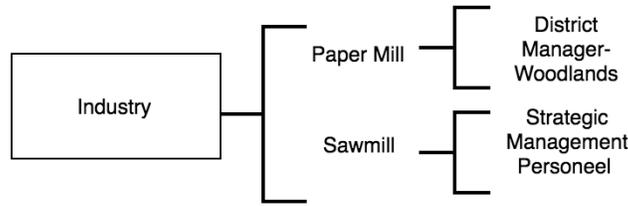
Figure 13. Industry Interviews

Two interviews were conducted with academia. Two professors were approached, both with areas of research related to the logging industry (see Figure 14).
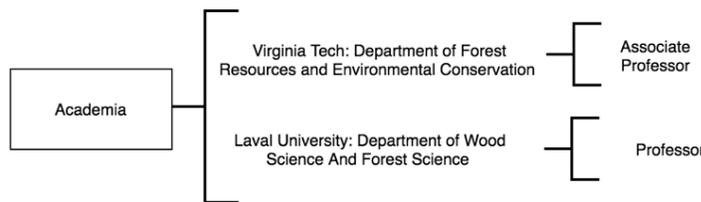
Figure 14. Academia Interviews

The goal of the interview was to develop further understanding of the current status of supplier selection within the industry. This included discussions on the capability of the criteria selected and its prior implementation in a structured tool. Feedback to further improve the tool was also sought. Table 18 shows the questions asked in the semi-structured interviews.

Table 18. Question Guide for Semi-Structured Interview with Industry and Academia

Question guide for Semi-Structured Interview with Industry and Academia
What raw material is needed for the production process, and where does the company get it? (Bolstorff & Rosenbaum, 2012)
Does the company work with a group of core suppliers in order to build a resilient supply chain? (Rezapour, Zanjirani, & Pourakbar, 2017)
How would the company describe the relationship with its suppliers? (Ren, Cohen, Ho, & Terwiesch, 2010).
What is the process that the company follows to select its suppliers? (Athawale, Mukherjee, & Chakraborty, 2009) (Yadav & Sharma, 2016)
What are the criteria that the company considers when selecting or assessing a supplier? (Chen & Chao, 2012).

The result was a list of criteria adapted to the wood industry reflecting the main considerations of the literature review performed and inputs from academia and industry.

4.2.2   Task 2: Determine the Selection Model to Create a Preference Order for the Number of Suppliers and Incorporate it in a Computational Tool.

4.2.2.1   Description of Activities and Methods:

The criteria obtained in the previous section was utilized for the creation of a preference order, with a number of suppliers. Since this a problem of decision making "supporting subjective evaluation of a finite number of decision alternatives under a finite number of performance criteria" (Behzadian, et al., 2012, as cited by Mahjouri, et al, 2017), it was classified as multiple-criteria decision-making problem. Multiple-criteria decision-making methods (MCDM) were selected because MCDM methodologies are a scientific way to select between several alternatives. This selection is performed through an informed and justified decision process (Abdulagader, Eid, & Daneshvar, 2018). Decision aiding is a significant procedure that adds a scientific perspective to an otherwise intuitive process. Decision approaches are presumably ongoing processes that do not use a rational procedure. Decision approaches take into account multiple factors with more or less conflicting stakes within a complex context (Roy, 1999).

The main multiple-criteria decision-making methods (MCDM) were obtained from a literature review, and two were selected based on the differences identified by Mahjouri, et al, (2017) of MCDM methods, and the applicability to Specific Objective 2. It was important that subjective criteria could be systematically organized. The differences between criteria are:

1. Aggregation philosophy
2. Structure
3. Algorithm
4. The process utilized to integrate multiple decision viewpoints on multiple criteria regarding selection or evaluation of programs.

Table 19. Differences between AHP and TOPSIS

Differences	AHP	TOPSIS
Aggregation Philosophy	Value measurement models (Wang, Cheng, & Kun-Cheng, 2009): Weight Assessment	Goal, aspiration and reference level models (Wang, Cheng, & Kun-Cheng, 2009): Ranking Model

Structure	Rigorous and systematic judgment in decision-making contexts, with a solid theoretical foundation, can incorporate tangible and in-tangible unstructured information (Mahjouri, et al, 2017)	Representation of relational human choices with the strength that a scalar value accounts simultaneously for best and worst alternatives (Mahjouri, et al, 2017)
Algorithm	AHP uses a pairwise comparison of the criteria importance with respect to the goal. This pairwise comparison allows finding the relative weight of the criteria with respect to the main goal (Mu & Pereya-Rojas, 2017)	Method obtains information based on decision matrices and weights, the shortest geometric distance from the positive ideal solution, and the longest distance from negative ideal solution (Shih, Shyyur, & Lee, 2007)
Process	Pairwise comparison (cardinal ratio measurement) (Shih, Shyur, & Lee, 2007)	The distances from PIS and NIS (cardinal absolute measurement) (Shih, Shyur, & Lee, 2007)

The most applied MCDM methods to supplier selection problems are AHP and TOPSIS (Chai, Liu, & Ngai, 2013). TOPSIS is considered an adequate assessment because the evaluation of a supplier's performance is based on the performance of the others, therefore it is a functional method for comparison of all candidate suppliers and selecting the best one (Sureeyatanapas, Sriwattananusart, Niyamosoth, Sessomboon, & Arunyanart, 2018). AHP and TOPSIS are methods that have been combined because they complement one another. TOPSIS usually assumes that the weights of attributes are given once the method is applied" (Shih, Shyur, & Lee, 2007). "TOPSIS does not provide weight elicitation or consistency checking for expert opinions, which are very crucial in group decision-making" (Kalbar & Karmakar, 2013). "Some authors suggest using AHP or other techniques to obtain the weights" (Shih, Shyur, & Lee, 2007).

The AHP model utilizes the Saaty scale which was selected because it is the original linear scale and has been, by far, the most often utilized in applications (Franek & Kresta, 2014). The original linear scale has been shown to be the best scale to represent weight ratios by Saaty (1994). The scale proposed is in Table 20.

Table 20. Scale Proposed for the AHP Model (Saaty & Vargas,2013,p.3)

Intensity of Importance	Linguistic Variable	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one activity over another

5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very Strong or Demonstrated Importance	An activity is favored very strongly over another, its dominance demonstrated in practice
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation

In the same way as the determination of relative importance of criteria, it was necessary to determine a scale to assign the rates in the AHP model. In order to have consistency across the phases in regard to scales, a Saaty scale was proposed to assign the rates for the alternatives. A modification of the fuzzy Saaty scale used by Sultana, Ahmed & Azeem (2015) was proposed for the model as shown in Table 21. The scale for the assignation of the rates for the alternatives was selected based on the simplicity.

Table 21. Scale Proposed for the Assignation of Rates for the Alternative Suppliers (Sultana, Ahmed, & Azeem, 2015)

Intensity of Performance	Linguistic Variable for the Level of Performance
1	Poor
3	Below Satisfactory
5	Satisfactory
7	Highly Satisfactory
9	Excellent

The computational tool is an application that has been designed using the visual basic application module in Microsoft Excel. The tool is the computer model resulting from the implementation of the structured AHP-TOPSIS model. The result is a model that uses quantitative and qualitative criteria and integrates them systematically to obtain an order of preference for a given number of alternative suppliers. The integration of findings into a single tool provides practitioners in the wood industry with a simple and structured way of selecting suppliers.

4.3   Objective 3

Objective 3: To verify and validate the supplier assessment and supplier selection computational tool in order to determine that the model as implemented prioritizes suppliers.

4.3.1   Task 1: To Verify the Supplier Assessment and Supplier Selection Computational Tool.

4.3.1.1   Description of Activities and Methods:

An option to validate scientific theory is to demonstrate that the results obtained match known results. Within the AHP "this usually means finding examples with measures in an already known scale." (Whitaker, 2007). The AHP and TOPSIS computational steps were verified by computing the steps manually and comparing the answers to the results obtained by one of the interviews conducted. The following procedures were performed manually and compared to the tool's output.

Steps of the AHP Verification

1. The grades that were assigned by the interviewee or the user were pairwise comparisons between criteria. These grades conform the matrix of pairwise comparisons in the AHP model. These grades were the input data to calculate the geometric mean of the i^{th} row of the matrix of pairwise comparisons.

2. Once the geometric mean was obtained for every row of each criteria, the weight was divided by the value of the summation of all the geometric means to obtain the normalized geometric mean.

3. The normalized geometric mean was multiplied by 100 to display results in percentages.

4. The results obtained in the final weight percentage or normalized geometric mean (Step 3) are the inputs to the TOPSIS model or phase II two of the supplier selection model.

Steps of the TOPSIS Verification

1. By using the matrix obtained by the interviewee to rate every supplier against the selected criteria, the normalized rating matrix was obtained by computing the normalized rating equation.

2. The weighted normalized matrix was computed by multiplying each entry of the normalized rating matrix by the corresponding weight for each criteria obtained in the AHP computation utilizing the weighted normalized rating equation.

3. The positive ideal solution and the negative ideal solution were obtained by using the positive and negative ideal solution equation respectively.

4. The distance of each alternative to the positive and negative solution was computed using the equation for the distance to the positive and negative ideal solution respectively.

5. The similarity coefficient to the positive ideal solution was calculated for every alternative using the corresponding equation (equation for the similarity coefficient to the positive ideal solution.

6. Once the similarity coefficient to the ideal positive solution was computed and multiplied by 100, the preference order was determined.

The result's from the tool's output were compared to the known results, in this case the known results were the manually computed output.

4.3.2   Task 2: Validate the Supplier Assessment and Supplier Computational Tool.

4.3.2.1   Description of Activities and Methods:

In order to validate the tool, seven companies were interviewed within the forest products industry. Three interviews were conducted with three different loggers (suppliers), two different interviews were conducted with both types of consumer companies (sawmill and paper mill). The following subsections describe the limitations, interview process, and the questions that were asked specifically of each stakeholder. The limitations, the interview process (depending on type of stakeholder), and the questions asked are discussed below.

Limitations

In order to validate a conceptual model, there needed to be a mathematical model and a validation experiment. It was particularly challenging to validate the supplier selection tool because the "usual way that buying firms make decisions on supplier selection is to simultaneously consider

the performances of all candidate suppliers against all chosen criteria. The decisions are then made subjectively or intuitively" (Zhang H, 2006 as cited by Sureeyatanapas, Sriwattananusart, Niyamosoth, Sessomboon, & Arunyanart, 2018).

Burke and Miller (1999) conducted interviews with more than sixty professionals across various industries in the United States, they found that managers usually made decision based on intuition (Burke & Miller, 1999). Therefore, finding a company that already applied the hybrid AHP and TOPSIS model was not possible. Furthermore, applying an industry case study for validation was challenging due to the time and resources available. Therefore, interviews were designed for validation.

Interview Process

The interview was designed to evaluate the capability of the completed functional tool for the industry. Two different semi-structured interviews were designed; one was to validate the criteria and the other was designed specifically for the consumer companies (tool validation). The personnel targeted were either procurement personnel or loggers (depending on the company). The interviews were conducted from August 29th to September 30th, 2018.

Supplier Interview

Figure 15 describes the supplier interview which consists of three steps: overview of the supplier selection process and the tool (step 1), feedback on criteria (step 2), and the discussion of potential opportunities of improvement to supplier/consumer relations through tool utilization (step 3).
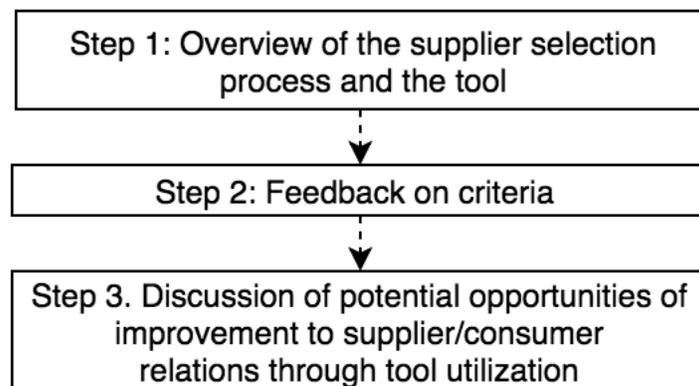
Figure 15.Validation of the Supplier Selection Tool

Consumer Interview

Figure 16 displays the consumer interview process which consists of the overview of the supplier selection process (step 1), feedback on criteria (step 2), using the tool (step 3 & 4), evaluation of the tool's result (step 5), and questions regarding the user's experience (step 6). The main purpose of the academic exercise was to obtain each stakeholder's perspective and to prove the accuracy of the tool. The criteria portion of both the consumer and supplier interview processes focused on the same topics.

Step 1: Overview of the Supplier Selection Process

Step 2: Feedback on Criteria

Step 3: Decision Maker Proceeds to Evaluate the Criteria Making Pairwise Comparisons

Scale (Saaty & Vargas, 2013, p.3)

1 Equal Importance- Two activities contribute equally to the objective
3. Moderate Importance- Experience and judgment slightly favor one activity over another
5. Strong Importance- Experience and judgment strongly favor one activity over another
7. Very Strong or Demonstrated Importance-An activity is favored very strongly over another, its dominance demonstrated in practice
9. Extreme Importance- The evidence favoring one activity over another is of the highest possible order of affirmation

Step 4:interviewee Assigns Overall Score for Each Supplier

Scale (Sultana, Ahmed, & Azeem, 2015)
1-Poor
3- Below Satisfactory
5-Satisfactory
7-Highly Satisfactory
9- Excellent

Step 5. Evaluation of Tool's Result

Focus of Questions (Lima Junior, et al., 2014)

1. Adequacy to Support Group Decision Making
2. Adequacy to Changes of Alternatives or Criteria
3. Agility in the Decision Process
4. Computational Complexity (Time or space complexity)
5.Uncertainty

Step 6. Questions on User's Experience

Evaluation of User Experience (Jung, et al., 2004)

1.   Functionality
2.   Usability
3.   Efficiency
4.   Maintainability

Figure 16. Consumer Interview Process

Questions

The first step of the process was an introduction to the supplier selection process. This provided a baseline for the mutual understanding of the concept for both the interviewer and the interviewee. The questions that were designated for the interview section are explained below. Two sets of questions were chosen for the interview, criteria and tool validation. The suppliers were only asked questions regarding criteria and consumers were asked both criteria and tool validation questions.

Criteria Questions

Table 22 lists the questions that were utilized in all the interviews, in order to validate the criteria selected in the previous objective. The same set of questions was utilized by the supplier and the consumer portion of the interview process.

Table 22. Questions Regarding Criteria

Questions on Criteria	Source
1. Does the criteria help a consumer evaluate and select suppliers?	(Zeydan, Colpan, & Cobanoglu, 2011)
2. Would the criteria help a consumer compare suppliers amongst themselves?	(Rodrigues, Osiro, Ribeiro, & Cesar, 2014) as cited by (Ha, Park, & Cho, 2011)
3. Would the criteria faithfully depict a buyer's requirements and therefore influence a purchasing decision?	(Rodrigues, Osiro, Ribeiro, & Cesar, 2014)
4. Overall, would the introduction of the criteria improve the current supplier selection process?	(Keskin, I_lhan, & Özkan, 2010)

Tool Validation Questions

The questions that were utilized to evaluate the tool's results are listed in Table 23.

Table 23 Questions to Evaluate the Tool's Output

Questions on the Tool's Output	Source
Is the tool applicable to your business? Are you satisfied with the tool's output?	(Sultana, Ahmed, & Azeem, 2015)
Is there a need for the following in the wood fiber supply chain? 1. Systematic approach for supplier selection 2. Identification of selection criteria 3. Prioritization of criteria	(Keskin, I_lhan, & Özkan, 2010; Sultana, Ahmed, & Azeem, 2015)

4. Evaluation of tradeoffs between technical, economic, and performance criteria	
Does the tool alleviate bias on behalf of the buyer?	(Keskin, I_lhan, & Özkan, 2010) (Weber, Current, & Benton, 1991)
Does the supplier selection tool support different perspectives from different functional areas (i.e. procurement, sales, production)?	(Rodrigues, Osiro, Ribeiro, & Cesar, 2014)
Would the tool facilitate the change in alternatives (suppliers) or criteria in the following situations? 1. When purchasing existing products from new suppliers 2. When purchasing new products from current suppliers	(Rodrigues, Osiro, Ribeiro, & Cesar, 2014)
Would imprecision be a concern when utilizing this tool to select suppliers? Imprecision due to: 1. Subjective evaluation by multiple decision makers 2. Inexistence of previous data on the performance of potential suppliers 3. Difficulty of assessing intangible aspects of supplier performance	(Rodrigues, Osiro, Ribeiro, & Cesar, 2014)
How would you describe your experience based on the following criteria? 1. Comprehensiveness 2. Objectiveness 3. Reliability 4. Flexibility 5. Mathematically Straightforward	(Zeydan, Colpan, & Cobanoglu, 2011)

5. Results

This chapter comprehends the steps and the outcomes of each objective. First, the VSMs developed for each of the case study firms are detailed. The process to select the value stream for each VSM and the equations utilized to capture qualitative and quantitative data are carefully documented. The current and future states of the systems understudy are presented. Second, the supplier selection model was elaborated and incorporated into a computational tool. The steps and results obtained from creating the computational tool are detailed. These steps comprehend:

    1. The determination of the supplier selection criteria to be utilized.

    2. The explanation of how phase I (AHP model) and phase II (TOPSIS) are computed through a series of equations.

    3. The computational tool in Microsoft Excel.

The final result is a computational tool programed in Microsoft Excel. The third and final portion of the results selection comprehends the verification and validation of the tool. The verification of the tool was performed by comparison of the tool's results to manually computed output. The validation of the tool was obtained through seven interviews to industry stakeholders.

5.1 Case Study 1: A Paper Mill

The data required for the VSM analysis for the paper mill case study was collected through interviews, direct observation, and data provided by the case study company's procurement personnel. Additionally, the research team visited a harvesting site to
interview the manager and owner of the logging crew. The logging business was a supplier to the paper mill. The areas that the VSM was applied to are displayed in Figure 17.

Figure 17. Elements of VSM in Case Study 1

The interviews and visits to the paper mill and harvesting site were conducted in June 2017. The VSM for the paper mill case study includes three processes: supplier, transportation to the wood yard, and receiving operations at the wood yard or consumer mill. The following sections explain how the necessary data for the VSM was collected and prepared for the case of the paper mill.

5.1.1 Choosing a Value Stream for Mapping

Table 24 shows the total amount of wood fiber delivered to the case study firm during 2016 from all suppliers. The research team was advised by the case study company to select hardwood pulpwood sourced from a location denominated as District A as the value stream for the VSM. District A represents the tons that are hauled directly to the mill from a specific geographic area within their wood basket. The value stream selected represents about 20% of the total wood fiber delivered to the company in 2016. Based on data provided by the paper mill, the amount of wood incoming to the value stream was estimated at 1,122.5 tons/week (data from December 2016).

Table 24. Wood Fiber Supply Volume During 2016 for Case Study 1

Delivered during 2016	Tons
Pine Pulpwood Grand Total	139,965
Pine Chips Grand Total	145
Hardwood Pulpwood Grand Total	659,743
Hardwood Chips Grand Total	426,559
Hardwood Logs Grand Total	101,435
Pine Logs Grand Total	1,778
Wood Chips§	141,278
Total	1,470,903

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§ Wood chips are the hardwood or softwood chips that are inventory on the wood/log yard. The main source of the chips is from chipping the roundwood that is brought into the wood/log yard, or chips that are bought from sawmills and are trucked in.

5.1.2 Supplier Process

The selected value stream was sourced from an area called District A where there were 10 tracts of timber, totaling 720 acres. The standing timber in these 720 acres was called the inventory. The company indicated that, on average, every acre produces 40 tons of wood, and that the consumption of wood from District A was 1,200 tons per day. Therefore; the amount of inventory in days for the District A forestland was:

$$ADOH = \frac{720\ acres * 40\ \frac{tons}{acre}}{1200\ tons/day} = 24\ days$$

Equation 1. Average Days on Hand of Supplier Case Study 1

The paper mill indicated that it takes approximately 40 days to deliver a request for hardwood pulpwood from District A (order to shipment). This time includes the time that it takes to issue the request from the procurement office, and the time that it takes to harvest the requested wood. The minimum order quantity to be harvested from a tract of standing timber in District A was not available. Therefore, the assumption was 400 tons, as in the firm in case study 3. In addition, the minimum transportation batch was a truck load that weighed 25 tons on average. The price per ton of standing timber at District A's location is $3/ton (stumpage rate) according to the procurement department. Therefore, the average annual value of the standing inventory for District A is estimated as:

$$Value\ of\ inventory = 720\ acres * 40\ \frac{tons}{acre} * 3\ \frac{\$}{ton} = \$86,400$$

Equation 2. Value of Inventory in Supplier Portion

The annual carrying cost of this inventory was estimated at a 10% of the annual value of the inventory, making the annual carrying cost $8,640. The carrying cost includes the following items: capital investment, insurance, obsolescence, damage, and shrinkage of the inventory.

Figure 18 displays all the metrics and calculations for the supplier process of the VSM for case study 1.

Supply
Acres of Stumpage
720

Order to Shipment	40	Days
Inventory (ADOH)	24	Days
Value of Inventory	$ 86,400	Dollars
Carrying Cost (10%)	$ 8,640	Dollars
Truck Payload	25	Tons
Minimum order quantity	25	Tons
Perfect-Order Execution	0%	
Quantity	0%	
Product	0%	
Place	0%	
Time	0%	
Quality	0%	
Cost	0%	
Service	0%	

Figure 18. Supplier Portion VSM Case Study 1

5.1.3   Transportation

Transportation was the second process for this case study. Transportation is the movement of wood from the supplier (harvesting site) to the wood yard of the consumer (paper mill). As mentioned before, the minimum batch size is a truck payload of 25 tons. The distance from the harvesting site to the wood yard was 55 miles (according to company sources). If an average speed of 55 miles per hour is used, a truck should take 1 hour to cover this distance or 0.061 days (1 working day equals to 16.5 hours).

Transportation		
Truck Payload		
25	Woods to Mill Distance (Miles)	
Tons	55	

Transit Time	0.061	Days
Value of Inventory	$ 38,569	Dollars
Carrying cost (10%)	$ 3,857	Dollars
Planned Order Frequency		
Planned Delivery Frequency	45	Trucks/Days
Perfect-Order Execution	0%	
Quantity	0%	
Product	0%	
Place	0%	
Time	0%	
Quality	0%	
Cost	0%	
Service	0%	

Figure 19. Inbound Logistics

An analysis of the data for December 2016 for tons received at the wood yard by the company was conducted to estimate the amount of wood in transit per day. The research team estimated the tons in transit per day as 1,122.50 tons/day. The procurement team at this case study firm indicated that the value of the wood in transit was $34.36/ton (logging, trucking, and stumpage included in the cost per ton). Therefore, the value of the inventory in transit is calculated as:

$$Value\ of\ Inventory = 1,122.50\ \frac{tons}{day} * \$34.36/tons = \$38,569$$

Equation 3. Value of the Inventory

The carrying cost of the inventory was estimated as 10% of the annual rate. Therefore, the carrying cost for the inventory in transit was estimated at $3,857 per year. Finally, the delivery frequency was estimated as 45 loads/day, each load weighing 25 tons/load. There was no information available to estimate perfect-order execution metrics for the transportation process, which is why all the perfect-order execution metrics in

Figure 19 show a value of 0%.

5.1.4 Receiving Operations

INV	Manufacturing site
ADOH	Average Daily Consumption of Mill (Tons)
21	1200

Receiving operations		
Inventory (ADOH)	21	Days
Value of Inventory	$ 859,000	Dollars
Carrying Cost (10%)	$ 85,900	Dollars
Lot Size		
Delivery Frequency to Line		
Perfect-Order Execution	65%	
Quantity	0%	
Product	0%	
Place	0%	
Time	0%	
Quality	65%	
Cost	0%	
Service	0%	

Figure 20. Receiving Operations Wood Yard

The third process in this value stream is receiving operations at the wood yard. Once wood has been transported from the harvesting site to the wood yard, it waits for further processing. During 2016, the average hardwood inventory carried and the average daily mill consumption was estimated by procurement personnel as 25,000 tons and 1,200 respectively. As indicated in the supplier process, the daily consumption of the selected value stream (hardwood pulpwood from District A) was 1,200 tons/day at the paper mill. Therefore, the average-daily on hands inventory (ADOH) is calculated as:

$$ADOH = \frac{25,000 \; tons}{1200 \frac{tons}{day}} = 21 \; days$$

Equation 4. Average Days on Hand

Figure 20 shows the metrics for this process of the value stream map. The company indicated

that the value of a ton of wood at the wood yard is $34.36 (this rate is the logging, freight, and stumpage cost together). Therefore, the value of the average annual inventory of the selected value stream at the wood yard is:

$$\$34.36/ton*25,000 \ tons = \$859,000$$

Equation 5. Value of Average Annual Inventory

The carrying cost of this inventory was calculated at a 10% annual rate. So that the annual carrying cost of the wood yard inventory was $85,900. Because the company processes roundwood using a continuous batch process set-up, an estimation of the lot size and delivery frequency to the production line did not apply in this case. These VSM metrics are shown in Figure 20. Finally, out of the eight perfect-order execution metrics intended to be measured for the receiving operations process, the company only tracked the quality of the inbound wood. This quality metric determined that 35% of the wood purchased was out of specification. Figure 20 displays a 65% quality metric (100%-35% metric). This data was provided by the company and not measured.

5.1.5   Fulfillment Cost of Case Study 1

In addition to calculating the inventory annual carrying costs for the three processes in the analysis, the research team also estimated additional logistics costs for this value stream. The value stream was divided in the following logistics activities: harvesting, inbound transportation, procurement, wood yard management, and supplier collaboration. Table 25 shows the summary of the calculations. Details are in Appendix A. These cost calculations are important because they represent a baseline when considering future improvements to the value stream being analyzed.

Table 25. Current Fulfillment Cost Case Study 1

Logistics Impact-Annualized	
Wood Yard Cost	
Personnel: Raw Material Handling	$207,240
Material Handling: Equipment	$1,162,025
Tons Out of Specification in 2016	$17,180
Overhead Cost (20%)	$273,853
Current Subtotal (Annual)	**$1,660,298**
Current Subtotal (20% of Annual)	**$332,060**
Procurement Cost	
Personnel: Ordering and Planning	$444,968
Overhead Cost (20%)	$88,994
Current Subtotal	**$533,962**
Harvesting Cost	
Harvesting Cost	$6,480,193
Current Subtotal	**$6,480,193**
Inbound Logistics	
Transportation: Inbound from supplier	$2,394,853
Overhead Cost (20%)	$478,971
Current Subtotal	**$2,873,825**
Supplier Collaboration	
Personnel	
Overhead Cost (20%)	
Current Subtotal	
Inventory Carrying Costs	
Current Subtotal	**$98,397**
Total Cost of Fulfillment	
Current Subtotal	**$10,318,436**

The harvesting cost was provided by the case study company. The total cost per ton is $34.36 which is divided into the following costs: (The percentages represent the proportion of each of the following activities compared to the entire cost per ton).

- Logging cost $23.00/ton (67%).

- Transportation cost $8.50/ton or $0.155 per ton mile (25%).

- Stumpage $3.00 per ton.

Therefore, the cost of harvesting 1,122.5 tons/day for 251 days is $6,480,193. The harvesting cost is the highest cost (63%). The costs of the other logistics activities are shown in Table 25. The second largest cost is transportation with $2.87 million (28% of total cost) for transporting 281,747 tons over 55 miles (at $0.15 per ton per mile**). The procurement cost (material ordering) was estimated $533,962 (5% of total cost). The annual fulfillment cost of carrying costs was ($98,397)†† which represents less than 1% of the logistics annual cost. The annual wood yard‡‡ management cost was estimated as $332,060 (3% of total costs). Therefore, the total annual cost of fulfillment for this value stream was estimated as $10,318,436 or $36.62 per ton (for 281,747 tons per year). No data was available to estimate the cost of supplier collaborations for this value stream.

5.1.6   Analysis of the VSM for Paper Mill (Case Study 1)

Figure 21 displays the final current state VSM for case study 1 showing the calculated metrics. The valued-added time or total process time for this value stream is 40 days, this is the sum of the order to shipment (40 days) time plus the transport time (0.061 days). The non-value-added time for this VSM is 45 days, which is the sum of the ADOH at the stumpage (24 days) and at receiving operations (21 days). Therefore; the total lead time for this value stream is 85 days, which implies that about 52.8% of the total lead time is considered NVA time (time spent in inventory is non-value adding because the product isn't being transformed). The VSM also indicates that the value of the annual average inventory for this value stream (only hardwood pulpwood from District A) is $983,969 with an annual carrying cost of $98,396. Other significant metrics from the VSM are:

- The average-daily on hands (ADOH) at receiving operations is 21 days with 25,000 tons of inventory at the consumer's wood yard.

- The minimum batch size for the harvesting site is 400 tons.

- The frequency of delivery is 45 truckloads per day.

** Company source rate per ton/mile.
†† The carrying cost in current state maps in each of three case studies includes the stumpage carrying cost.
‡‡ The annual wood yard cost was calculated as 20% of the annual wood yard cost because the stream chosen represented 20% of the total tons delivered in 2016.

- The distance from the harvesting site to the receiving operation (wood yard) is 55 miles.

- The quality perfect-order execution metric at the receiving operations is 65%.

The current VSM stream map for case study one displays a snapshot of the selected value stream. The value stream represents about 20% of the total incoming wood fiber delivered to the company in 2016. The amount of incoming wood was estimated as 1,122.5 tons/week. This estimation was calculated from December 2016 data. The amount of inventory on hand for the District A forestland was of 24 days. It is important to note that the minimum order quantity to be harvested from a tract of standing timber in District A was not available and therefore assumed. The value of inventory in one day of hauling is calculated to be $38,569 which is the value of 45 trucks/day. In receiving operations (wood yard) the average hardwood inventory carried and the average daily mill consumption was estimated by procurement personnel as 25,000 tons and 1,200 respectively. The value of average annual inventory was $859,000, and the annual carrying cost of the wood yard inventory was $85,900. Throughout the value stream selected for case study 1, the perfect execution orders were not tracked except quality at the receiving operations.

The VSM allows to oversee the current state of the overall operation of the value stream selected. This entails coordination along with extraction and visualization of strategic information for decision making. Coordination refers to the information flows. Wood procurement makes the decisions according to information based on historical and then sends weekly and monthly orders for supply. Therefore, within these communication channels there are not reciprocal feedbacks, so decisions are not taken with knowledge of strategic information from supply chain partners. Visualization of strategic information for decision making is also abstracted through the VSM. In regards to strategic information it is important to distinguish that a significant amount of information was assumed or extracted based on educated assumptions (i.e. the amount of incoming wood daily, minimum order quantity to be harvested from a tract of standing timber, average hardwood inventory carried and the average daily mill consumption). This signifies that important logistic information such as annual inventory and carrying cost, number of trucks transported per day, etc. are not known by the case study company which in return affects the capacity to take assertive decisions to

improve efficiency and reduce costs accurately.
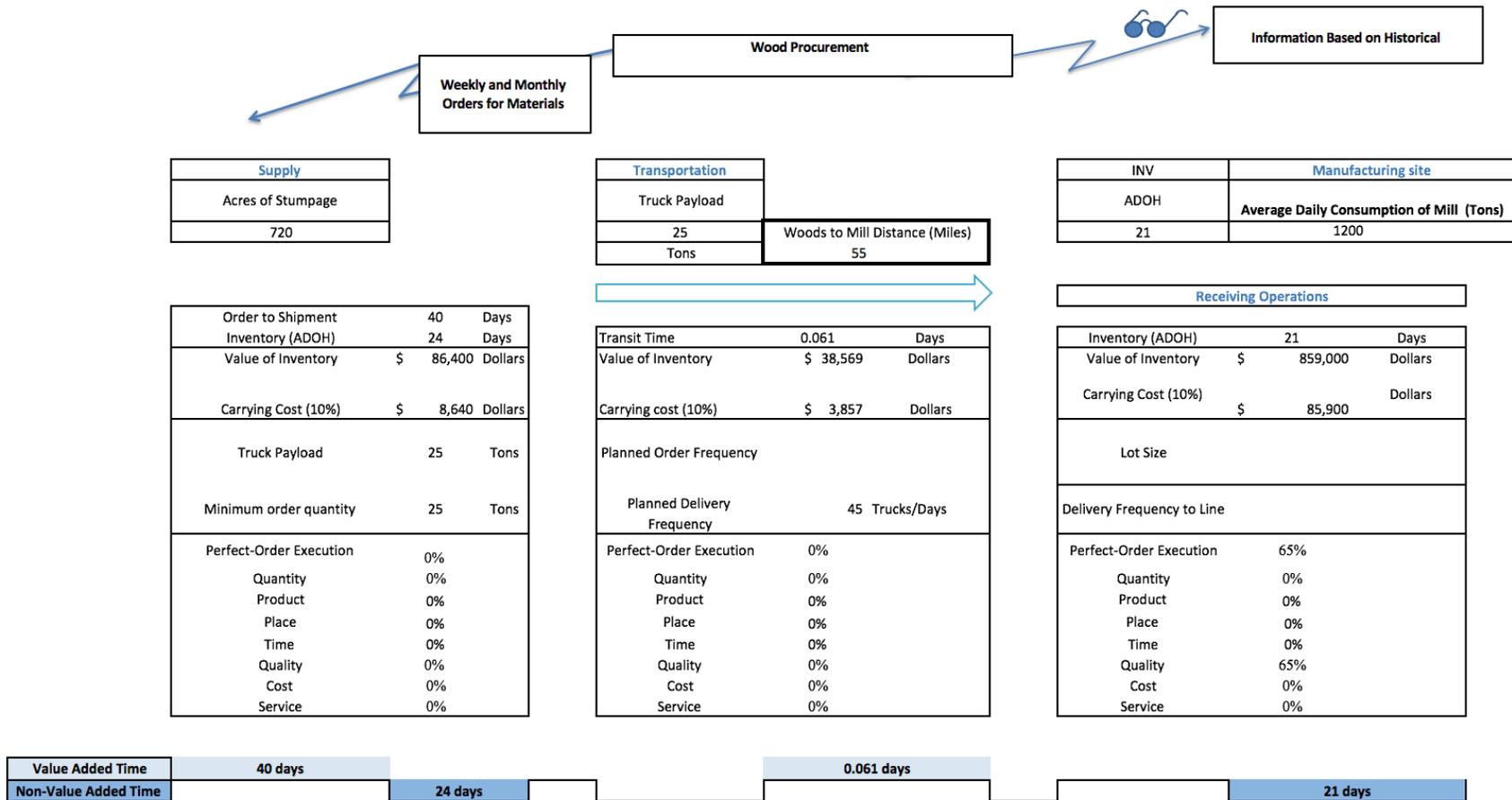
Figure 21. Current VSM for Case Study 1

Based on the interviews, site observations, and document analysis the research team was able to uncover potential waste sources as shown in Table 26.

Table 26. Identified Waste in VSM for Case Study 1

Type of waste	Logistics area impacted	Specific issue
Inefficient use of human resources	Supplier collaboration	• Errors when marking trees at harvesting sites caused delays that could cause the logger to cut down the wrong trees.
	Procurement	• Loggers are seldom considered for strategic planning decisions.
Unnecessary transportation	Inbound transportation	• Trucks travel longer distances between harvesting and wood yard sites.
Excessive movements	Wood yard management	• Unloading of trucks cause delays to logging crews.
	Supplier	• How the logger determines the layout of the cutting operations may increase the amount of movements necessary.
Excessive waiting times	Supplier collaboration	• An excessive amount of turn time
	Supplier collaboration	• Logging crews need to idle equipment and personnel due to lack of demand. Wood quotas and how they are distributed may be a cause.
Overproduction	Supplier	• Logging crews harvest more than planned to take advantage of good weather conditions.
Inventory holding	Supplier and wood yard management	• The carrying cost of inventory

The interview with the logging crew manager supplying wood to the paper mill was critical for understanding some of the major waste generated in this value stream. The supplier recognized that tree markings were sometimes confusing. The supplier said that the notice for when and where the next tract would be, was a short timeframe.

Lack of coordination between the procurement team of the case study firm and the logging crews could cause unnecessary waiting and idle times for the logging crews. For example, if there was miscommunication between these parties, logging crews could move equipment to the wrong harvest tract. Another example that could cause delays and waiting for the logging crews was the wrong marking of trees to be felled. When this happened, the logging crew

manager needed to contact the forester to get issues clarified. Inefficient communication between the logging crews and the consumer mill causes a lot of waste, because it impacts waiting times, causes unnecessary transportation, excessive movement, defective product, and lower material yields as indicated in Table 26. For example, every time a logging crew waits or idles equipment, there is a significant increase in cost per ton, as fixed cost does not depend on production volumes. As Greene et al (2002) concluded, the cost of idled equipment averages $2.70/ton (already in 2018 present value considering an annual inflation rate of 3%). In addition, these delays, due to lack of coordination and communication among procurement and the logging crew, could be one of the most significant causes of waste, explaining that 52% of the total lead time is NVA time.

Another cause of waste, in the form of unnecessary waiting and idled equipment, are extra movements at the wood yard operation. Poor scheduling of truck arrivals, lack of space at the wood yard, lack of visual controls to quickly identify storage areas for logs, scheduling of unexperienced loader operators, and lack of standard procedures to efficiently unload trucks are main sources of waste in this situation. Every extra minute a truck waits for unloading can be translated to an opportunity cost of $1.72/min§§or $103.13/hr.

Unnecessary transportation is also a source of waste and cost as indicated by the logging crew manager and the procurement team at the paper mill. When distances to transport the raw material are increased, the logging crews or the procurement team need to add extra capacity in transportation equipment to move the same amount of wood. For example, the distance from the harvesting site to the wood yard is 55 miles and 45 truck loads are delivered per day for the selected value stream. But if the distance changes to 110 miles, then the transportation capacity needs to be increased to haul the same amount of wood, and the cost per ton per mile will increase by 100%.

It is worth mentioning that quota management (changes in demand of wood fiber) is a critical source of waste that the suppliers (logging crews) face. When mills impose quotas, changes must be made by suppliers to adjust to these requests. As indicated earlier, idle or unused

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§§ Considering a round trip of 55 miles, at 55 mph with a cost of $0.15/ton per mile

equipment increases the cost per ton. Also, it impacts the management of the logging crew as some personnel are not needed when demand decreases or on the contrary, loggers need to rush to find additional logging workers.

Weather also plays a key role in terms of waste along the value stream. For example, when weather is good, loggers tend to harvest more than required, hoping that the extra inventory of logs will help to meet demand when weather conditions worsen. Overproduction at this point of the value stream also means an increase in the carrying cost of the inventory, since the carrying cost of the inventory at the wood yard was estimated at an annual rate of $3.44/ton. The consumer mill understands that once the logs are received from the logger, the company needs to absorb the inventory's carrying cost. The procurement team would rather have the logger holding the inventory until it is needed at the wood yard.

A particular issue related to holding inventory at the supplier end is that standing timber might also be considered a product itself, and not necessarily inventory. Standing timber in the forestland continues to grow as time passes, so the value increases over time. Therefore, instead of thinking that standing timber is an inventory owned by the supplier that carries inventory holding costs, standing timber could be seen as an ongoing product that has associated production costs and other administrative expenses leading to a profit. In this case, the project team treats standing timber as an inventory that has an associated carrying cost. In fact, the research team has estimated other related logistics costs for this value stream including procurement, harvesting, inbound transportation, supplier collaboration, and wood yard management. These costs are presented in the next season with the intention of being used as a cost baseline to quantify cost improvements when the future VSM is discussed.

5.2 Case Study 2: A Sawmill

All the data used in this case was provided by the company's procurement team. The company site, located in the southern region of the US, consists of two mills. A lumber mill and a timber mill that also produces lumber. The case study focused only on the value stream for the lumber mill and gatewood provided. The average amount of raw material received weekly for this sawmill was of 16,669 tons or a total of 183,535 tons (13-week interval). The

average mill use was 15,400 tons weekly. The areas of the supply chain where the VSM was applied is displayed in Figure 22.

Figure 22. VSM Elements of Case Study 2

5.2.1 Demand Analysis

5.2.1.1 Wood Order Process and Information Flow

The wood procurement team at this company decided the weekly quota given to suppliers based on the sawmill's forecast and existing inventory levels. Two procurement team members decided which of the 30 gatewood suppliers received the determined amount of the quota. There was not a formal rule to distribute the quota, but factors that affected how loads were distributed were the logger's size (production capacity), and loyalty since some would only work for the company when they needed the quota (consistency).

The supply data used in this case study was from January 2, 2017 through March 27, 2017. According to an interview with the procurement department, the company received wood from two different sources: the company (45%) which were tracts that the company owned, and outside wood (55%). In the outside wood category 80% was gatewood or contract wood, and 20% was purchase tracts. The case study company wanted to focus this study on gatewood only.

5.2.1.2 Daily Demand Estimation

$$\frac{21,824\frac{tons}{week}*80\%*55\%}{4.5\ days} = 2,134\ tons$$

Equation 6. Gatewood Allocated to Daily Demand

Equation 6 provides an estimate of the daily demand or consumption of gatewood only. The company indicated that the total weekly consumption was 21,854 tons (actual log usage) and

the company worked 4.5 days. The daily demand focused the study on the rate at which the gatewood is consumed by the amount of loads of gatewood coming in.

5.2.1.3 Weekly Loads Delivered

Figure 23 displays a histogram, boxplot, and normal quantile plot of the weekly loads (loads equal a truck payload) delivered for a 13 week period. During this period, the company received 107,304 tons of wood. The normal quantile plot shows that the data follows a normal distribution with a mean of 290 loads and a standard deviation of 63.62 loads. The histogram shows that there is a weekly variability regarding the loads delivered. The boxplot shows the spread or variability of the data. In this case, 50% of the data is between 250 and 325 loads.
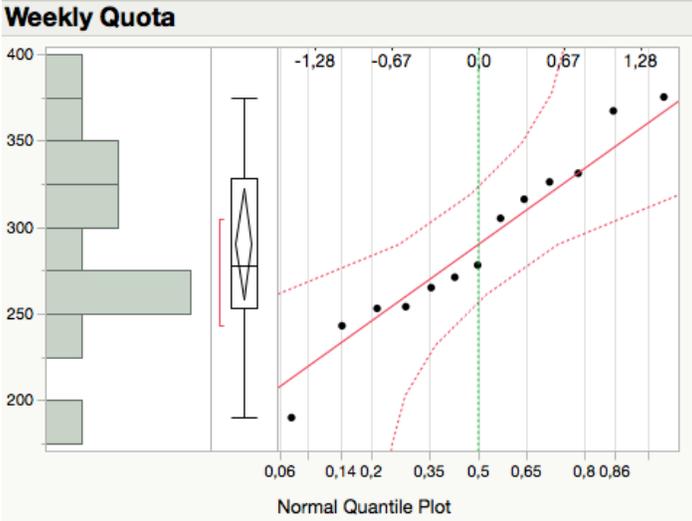
Figure 23. Weekly Loads Received from Suppliers for 13 Weeks

5.2.2 Supplier

The sawmill indicated that the supplier had one week to deliver quota. There was no information available regarding how much standing timber (annual average inventory for this case) the supplier had available. In the absence of this data, the amount of wood required to supply a 13 week-period was used as the inventory of standing timber. Therefore, the average days on hand (ADOH) was calculated by dividing the total amount of tons (on average) received weekly by the daily demand.

$$ADOH = \frac{107,304\ tons}{2,134\frac{tons}{day}} = 50.3\ days$$

Equation 7. Average Days on Hand

Figure 24 displays the calculations for the supplier portion of the VSM. The case study firm reported that the value of the standing timber was $30.10/ton. Hence, the value of the annual average inventory is:

$$Value\ of\ Inventory = Tons\ Received * \$30.10/ton = 107{,}304\ tons * \$30.10 = \$3{,}230{,}318$$

Equation 8. Average Value of Inventory

Supplier	Inventory	
Pine	50.3	ADOH

Order to Shipment	7	Days
Inventory (ADOH)	50.29	Days
Value of Inventory	$ 3,230,318	Dollars
Carrying Cost (10%)	$ 323,032	Dollars
Batch Size (Truckload)	28.15	Tons of Logs/Truck
Minimum Order Quantity (Truckload)	28.15	Tons of Logs/Truck
Perfect-order execution	0%	
Quantity	0%	
Product	0%	
Place	0%	
Time	0%	
Quality	0%	
Cost	0%	
Service	0%	

Figure 24. Supplier Portion of VSM Case Study 2

The annual carrying cost of the inventory was estimated as 10% of the value of the annual average inventory. These carrying costs involve capital investment, insurance, and inventory damages. Finally, the batch size was assumed to be the amount of 1 truck-load (28.15 tons/truck). The ADOH (amount of wood available in days) was 50.3 days. No data was available to calculate the metrics for perfect-order execution (all values are zero) for this particular process.

5.2.3 Inbound Logistics

The transit time was calculated based on the average speed, the average distance from the supplier to the mill, and the number of working hours per day. Therefore, the transit time is calculated as:

$$Transportation\ time = 47{,}61\ miles * \frac{1h}{35\ mph} * \frac{1\ day}{16.55\ hours} = 0.08\ \text{days}$$

Equation 9. One Way Transit Time

In this case, the lot size is equal to a truck load or 28.15 tons of wood per load. The value of inventory in transit is calculated by breaking down the number of tons received per week into a daily value. On average, the company received 8,163.5 tons of wood, which is equivalent to 290 truckloads, with a cost per ton of $48.17. Therefore, the value of the inventory in transit is:

$$Value\ of\ Inventory = 8{,}163.50\ \frac{tons}{week} * \frac{1\ week}{5\ days} = 1632.70\ \frac{tons}{day} * \$48.17 =$$
$$\$78{,}647\ in\ transit$$

Equation 10. Value of Inventory in Transit

The planned delivery frequency is obtained by dividing the amount of quota (truck loads) into 5 days. The scale house was open 5 days a week. The perfect-order quantity indicator was calculated based upon the amount of quota requested and the amount of quota received across all suppliers. The quality was determined by obtaining the percentage of deductions weighted out of the net weight received, which corresponded to less than 1% according to the case study firm. The perfect order execution is calculated as:

$$Perfect\text{-}order\ execution = Quality*Quantity = 99.84\%*77\% = 77\%$$

Equation 11. Perfect-Order Execution

The inbound logistics portion (transportation from supplier to mill) of the VSM is displayed in Figure 25.

Transportation	
Truck Payload	Woods to Mill
28.15	Distance (Miles)
tons	47.61

One Way Transit Time	0.08	Days
Value of Inventory	$ 78,647	Dollars
Carrying Cost (10%)	$ 7,865	Dollars
Loads Delivered per Week	290	Loads
Planned Order Frequency	1	Week
Planned Delivery Frequency	58	Trucks/Day
Perfect-order Execution	0%	
Quantity	77%	
Product	0%	
Place	0%	
Time	0%	
Quality	99%	
Cost	0%	
Service	0%	

Figure 25. Inbound Transportation

5.2.4 Receiving Operations

The average-daily-on-hands (ADOH) was calculated by dividing the amount of average inventory of wood in the log yard by the daily demand (2,134 tons/days). In this case, the company reported that, on average, they had 7,187 tons in the log yard (end of crane inventory). Therefore, the ADOH is calculated as:

$$ADOH \ receiving \ operations = \frac{\bar{y}}{\bar{g}} = \frac{7,187}{2.134} = 3.4 \ days$$

Equation 12. ADOH Receiving Operations

The value of annual average inventory at the log yard and the annual carrying cost (10% of the value of inventory) of this inventory is calculated as:

$$Value \ of \ Inventory \ = 7,187 * \$48.17 = \$346,198$$
$$Annual \ Carrying \ cost = \$346,198 * 10\% = \$34,620$$

Equation 13. Value of Inventory in Log Yard

	INV	Sawmill Forecast
		Gatewood
3.4	ADOH	Daily Demand Tons
		2,134

Receiving Operations

Inventory (ADOH)	3.4	Days
Value of Inventory	$ 346,198	Dollars
Carrying Cost (10%)	$ 34,620	Dollars
Lot Size		
Delivery Frequency to Line		
Quantity of Collaborators	2	
Perfect-order execution	0%	
Quantity	0%	
Product	0%	
Place	0%	
Time	0%	
Quality	0%	
Cost	0%	
Service	0%	

Figure 26. Receiving Operations

Figure 26 shows all the metrics and related calculations at the log yard or receiving operations. No data was available to calculate perfect-order execution metrics. That is the reason these metrics show zero.

5.2.5   Fulfillment Cost of Case Study 2

Table 27 shows a summary of the fulfillment cost for the sawmill case study. The total annual cost was $10,173,931, including inbound and outbound transportation, procurement activities (material ordering), harvesting operations, log yard management, and inventory carrying costs. There was no information available to calculate supplier collaboration costs.

Table 27. Current Fulfillment Cost Case Study 2

Logistics Impact-Annualized	
Log Yard	
Personnel: Raw Material Handling	$69,080
Material Handling: Equipment	$435,799
Overhead Cost (20%)	$100,976
Current Subtotal	**$605,855**
Material Ordering	
Personnel: Ordering and Planning (Procurement Cost)	$141,100
Overhead Cost (20%)	$28,220
Current Subtotal	**$169,320**
Inbound Logistics	
Transportation: Inbound from Supplier	$2,526,367
Overhead Cost (20%)	$505,273
Current Subtotal	**$3,031,641**
Harvesting Cost	
Harvesting Cost	**$6,001,600**
Supplier Collaboration	
Personnel	
Overhead Cost (20%)	
Current Subtotal	
Inventory Carrying Costs	
Current Subtotal	**$365,516**
Total Cost of Fulfillment	
Current Subtotal	**$10,173,931**

The largest cost corresponded to harvesting costs which represented 59% of the total fulfillment costs. The case study firm indicated that the harvesting costs were $12.50/ton. The company also stated that it works 225 days per year. Therefore, the annual harvesting cost of 2,134 tons/day is:

Harvesting cost= 2,134 tons/days*225 days * $12.50/ton=$6,001,600
Equation 14. Harvesting Cost

The second largest cost was inbound transportation with 30% of the total cost. The details of the cost fulfillment calculations are included in Appendix B. Performing cost calculations is critical to add a financial dimension to the performance of the value stream. With suggestions

and recommendations to improve the performance of the supply chain based on the elimination of waste, these recommendations will have an impact on the cost of fulfillment.

5.2.6 Analysis of the VSM for Case Study 2

Figure 27 shows the final VSM for the firm in case study 2. The supplier's procurement relied on the sawmill's consumption forecast to determine the weekly orders. This forecast was communicated to the suppliers and is displayed in the VSM as a blue line that connects the procurement team and the supplier. There was not a formal rule for quota distribution, factors were taken into consideration such as logger production capacity and the logger's consistency to deliver tons. The gatewood allocated demand was estimated based on percentages provided by the procurement department (i.e 2,134 tons). Information inherent to the consumer's operation such as the gatewood consumption at the site were unknown to the consumer. Similarly, the consumer company was not aware of their supplier's inventory. This gap of knowledge reflects the lack of communication between supply chain partners.

The supplier portion of the VSM, was elaborated based on assumptions because the procurement department did not have knowledge of the how much standing timber their suppliers had available. Therefore, the amount of wood required to supply a 13 week-period was used as the inventory of standing timber with an average value of inventory of $3,230,318 and with a carrying cost of $323,032. On average the company received 8,163.5 tons of wood, which is equivalent to 290 truckloads with a cost per ton of $48.17. The value of the inventory in transit per day is $78,647. Two perfect execution metrics were calculated in the inbound transportation portion of the VSM, these were quantity (77%) and quality (99%). The ADOH at receiving operations is of 3.4 days. The annual value of inventory is $346,198 with a carrying cost of $34,620. No data was available to calculate the perfect-order execution metrics at receiving operations.

The total process time was 7 days (Figure 27) which reflects the time that it takes a ton of wood to flow from the supplier to the log yard, from the time one order for quota was executed, in addition to the harvesting time (this time is considered value adding time). The amount of inventory in the pipeline (from supplier to log yard) was estimated as 54 days (non-value added time). The majority of time in this value stream is spent in non-value adding operations (i.e. inventory), 88% of the total lead time is non-value adding. When adding the

process time and number of days of inventory, the total lead time was 60 days. Also, the cost of the annual average inventory was estimated at $3,655,163, and the annual carrying cost of the inventory along the supply chain was $365,516. Table 28 shows the summary of identified waste in this supply chain classified under lean thinking principles. The following section provides more details on the waste identified in this VSM.

Procurement Team

Weekly orders for materials

Forecast

Supplier	Inventory			Transportation					INV	Sawmill Forecast
										Gatewood Daily Demand Tons
Pine	50.3	ADOH		Truck Payload		Woods to Mill		3.4	ADOH	
				28.15		Distance (Miles)				2,134

Receiving Operations

Order to Shipment	7	Days		One Way Transit Time	0.08	Days		Inventory (ADOH)	3.4	Days
Inventory (ADOH)	50.29	Days		Value of Inventory	$ 78,647	Dollars		Value of Inventory	$ 346,198	Dollars
Value of Inventory	$ 3,230,318	Dollars		Carrying Cost (10%)	$ 7,865	Dollars		Carrying Cost (10%)	$ 34,620	Dollars
Carrying Cost (10%)	$ 323,032	Dollars		Loads Delivered per Week	290	Loads		Lot Size		
Batch Size (Truckload)	28.15	Tons of Logs/Truck		Planned Order Frequency	1	Week		Delivery Frequency to Line		
Minimum Order Quantity (Truckload)	28.15	Tons of Logs/Truck		Planned Delivery Frequency	58	Trucks/Day		Quantity of Collaborators	2	
Perfect-order execution	0%			Perfect-order Execution	0%			Perfect-order execution	0%	
Quantity	0%			Quantity	77%			Quantity	0%	
Product	0%			Product	0%			Product	0%	
Place	0%			Place	0%			Place	0%	
Time	0%			Time	0%			Time	0%	
Quality	0%			Quality	99%			Quality	0%	
Cost	0%			Cost	0%			Cost	0%	
Service	0%			Service	0%			Service	0%	

Value Added Time	7 days		0.08 days	
Non-Value Added Time	50.29 days			3.4 days

Figure 27. Case Study 2 Current VSM

Table 28. Summary of Waste Found for Case Study 2

Type of waste	Logistics area impacted	Specific issue
Inefficient use of human resources	Supplier collaboration	• There is no knowledge of the logger's quantity of standing timber, which would allow better allocation of loads.
	Procurement	• Loggers are seldom considered for strategic planning decisions.
Unnecessary transportation	Inbound transportation	• If the load needs to be redirected because the mill isn't accepting more loads, extra miles are incurred.
Excessive movements	Log yard management	• Lack of space in log yards cause loaders to travel longer distances with loads. • Excessive turn times
	Supplier/Supplier collaboration	• Logging crews spend extra time in handling standing inventory because terrain conditions or logger's equipment is not adequately designed for the tract.
Excessive waiting times	Supplier collaboration	• Logging crews need to idle equipment and personnel due to lack of demand.
Defective product	Supplier/Supplier collaboration	• Loggers deliver the wrong product to a consumer mill or they deliver loads to a mill that wasn't initially in the plan.
Overproduction	Supplier	• Logging crews harvest more than they planned, to take advantage of good weather conditions.
Inventory holding	Supplier and log yard management	• Carrying cost of inventory • Low inventory levels (running out of wood)

5.2.7 Inefficient Use of Human Resources: Lack of Collaboration and Communication in the Supply Chain

By increasing the level of communication and working closer with suppliers, the sawmill used in the case study could increase its supply chain performance. The sawmill indicated that there was no knowledge of the amount of available standing timber by the logger. This information could improve load allocations. The case study 2 company should work on developing a strategy to select its suppliers. The lack of models and tools to support the supplier selection process was evident from the testimony of case study 2 personnel.

The lack of performance metrics for this supply chain was detrimental, if the company wishes to improve the performance of this supply chain. There was no data available to determine the different perfect-order execution metrics as shown earlier, except for the inbound process (quality and quantity). The sawmill should put effort into developing these metrics, so that the supply chain performance can be easily monitored.

5.2.8 Unnecessary Transportation and Excessive Movements

The implementation of the VSM and the interviews of sawmill personnel did not indicate that the company was generating waste by unnecessary transportation and movements in the log yard. However, every extra mile that trucks need to travel to transport wood from the supplier to the log yard, increases the cost by an estimated \$0.1/ton/mile. If for some reason the mill is not accepting any more truck loads, and the truck needs to be redirected, this would cause time to be wasted and cost incurred. This reactive planning environment needs to become proactive. Keeping the suppliers informed about changes that affect them is important to combat inefficient practices.

In the case of unnecessary movements in the log yard, the company only handles 3.4 ADOH, so the amount of inventory handling in this point seems to be minimal. However, the following excessive movements could cause delays and increase costs to the sawmill and their suppliers:

- Lack of standard procedures when unloading trucks

- Poor visual marking around the wood yard that prevents operators from knowing where to place the wood loads

5.2.9 Excessive Waiting and Idle Times

Although the process time data does not suggest critical waiting or idle times in the supplier process (standing timber and harvesting operations), the analysis of the demand suggests that in many cases harvesting crews might suffer long, unexpected delays and idle times related to how the quota is managed by the mill. When analyzing the quota data provided by the company, it followed a normal distribution with a mean of 290 and a standard deviation of 52.50. Using these parameters, the research team generated 500 data points of quota to

visualize how quota behaves in the long term (see Figure 28).
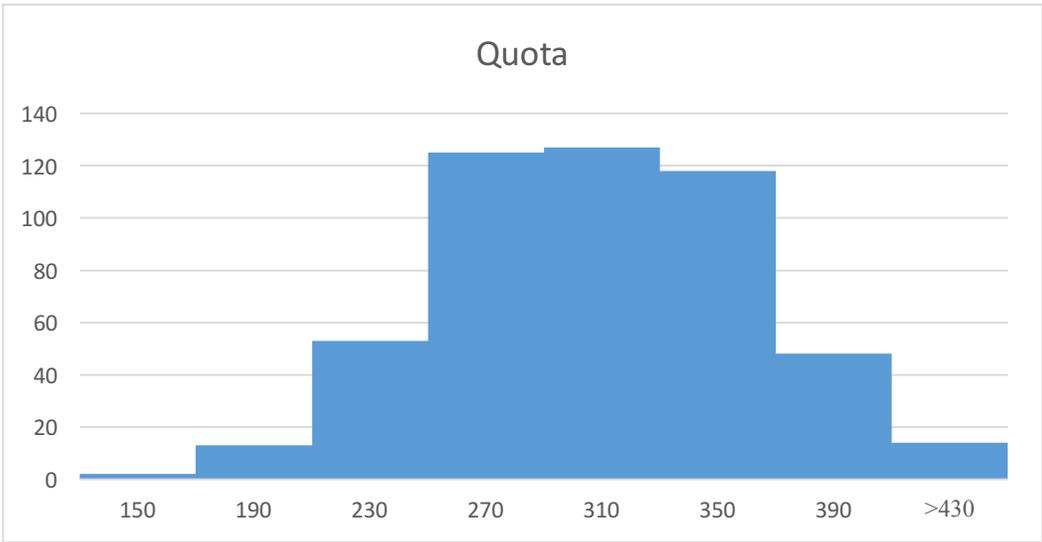
Figure 28. Monte Carlo Simulation of Demand

Using a confidence level of 90%, it was determined that the weekly quota varied from 227.4 to 335.3 truckloads per week. If the number of truck loads fell below 227.4 trucks per week, then this could lead to significant idling time for harvesting crews. In other words, there is a 10% chance that the quota will fall below 227.4 trucks per week. As estimated by Greene (2002), the cost of idling equipment on the harvesting end of the supply chain can be translated to a cost of $2.70/ton (already in present value). Harvesting crews need to learn how to manage variability from their customer (sawmill), in order to avoid excessive cost and unexpected delays.

5.2.10 Overproduction and Defective Product

Overproduction was not detected along this supply chain. Standing timber remained standing until the consumer mill issued a request for quota. Only then, the harvesting crews harvested the requested quota and shipped it to the supplier. As long as the timber remained standing it continued to grow, potentially increasing its value. The percentage of cull was 1% (quality metric).

5.2.11 Excessive Amount of Inventory in the Supply Chain

The research team did not identify an excessive amount of inventory along the supply chain. It was estimated that the company kept about 54 days of inventory on-hand at the supplier

end. This is not considered excessive and is normal for the industry. On the contrary, the ADOH at the log yard was estimated as only 3.4 days.

5.3 Case Study 3: A Logging Operation

This case study involves a logging operation in the southern region of the U.S. The company reported that from January 2017 to April 2017 there was more supply than demand, meaning that the logger had more inventory than planned. In addition, the logging company reported that quotas were being poorly managed by its customers and that there was a lack of cooperation and communication across the industry.

In this case, the wood that was harvested was either bought from land owners in lump sums or at an agreed stumpage rate. Harvesting operations were also fulfilled by paying a harvesting rate to the company. Based on market conditions, mills sometimes issued the logger a quota, or limit the number of loads that could be hauled. They operated seven company owned crews, and there was usually one crew per tract. Crews produced from nine to eighteen loads on an average day, depending upon variables such as terrain, weather, proximity to delivery points, and available trucking capacity. The areas where the VSM is applied in this case study are displayed in Figure 29.

Figure 29. VSM Elements for Case Study 3

5.3.1 Daily Consumption

The daily consumption was based on the number of tons hauled during the year 2016 (600,000 tons) and the average reported weekly hours, if the hours worked per week (harvesting and hauling) equals $60 \frac{hours}{week}$, and a week was equal to 6 days of work, with 10 working hours per day. The company reported to work 50 weeks per year, so the daily

consumption is calculated as:

$$Daily\ Consumption = \frac{Annual\ Tons\ Delivered}{Days\ worked\ in\ a\ year} = \frac{600,000\ tons}{50\ weeks * 6\ days} = 2,000\ tons\ /work\ day$$

Equation 15. Daily Consumption at Manufacturing Site

The amount of daily consumption for six different facilities was reported by the logging company.

5.3.2 Supplier

Supplier		
Supplier Owned Standing Timber Tons Available for Harvest		
	30,000	

Order to Shipment	7-22	Days
Inventory (ADOH)	15	Days
Value of Inventory	$ 500,000	Dollars
Carrying Cost (10%)	$ 50,000	Dollars
Batch Size		Acre-Tons
Minimum Order Quantity	20-400	Acre-Tons
Perfect-order Execution	0%	
Quantity	0%	
Product	0%	
Place	0%	
Time	0%	
Quality	0%	
Cost	0%	
Service	0%	

Figure 30. Supplier Section of Logger (VSM)

In this case stumpage belonged to the logging company, so the stumpage represented the average annual standing inventory. The logging company had over 30,000 tons of wood available for harvest. The company reported that 60 tons per acre was a reasonable production rate. The order to shipment time was assumed to be 7 to 22 days, which the company reported as variable. The logger's customer orders could be delayed for weeks because of inconsistent demand from mills. The average daily on hand (ADOH) inventory was 15 days, calculated as follows:

95

$$ADOH = \frac{Standing\ Inventory}{Daily\ Consumption} = \frac{30,000\ tons}{2000\ \frac{tons}{daily}} = 15\ days$$

Equation 16. ADOH of Standing Timber

The logging company reported the value of the inventory (30,000 tons) as between $400,000 to $600,000; the value of the inventory (standing timber) was estimated as the middle point of this range. The annual carrying cost was estimated at 10% of the value of the annual average inventory; the annual carrying cost was $50,000.

As reported by the logger, the minimum amount of timber harvested in one location (minimum order quantity) was 20 acres or 400 tons (see
Figure 30). The logger did not track any of the data for the calculation of perfect-order execution metrics, so these metrics were not calculated.

5.3.3 Outbound Logistics

The logger reported that each truck's payload was 28.5 tons. The transit time for trucks was estimated at 35 mph, for the distance of 60 miles from the logging operations to the mill, with a 10 hour working day. Therefore, the transit time was 0.171 days.

$$Transit\ Time = \frac{60\ miles}{35\ mph} * \frac{1\ day}{10\ hr} = 0.171\ days$$

Equation 17. Transit Time Woods to Mill

Figure 31. Logger Outbound Logistics

Equation 17 was used to calculate the transit time from the woods to the mills. As indicated earlier, the company hauled 2,000 tons/day, and the estimated value per ton was $48 (reported from other industry source), so the annual cost of this inventory was $96,000 with an annual carrying cost of $9,600 (10% of the value of the inventory). The planned delivery frequency was obtained by dividing the inventory carried per day into the capacity of each truck. The planned delivery frequency was the number of trucks that the supplier sent outbound per day.

$$Planned\ Delivery\ Frequency = \frac{2,000\ tons}{28.5\ tons\ per\ truck} \approx 70\ trucks\ per\ day$$

Equation 18. Planned Delivery Frequency

Therefore, there were 70 trucks transporting raw materials six days a week. Similar to the supplier process, the company did not report any data to allow for calculating perfect-order execution metrics (see Figure 31).

5.3.4   Receiving Operations

Figure 32 shows the main lean logistics metrics for the receiving operations, or the wood/log yards at the facilities. It was assumed that each of the six facilities had an average annual inventory of 25,000 tons, so that the average-daily on hands (ADOH) inventory is calculated as:

$$ADOH = \frac{Average\ inventory\ per\ site * Number\ of\ sites}{Daily\ Demand}$$

$$ADOH = \frac{25,000\ tons * 6\ facilities}{2,000\ tons/day} = 75\ days$$

Equation 19. Average Days on Hand at Receiving Operations

INV	Logger
ADOH (Tons)	Tons Delivered per Day in 2016
75	2,000

Receiving Operations (Wood Yard) at Consumer Company		

Inventory (ADOH)		75	Days
Value of Inventory	$	7,200,000	Dollars
Carrying Cost (10%)	$	720,000	Dollars
Perfect-order		0%	
Quantity		0%	
Product		0%	
Place		0%	
Time		0%	
Quality		0%	
Cost		0%	
Service		0%	

Figure 32. Receiving Operations

The value of inventory was the number of tons at the inventory point multiplied by the cost per ton.

$$Value\ of\ average\ annual\ inventory = Number\ of\ sites * inventory * \$/ton$$
$$Value\ of\ average\ annual\ inventory = 6\ sites * 25,000\ tons * \$48/ton = \$7,200,000$$

Equation 20. Value of Average Annual Inventory

The value of the average annual inventory, the ADOH, and the annual carrying cost of the inventory (calculated at a rate of 10% of the value of the inventory) is shown in Figure 32. There was no information available to calculate the perfect-order execution metrics.

5.3.5 Fulfillment Cost for Case Study 3

Table 29. Fulfillment Stream for Case Study 3

Logistics Impact-Annualized	
Material Ordering	
Personnel: Ordering and Planning	$291,800
Overhead Cost (20%)	$58,360
Current Subtotal	**$350,160**
Harvesting Cost	
Harvesting Cost Per Ton	**$7,500,000**
Current Subtotal	**$7,500,000**
Outbound Logistics	
Transportation: Outbound from Supplier	$5,027,400
Overhead Cost (20%)	$1,005,480
Current Subtotal	**$6,032,880**
Log Yard	
Personnel: Raw Material Handling	$69,080
Material Handling: Equipment	$435,799
Overhead Cost (20%)	$100,976
Current Subtotal	**$3,635,127**
Customer Collaboration	
Current Subtotal	
Inventory Carrying Costs	
Current Subtotal	**$779,600**
Total Cost of Fulfillment	
Current Total Cost of Fulfillment	**$18,297,767**

The total cost of fulfillment involves the following costs: material ordering, harvesting, outbound logistics, wood/log yard management, and inventory carrying. The total fulfillment cost was calculated as $18,297,767. Table 29 shows a summary of the fulfillment costs, and the detailed calculations are presented in Appendix C.

The largest cost in this supply chain was the harvesting cost, with a value of $7,500,000 per year, using an estimated harvesting cost of $12.50 and 2,000 tons/day. The second largest cost was outbound logistics which was estimated as $6,032,880. The third largest cost was the wood/log yard management*** which was estimated as $3,635,127.

5.3.6   VSM Analysis for the Logger

The complete VSM for the logging firm is shown in Figure 33. The daily consumption was based on the number of tons hauled during the year 2016 which was reported by the logger as 600,000 tons and the average reported weekly hours. The daily consumption was set to 2,000 tons/day. The logger (supplier) owned stumpage, this was represented in the VSM as the average annual standing inventory. The logging company had over 30,000 tons of wood available for harvest. The ADOH of standing timber is 15 days. The value of the inventory (standing timber) was reported between $400,000 to $600,000. The minimum order quantity was 20 acres or 400 tons. The logger did not calculate any perfect-order execution metrics or collected data. The logger's outbound logistics described the transportation to the consumers' log yards. The transit time was of 0.171 days, the value of inventory carried per day was of $96,000 dollars and the carrying cost was of $9,600 dollars. The quantity of trucks utilized per day were 70. In absence of communication with the consumer mills (those that the logger worked with), all of the data in receiving operations was an educated assumption by the logger. The logger had six main consumer companies that it delivered to, therefore six consumer mills are represented in the VSM. The reported ADOH was 75 days (total between all six consumer companies delivered).

The total process time varied from 7 to 22 days this includes the variable order to shipment time reported (7 to 22 days) plus the transit time (0.171 days). The inventory in the pipeline was calculated as 90 days, which is the sum of 15 ADOH at the supplier owned standing timber and the 75 ADOH delivered at the consumers' wood yard. The total lead time ranged from 97 to 112 days, 97 days occur if the order to shipment time is established at 7 days plus the 90 ADOH, similarly 112 days occur if the order to shipment time is established at 22

*** Wood/log yard cost was obtained from case study 2, and it is multiplied by 6 (six facilities).

days plus the 90 ADOH. The value of the annual average inventory for this VSM was estimated as $7,796,000 with an annual carrying cost of $779,600.

The supplier had to estimate important data such as daily consumption at the consumer mills and had to make an educated assumption for the amount of inventory on site for all consumer companies. This situation reflects the lack of knowledge of strategic information of behalf of the logger. Information such as daily consumption at the consumer site and the amount of inventory directly impact the logger's logistic operations. These information gaps generate a reactive environment instead of a proactive environment for the logger.

The main lean logistics metrics prepared and shown in the VSM were important in understanding the time that it took to move the raw material from the supplier to the wood yard. This metric was necessary to know if there were important or critical delays in the entire process. The amount of inventory at each point was also calculated show whether the company was managing inventory levels for unexpected delays in the supply chain. Further data analysis and information obtained from the interview process helped to determine the main sources of waste impacting this supply chain. Table 30 shows the main sources of waste that were detected for the logging firm, which are discussed in the following sections.
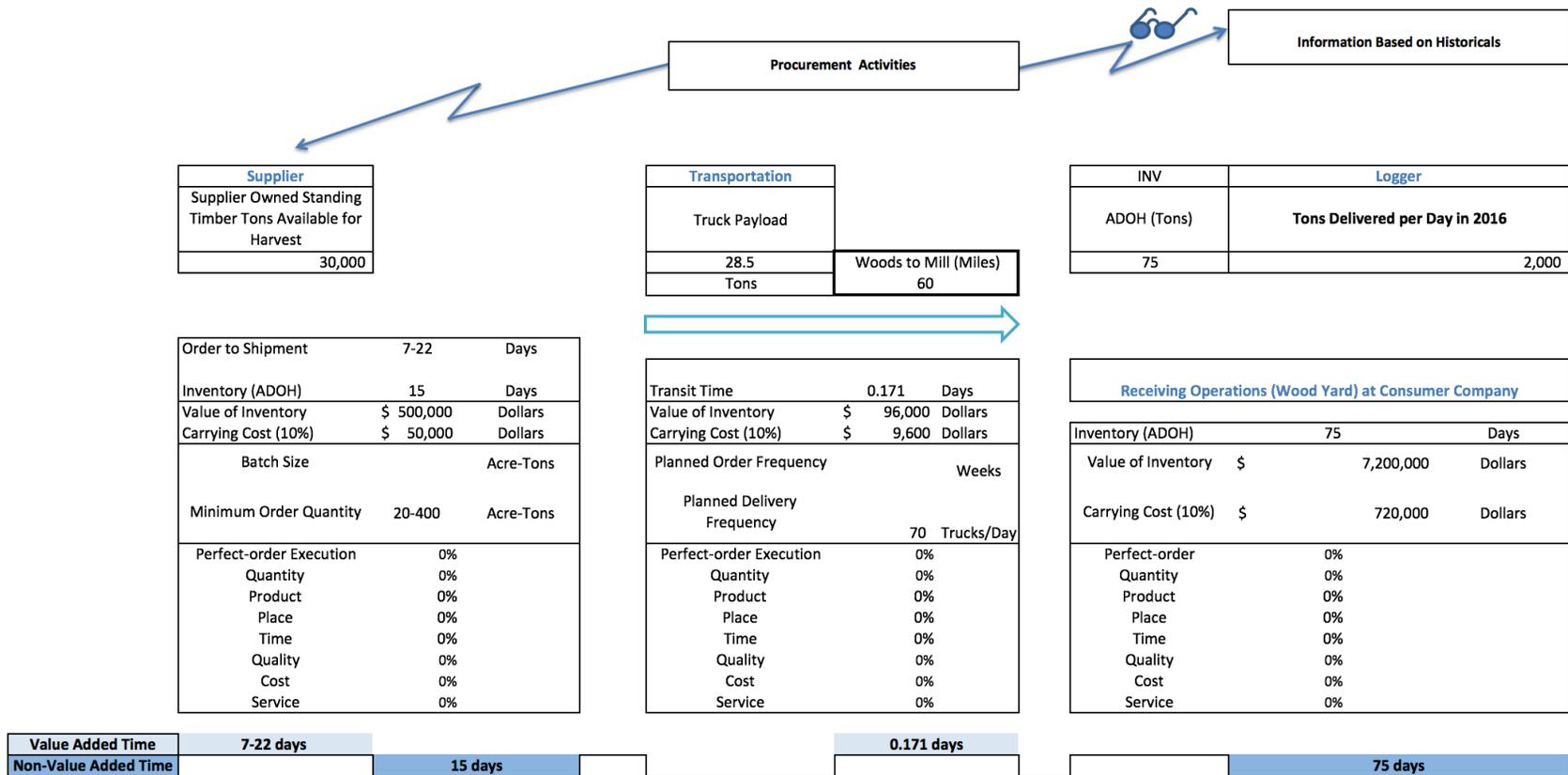
Figure 33. Current VSM of Case Study 3

Table 30. Identified Waste in VSM for Case Study 3

Type of waste	Logistics area impacted	Specific issue
Inefficient use of human resources	Procurement	• Loggers are seldom considered for strategic planning decisions. • There is no proper communication or planning horizon for the loggers (reactive environment).
Unnecessary transportation	Inbound transportation	• Trucks travel longer distances between harvesting and wood/log yard sites because of quota restrictions.
Excessive waiting times	Supplier collaboration	• Logging crews need to idle equipment and personnel due to lack of demand.
Overproduction	Supplier	• Logging crews harvest more than planned, to take advantage of good weather conditions.

Inefficient Use of Collaboration and Relationships (the Human Resource Factor)

As shown in the VSM, the logging firm did not provide any data to calculate perfect-order execution metrics, which are necessary to make better strategic decisions and work closer with suppliers and customers. Literature supports the need for communicating with consumer companies and performance measure indicators play a substantial part in measuring productivity. "*Suppliers…should inform the consumer of any planned moves or reduction unproductivity levels of the operation*" (Rodgers et al., 2002).

Excessive Waiting Times

The logging company reported the process time as variable, because of inconsistent demand from the mill. However, pulpwood tracts have a shorter processing time, because they were delivered on an agreed timeframe. The variability in this process was a critical source of waiting times and idling on the supplier end. The cost of idled equipment could be untenable in some cases.

Unnecessary Transportation

The lack of communication and collaboration between the supplier and the consumer mill could also impact the cost of transportation, because loads that were rejected at some mills were rerouted to a different location, causing extra transportation costs. As explained earlier, transportation cost was the largest fulfillment cost in this supply chain (33% of the total

fulfillment cost) and any decision related to increased travel distances or rerouting truck loads must be carefully considered.

Overproduction

It was reported that logging crews usually harvested more than required when weather conditions were better, hoping that the consumer mills would buy extra loads. However, that was not always the case. The cost of holding inventory (estimated as 10% of the value of the inventory) should be considered, especially when the timber is already cut and needs to be delivered quickly to avoid damage.

Excessive Inventories

The supplier's procurement team relied on experience and historic records to buy standing timber, given the lack of collaboration and communication with consumer mills. When there is no active collaboration between supplier and consumers, the supplier tends to increase their inventory levels to protect the company against demand uncertainties. In addition, it was found that the wood yards with an unusual amount of inventory also have large costs associated with carrying inventory.

5.4 Future VSM: Recommendations

The strength of a tool like value stream mapping lies in the power to visualize waste and the implementation of recommendations to improve the current state. The application of VSM to specific value streams in the wood fiber supply chain helps to identify recurrent issues that have been reported in the literature.

Wood Flow Planning and Communication

The author highly recommended that all the case study firms in this project implement a strategy to improve their wood flow planning to eliminate or decrease the following major sources of waste in their value stream such as carrying cost of inventory. To improve wood flow planning the following can help:

- Consider loggers in strategic planning decisions
- Provide formal communication, or planning horizon for the loggers (to eliminate the reactive environment). For example, loggers deviate truck payloads in their everyday routine, if the mill closes

It was also clear that market constraints played a critical role in the generation of waste in all the value streams that were analyzed. These market constraints included (Greene et al., 2002):

Lost utilization of wood assets created by low demand for products.

- Lost utilization of transport vehicles loaded with such products
- Increased hauling distances to markets that are only used when wood orders at primary markets are restricted
- Complete shutdown of operations

To decrease waste, the industry dynamic between suppliers and consumers must change. Suggested changes would include collaboration and information sharing between the supply chain partners. Figure 34 shows a proposed communication scheme for mills and suppliers. A yearly plan of consumption and inventory levels should be available for procurement and suppliers. A second communication should be provided within 2-4 weeks with an immediate supply and specification plan, which should be given to the procurement department. Figure 34 shows the questions that must be answered for optimal performance, and as Taylor (2012) pointed out, a more stable operating environment is necessary in order to provide better

information to loggers in terms of future demand for wood, given their high levels of capital costs in harvesting and transportation equipment.

Mill Managment
determines:

↓

Consumption and inventory levels
(goals)

- When will the change take place?
- How will the change affect current inventory?
- How will the change affect future purchases?
- How long the change will last?

↓

Inmediate supply requirments
(with predicted changes, volumes, and specifications)

↓

Make information available for procurement department and suppliers
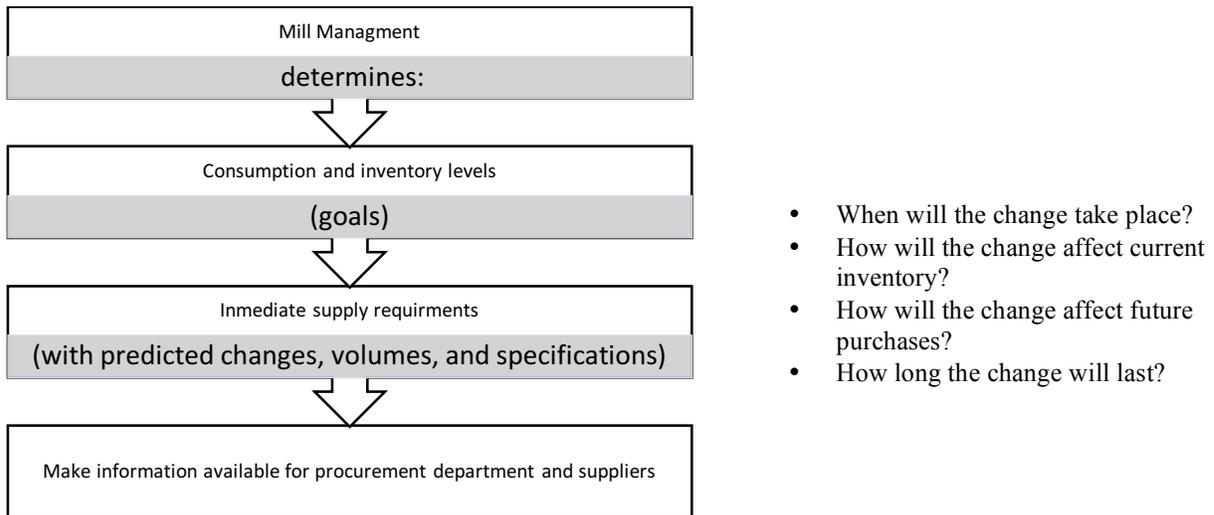
Figure 34. Wood Flow Planning Adapted (Rodgers et al., 2002)

Similar to an improvement in wood flow planning, causes of lean waste can be improved through better communication between the supply chain partners. This would include:

- Recognition of impact of consumer actions

- Consider loggers in strategic planning decisions

- Logging crews need to idle equipment and personnel due to lack of demand

- Logging crews harvest more than planned to take advantage of good weather conditions

- There is no proper communication, or planning horizon for the loggers (reactive environment)

In all the three case studies, communication should increase to reduce waste and inefficiency in the wood fiber supply chain. Communication between suppliers and middle and upper mill management is less frequent than with foresters, for example, Don (2012), advised that senior procurement managers communicate situations to the company's top management. Don's recommendation also indicated that the communication flow needs to improve, even within the company. "While communication with front line foresters is crucial to the successful implementation of a plan, communication with those responsible for the creation of the plan is just as important" (Rodgers et al., 2002).

Suggestions to alleviate miscommunication can be determined by written plans that outline key planning parameters. Along similar lines, a written contract should be provided to the supplier, outlining expectations and obligations on behalf of procurement. Loggers have reported that they want further information on lead time and quota. In order to improve their ability to plan in order to meet the suppliers requests (Rodgers et al., 2002). Important communications include:

- Future mill supply needs
- Lead time
- Information on shutdowns
- Current supply levels, inventory levels
- Foreseen changes that have the potential to affect productivity of the operation

The supplier must also communicate with the consumer company about their operations (Rodgers et al., 2002).

5.4.1 Metrics-Driven Core Logger Systems -Tract Allocation

The three case studies, indicated that the performance of wood fiber supply chains are impacted by the lack of knowledge on the logger's quantity of standing timber, and by the overcapacity of suppliers. If more information from the suppliers was available; the procurement teams of the consumer mills would have more data to better allocate demand to suppliers. For example, if data on wood flows from tracts (type of timber, terrain parameters, etc.) and capacity of loggers is known, each tract can be allocated to a supplier based on these

characteristics. The next figure explains considerations that could be taken.
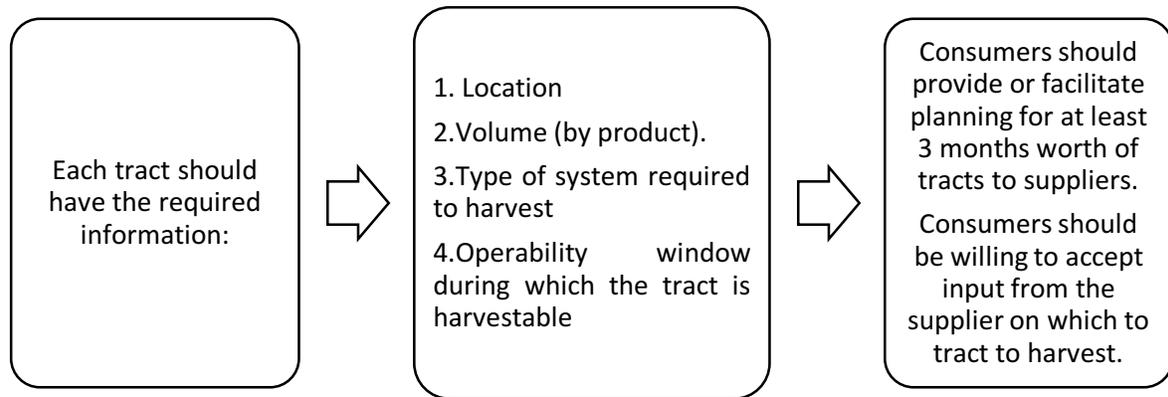
Figure 35. Consumer Considerations for Supplier

The supplier should play a key role in effective tract allocation. "Each portion of the operation that the supplier is left out of greatly eliminates the ability to accurately plan a harvesting or trucking system to satisfy the needs of the consumer without building inefficiency into the system" (Rodgers et al., 2002).

Companies operating a preferred supplier system should give 80% of annual consumption to those suppliers. The remaining percentage can be either open market or given to preferred suppliers. Communication plays a vital part for optimization of supply chains. More than two thirds of loggers in carried unused capacity in their harvesting operation, 50% specifically to increase productivity, in case quota was to be introduced (Rodgers et al., 2002).

An intriguing idea that could improve the communication between supplier and customer would be to develop a synchronized measurement system across all parties (suppliers, consumers, transportation) that could increase visibility across the supply chain. Specific requirements that this supplier/consumer system would require are:

- These systems should inform the consumer companies when productivity is being negatively impacted by their decisions

- Development of short and long-term communication plans with their suppliers and the procurement department
- Development of selection metrics driven core supplier systems, that allow the company to distribute loads, tracts, etc..., while minimizing the impact to their most important suppliers (metrics-driven core logger systems)
- After identifying key suppliers, inform each of them ahead of time of any significant changes that affect the loggers
- Development of an information sharing culture between the consumer company and the suppliers that allows the allocation of resources designed to reduce waste. For example, allocate tracts and quota according to logger's capacity

5.4.2 Decrease in Inventory

As it has been mentioned throughout the report, that determining the right amount of inventory at each point of the supply chain is critical for all parties involved. An excessive amount of inventory could help to protect against variability, but the carrying costs of the inventory should be also considered. Each company needs to dedicate enough resources and time to make sure the right inventory models are implemented, based on several factors such as: customer service levels, market fluctuations, available space and equipment, and cost considerations.

5.4.3 Specific Recommendations

Table 31 shows the specific recommendations to improve the performance of the wood fiber supply chain. These recommendations are summarized from the individual case studies, and they focus on the elimination or reduction of unnecessary transportation, excessive movements, and inefficient use of human resources. Each one of these focus areas is further divided in specific aspects of logistics including inbound transportation, wood yard management, supplier, and procurement.

The second part of Table 31 shows recommendations with a focus on the reduction of waste due to excessive waiting times, defective product, overproduction, and excessive inventory holding. These recommendations are also summarized from the case studies presented earlier

in this report. The user may see recommendations to solve specific issues impacting selected areas of the logistic and supply chain activities.

Table 31. Specific Recommendations

Type of waste	Logistics area impacted	Specific issue	Recommendation
Unnecessary transportation	Inbound transportation	• Traveling longer distances between harvesting and wood yard sites • If the load needs to be redirected because the mill isn't accepting more loads, extra miles are incurred	• Reduce reactive environment for suppliers • Make loggers aware of changes in a reasonable timeframe • Develop a model that uses a metric driven core supplier system that allocates quota according to capacity
Excessive movements	Wood/log yard management	• Unloading of trucks causes delays to logging crews • Lack of space in wood/log yard causes loaders to travel longer distances with loads • Excessive turn times	• Loggers need to identify the time slots that minimize the time spent in queue • Coordinate deliveries • Distribute arrivals • Perform simulation analysis to validate the assignation of arrivals
	Supplier	• How the logger determines the layout of the cutting operations may increase the amount of movements necessary	• Distribute the layout at the harvesting site, such that movements are minimized
		• Logging crews spend extra time handling standing inventory due to terrain conditions or logger's equipment is not adequately designed for the tract	• Consumers need to be aware of supplier's capacity. Match the tracts according to supplier's equipment
	Supplier collaboration	• Marking errors in harvesting sites	• Make sure there is proper labeling and signaling of trees • Standardization of processes
		• Share information of the logger's quantity of standing timber to allow better allocation of loads	• Develop a model that uses a metric driven core supplier system which allocates loads according to capacity
Inefficient use of human resource	Procurement	• Loggers are seldom considered for strategic decision planning. There is no proper communication, or planning horizon for the loggers (reactive environment)	• Design of communication plans annually, monthly, and weekly • Apply joint-planning between mill management, procurement department and suppliers

Continued…			
Type of waste	**Logistics area impacted**	**Specific issue**	**Recommendation**
Excessive waiting times	Supplier/Supplier collaboration	• Excessive turn time	• Distribute arrivals • Perform simulation analysis to validate the assignation of arrivals
		• Logging crews need to idle equipment and personnel due to lack of demand	• Reduce reactive environment for the suppliers
		• Logging crews need to idle equipment and personnel due to lack of demand. Wood quotas and distribution may be a cause	• Implement metric driven core supplier systems
Defective products	Supplier/ Supplier collaboration	• Loggers deliver the wrong product to a consumer mill or they deliver loads to a mill that wasn't initially in the plan	• Reduce reactive environment for the suppliers
Overproduction	Supplier/Supplier collaboration	• Logging crews harvest more than planned, to take advantage of good weather conditions	• Improve communication and aid the loggers to plan • Implement joint planning between suppliers and consumers
Inventory holding	Supplier and wood/log yard management	• Carrying cost of inventory • Low inventory levels (running out of wood)	• Improve coordination in the supply chain • Implement metric driven core supplier systems. Coordinate with loggers to mitigate the risk of stock out or carrying an excessive amount of inventor

5.4.4   Potential Savings of Recommendations.

The design of a future VSM implies making assumptions regarding the potential benefits from the implementation of recommendations and improvements. Baseline percentages, as developed by Rodgers et al. (2012), are used to quantify the potential benefits of implementing the recommendations described earlier, in a future VSM for each case (see Table 32). The application of the potential benefits are reflected in the value of the inventory, the inventory carrying cost, and the inbound logistics fulfillment cost.

The following section shows the conservative potential savings by applying the recommendations mentioned previously. The inventory carrying cost reduction is applied only in the transportation and wood/log yard cost.

Table 32. Suggested Savings as Indicated by Rodgers et al. (2002)

Future VSM		Lower Scope Gain in Percentage
• Wood Flow Planning: Mill Management • Tract Allocation: Procurement • Communication: Mill Management, Procurement and Supplier	Inventory Carrying Costs (Transportation & Wood Yard)	21%
• Truck Scheduling Coordination: Mill Management • Tract Allocation: Procurement	Inbound Logistics	10%

5.4.5 Potential Savings in Case Study 1

Table 33. Potential Savings in Case Study 1

Component of Logistics Cost	Current Cost	Future Cost
Inbound Logistics	$2,873,825	$2,586,442
Inventory Carrying Cost (Transportation and Wood/log Yard)	$98,397	$79,548
Total Savings	$306,232	

Table 33 shows the inbound logistics costs were calculated as $2,873,825 annually and $98,397 for the inventory carrying cost. Inbound logistics is reduced by $287,383. The inventory carrying cost reduction is $18,849. A conservative estimate for total savings annually would be $306,232. The estimated total cost of fulfillment would be reduced from $10,318,436 to $10,012,204.

5.4.6 Potential Savings in Case Study 2

Table 34. Potential Savings in Case Study 2

Component of Logistics Cost	Current Cost	Future Cost
Inbound Logistics	$3,031,641	$2,728,476
Inventory Carrying Cost (Transportation and Wood Yard)	$365,516	$356,595
Total Savings	$312,085	

Table 34 displays the current and future costs of Case Study 2. In inbound logistics, the savings totaled $303,165. In inventory carrying costs the savings are $8,921. The total savings in the annual fulfilment cost add up to $312,086. The current fulfilment cost is estimated as $10,173,931 and the future is estimated as $9,861,845.

5.4.7 Potential Savings in Case Study 3

Table 35. Potential Savings in Case Study 3

Component of Logistics Cost	Current Cost	Future Cost
Outbound Logistics	$6,032,880	$5,429,592
Inventory Carrying Cost (Transportation and Wood Yard)	$729,600	$626,384
Total Savings	$756,504	

The table above displays the potential savings in case study 3 in one year. In inbound logistics, the savings total $603,288. In inventory carrying costs the savings total $153,216. The total savings in the annual fulfilment cost total $756,504. The current fulfilment cost is estimated as $18,297,767 and the future is estimated as $17,541,263.

5.5   Supplier Selection Tool

After the application of the VSM to the three case study firms, major recommendations focused in improvements such as wood flow planning and communication to reduce waste (i.e. the carrying cost of inventory). A metric driven logger system was also encouraged as a way to facilitate collection of information such as: quantity of standing time, type of timber, terrain parameters, capacity of loggers, etc. Such information provides the data to make well-informed decisions, and hence reduce waste through proactive planning.

For such recommendations to be feasible, there needs to be strong communication between suppliers and consumers. Therefore, the current industry dynamic must change. Change is difficult when there is no structured approach to selecting suppliers. An unstructured approach lacks order and organization. Furthermore, there is no current scientific perspective to an otherwise intuitive decision-making process. In an effort to achieve a method that aids consumers in identifying value in their company's supplier base and to encourage the creation of metrics-driven core logger systems, a supplier selection tool was created.

The supplier selection model was designed with the purpose of helping the mills in the wood industry make better decisions when selecting and assessing their suppliers by prioritizing. Most mills do not use a structured way to select and prioritize their suppliers, as found in objective one. Their methods vary in complexity, going from just a few phone calls, to considering certain criteria and making the decision in a meeting using unstructured methods.

The proposed model created a framework for supplier selection that industries could apply in their companies according to their needs. The model provides criteria taken from literature reviews which are considered important for the decision-making process regarding supplier selection. Criteria was also gleaned from experts in the field, practitioners and academics. The proposed system was programmed using visual basic programming language for applications in Microsoft Excel with a dynamic interface to enter data and obtain results. A user guide was also designed to assist users when employing the application. This research bridges the gap by providing an application to select suppliers that uses structured and proven-effective methods.

5.5.1 Hybrid Model AHP-TOPSIS

The model selected for the framework and the application combined two different multi-criteria decision-making methods, the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS). The AHP method was used to get the weights of the selected criteria, while the TOPSIS method was utilized to compute the rankings of each alternative for the criteria and sub-criteria considered.

The main advantage of TOPSIS is that this method has been proven to produce the least rank reversals when compared to other multi-criteria decision-making techniques (Zanakis, Solomon, Wishart, & Dublish, 1998), which makes it adequate as a prioritization tool, and therefore, was selected as the method to be used in the ranking phase of the model. However, TOPSIS may not be adequate when the objective is to obtain the weights of different criteria, in which case, the interest is not to obtain a prioritization of the criteria itself, but rather the proportions between them. Therefore, the AHP method of relative measurement by pairwise comparisons was applied for the weighting phase of the model.

The hybrid AHP-TOPSIS model proposed in this study was designed to use exact values, or crisp values, using the fuzzy terminology, related to linguistic variables on the basis that, as presented by Saaty & Tran (2007), if a decision maker is well informed, the AHP, and other multi-criteria decision-making techniques, were proven to provide valid results. The validity of the results provided by any decision-making model, and specifically for the model and application developed in this study, was dependent on the quality of the information available to the decision maker, for which only the decision makers were responsible.

5.5.2 The Criteria

The supplier selection model developed was based on the criteria used to assess the performance of the alternative supplier candidates. For the purpose of this study, the criteria proposed for this model have been taken from literature review, and with consultation with practitioners from the wood industry and academics related to that industry, as described in the current situation analysis.

The literature review conducted to find supplier selection criteria was aimed at finding what other industries consider important when selecting their suppliers. The consultations with practitioners and academics was made with the objective of having an input from sources related to the wood industry and then contrasting that information with the findings from the literature review. The result was a list of criteria which intersects the information provided by academics, practitioners and the literature review (see Figure 36).

Figure 36.Representation of Information Intersection from Academics, Practitioners and Literature Review

The resulting criteria from the intersection of findings in the literature review, and from the practitioners and academics consulted is showed in Table 36.

Table 36. Supplier Selection Criteria Proposed for the Model

Criteria Proposed for the Model
Quality
Cost
Delivery
Financial Position
Relationship

Reputation
Technical Capability
Reliability
Geographic Location
Flexibility

5.5.2.1 Criteria Definition

Although the model proposed is flexible and adaptable to the practitioner's needs, the focus of this study was to take an approach from the perspective of the wood industry in the United States. Therefore, it is useful to define the meaning of the criteria involved, so that the user has a clear understanding of how to make a judgment according to the definition.

5.5.2.2 Quality

Quality is defined as the ability of a contractor to meet the specified product requirements regarding wood features like length, damage, diameter, and species of provided logs (Eriksson, LeBel, & Lindroos, 2015). By managing these quality features, a mill can work with a defect rate for their suppliers, which will represent the percentage of product that does not meet the specified requirements. Other metrics could be established as well to assess the quality performance of delivered products and get a defect rate that adapts to the specific situation and practices of a given company.

5.5.2.3 Cost

The product cost is the price that a mill must pay to a contractor for a delivered ton of purchased wood or the price for harvesting services, in the case of contractors that harvest in the company's lands.

5.5.2.4 Delivery

Delivery refers to the contractor's ability to deliver an agreed volume of wood on time (Eriksson, LeBel, & Lindroos, 2015). Using this metric a delivery indicator can be established, representing the percentage of time in which an agreed volume was provided on time.

5.5.2.5 Financial Position

The financial health of a supplier is crucial for the stability and resiliency of a company, the possibility of a supplier going bankrupt represents a major source of risk in the supply chain (Jung, Lim, & Oh, 2011). According to practitioners consulted, financially weak suppliers are more likely to ask for wood price increases more often, compared to those who are financially healthy, so supplier financial well-being is also beneficial for the company from the prospective of material price stability.

If the supplier's quantitative financial information is not available to the decision maker, there are other non-financial measures useful for qualitatively estimating the financial health of the supplier. A list of these measures is presented by Cancro & McGinnis (2004) as follows:

- Loss of important accounts

- Supplier operating bottlenecks that result in production or delivery delays

- Slower bill payment

- Additional incentives for prompt bill payment

- Willingness to make price concessions that are out of the ordinary ·

- Poor morale by supplier personnel

- Turnover among long-time employees (especially the best employees)

- Workforce reductions

- Rumors of creditor pressure

- Frequent changes in a supplier's sources

- Reduction in services

- Shortages of raw materials and components

5.5.2.6 Relationship

The ease of the relationship between a consumer mill and its contractor is very important according to practitioners consulted, given that the mill's personnel will have to work on the ground with the contractor's personnel to manage the wood procurement. Therefore, relationship refers to how easy it is to communicate, coordinate, and cooperate with a contractor at the tactical and operations levels.

5.5.2.7 Reputation

Reputation refers to the widespread perception of the contractor's overall performance within the industry. When selecting or evaluating suppliers, a company should consider what experiences and references other businesses in the industry share about a contractor.

5.5.2.8 Technical Capability

Technical Capability constitutes the ability of a contractor to perform harvesting operations successfully, for which appropriate equipment is required.

5.5.2.9 Reliability

A reliable contractor is one that perform its services in accordance with negotiated agreements (Erlandsson & Fjeld, 2017).

5.5.2.10 Geographic Location

Geographic Location can refer to the distance between the contractor and the land that a company wants to harvest or the distance between the contractor and the facility where the company requires the wood to be delivered.

5.5.2.11 Flexibility

Flexibility refers to the ability of a contractor to increase or decrease production level according to demand (Erlandsson & Fjeld, 2017) and/ or to move effectively to new operating areas (Eriksson, LeBel, & Lindroos, 2015).

5.5.3 Determination of the Relative Importance of the Selected Criteria.

Once the criteria for the model were selected, the first phase in the construction of the supplier selection model was to define the structure and method used to determine the relative importance of the criteria selected. This phase was important because using weights for each

criterion would result in a better assessment of the supplier's ability to meet the decision maker's requirements.

5.5.4   The Analytic Hierarchy Process.

The technique selected for the first phase of the model was the Analytic Hierarchy Process. This method was developed by Professor Thomas Saaty in 1980 and it is a widely-used method among all multiple-attribute decision-making methods that enables decision makers to make pairwise comparisons between qualitative and quantitative criteria. (Kasirian & Yusuff, 2013). This model was developed following these steps (Athawale, Mukherjee, & Chakraborty, 2009).

The first step in the AHP is to create the hierarchy., This was done by defining the main goal or objective and the criteria and sub-criteria that were being considered. The hierarchical structure of the model proposed is shown in Figure 37. The second step was to compute the weights for each criterion by setting pairwise comparisons for the criteria. This method uses a score system from 1 to 9 that indicated the relative importance of one criterion with respect to the other. If an element had the same relevance as another, a score of 1 was assigned.
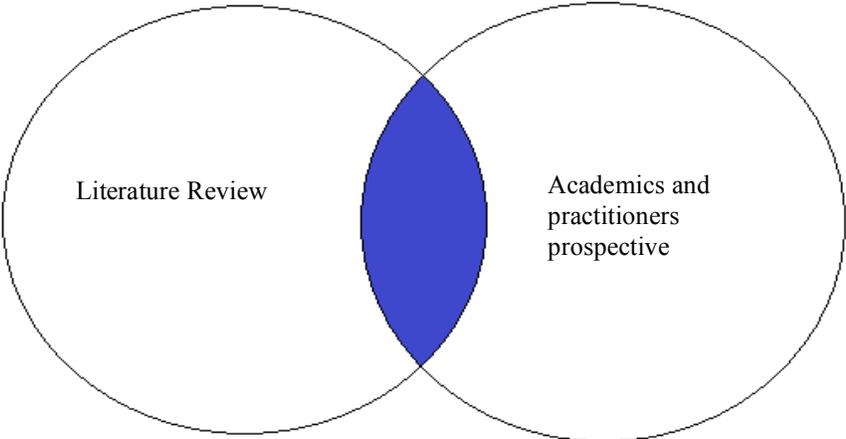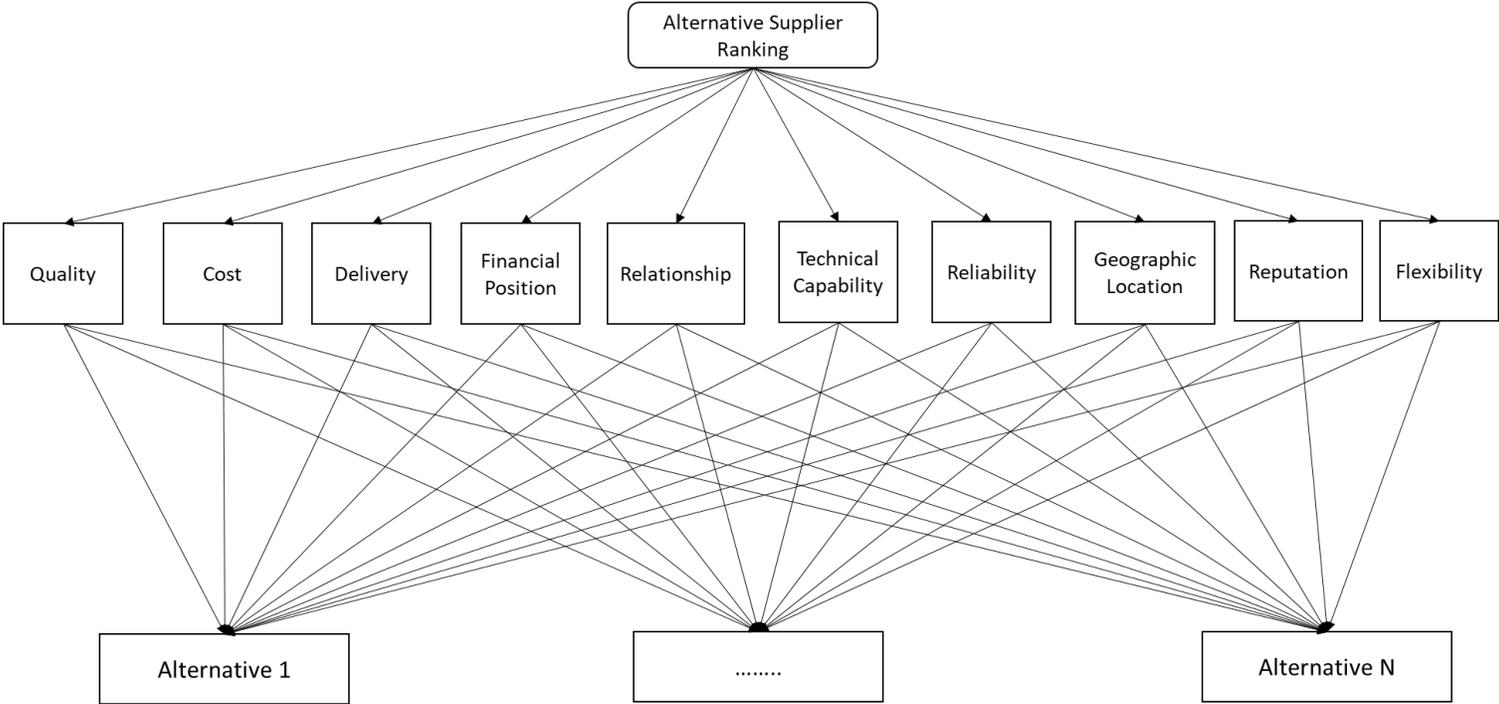
Figure 37.Representation of Information Intersection from Academics, Practitioners and Literature Review

The structure was composed of three levels, with the goal placed on top. In this case, the goal was to get a ranking for the considered suppliers, so that the company could select and work with the best. In the second level, all the criteria were defined for the model. As previously stated, the criteria were defined by combining inputs from literature review, as well as consultation with academics and practitioners related to the wood industry. Finally, in the third level, the alternative suppliers were represented. Having M as the number of criteria for the model, the pairwise comparison of the i^{th} criterion to the j^{th} one produced a square matrix as shown in the figure below.

Criteria	C1	C2	C3	...	Cm
C1	1	A12	A13	...	A1m
C2	A21	1		...	A2m
C3	A31	A32	1	...	A3m
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
Cm	Am1	Am2	Am3		1

Figure 38. Resulting Matrix of the Pairwise Comparisons for M Criteria in the AHP Model

Each entry in the matrix shown in Figure 38 is a comparison between each of the criteria. For example, a_{ij} is the relative importance of i^{th} criterion to the j^{th} one. The diagonal row in the matrix will always be 1, given that it is the i^{th} criterion compared to itself. Also, if a_{ij} is the relative importance of i^{th} criterion to the j^{th} and has a value of N, then a_{ji} will have the inverse value, $1/N$, which will look like the matrix presented in Figure 39.

$$A = \begin{pmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{pmatrix}$$

Figure 39. Resulting Matrix of the Pairwise Comparisons for M Criteria in the AHP Model (Brunelli M. , 2015, p. 5)

Each of these entries in the model represented the perception of the decision maker about the relative importance that one criterion has over another. The Saaty scale, consisting of grades of intensity from 1 to 9, was used for determining the relative importance of the selected criteria by giving a numeric value that could be associated with a linguistic variable (see **Table** 37).

Table 37. Scaled Proposed for the AHP model (Saaty & Vargas,2013, p.3)

Intensity of Importance	Linguistic Variable	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one activity over another
5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very Strong or Demonstrated Importance	An activity is favored very strongly over another, its dominance demonstrated in practice
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation

The final weight for each criterion was obtained by computing the normalized geometric mean of rows in the matrix of pairwise comparisons using the following equations. In order to achieve this, it is necessary to compute the geometric mean of each row first, using the product function with each comparison in the row and the number of criteria M considered.

$$GM_j = \left[\prod_{j=1}^{M} a_{ij} \right]^{1/M}$$

Equation 21. Geometric m Mean of the i^{th} Row of the Matrix of Pairwise Comparisons (Athawale, Mukherjee, & Chakraborty, 2009)

Once the geometric mean was obtained for every row of criteria, the weight was computed by dividing each value by the summation of all the geometric means, as shown in Equation 22.

$$W_j = \frac{GM_j}{\sum_{j=1}^{M} GM_j}$$

Equation 22. Normalized Geometric Mean (Athawale, Mukherjee, & Chakraborty, 2009)
The normalized geometric mean represents the weight of each defined criterion. As the relative importance of the criteria was determined, phase I of the model concluded and phase II began.

5.5.5   Assignation of Rates to Each Alternative

Phase II of the model consisted of assigning rates to each of the alternatives for each of the criteria considered. These rates were assigned according to the information available to the decision- maker about the level of performance of each alternative for each criterion. The validity of the results provided by the model depended upon the accuracy of the information provided for the model by the decision maker. The results are as valid as the information provided.

In the same way as the determination of relative importance of criteria, it was necessary to create a scale to assign the rates in phase II. In order to have consistency across the phases in regard to scales, a Saaty scale was used to assign the rates for the alternatives. A modification of the fuzzy Saaty scale used by Sultana, Ahmed & Azeem (2015) is proposed for this model as shown in Table 38.

Table 38. Scale Proposed for the Assignation of Rates for the Alternative Suppliers (Sultana, Ahmed, & Azeem, 2015)

Intensity of Performance	Linguistic Variable for the Level of Performance
1	Poor
3	Below Satisfactory
5	Satisfactory

7	Highly Satisfactory
9	Excellent

5.5.6 Calculation of the Overall Score for each Alternative

The proposed method for the scoring phase was the technique for order preference by similarity to the ideal solution (TOPSIS), which is a relatively easy way of ranking alternatives. The best alternative, according to this method, is the nearest to the positive ideal solution, one that maximizes the benefit criteria and minimizes the cost criteria, and the farthest from the negative ideal solution. For the purposes of this model, all criteria have been defined as positive criteria, which means that the greater the rating for the any criterion, the better. The first step in the TOPSIS procedure described in Figure 40 is to assign the rates for each alternative to the selected criteria.

Figure 40. Generic TOPSIS Ratings Matrix for a Set of Alternatives A, a Set of Criteria C, a Set of Ratings X and a Set of Weights W

Alternatives	Criteria				
	C_1	C_2	C_3	...	C_m
A_1	X_{11}	X_{12}	X_{13}	...	X_{1m}
A_2	X_{21}	X_{22}	X_{23}	...	X_{2m}
A_3	$X3_1$	X_{32}	X_{33}	...	X_{3m}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
A_n	X_{n1}	X_{n2}	X_{n3}	...	X_{nm}
W	W_1	W_2	W_3	...	W_m

Equation 23 represents a generic TOPSIS rating matrix, with a set of alternatives $A = \{A_k \mid k = 1, \dots, n\}$, a set of criteria $C = \{C_j \mid j = 1, \dots, m\}$, a set of ratings $X = \{X_{kj} \mid k = 1, \dots, n; j = 1, \dots, m\}$ and a set of weights $W = \{W_j \mid j = 1, \dots, m\}$. This set of weightings was obtained from phase I (AHP Method). Using the information from the TOPSIS ratings matrix, the next step was to compute the normalized ratings matrix using Equation 23.

$$r_{kj}(x) = \frac{x_{kj}}{\sqrt{\sum_{k=1}^{n} x_{kj}^2}}, k = 1, \dots, n; j = 1, \dots, m.$$

Equation 23. Normalized Rating Equation (Athawale, Mukherjee, & Chakraborty, 2009)

The next step consisted of calculating the weighted normalized matrix, for which Equation 24 is utilized, where w_j represents the weight obtained in phase II for criterion j.

$$v_{kj}(x) = w_j * r_{kj}(x), k = 1, \dots, n; j = 1, \dots, m.$$

Equation 24. Weighted Normalized Rating Equation (Athawale, Mukherjee, & Chakraborty, 2009)

According to the TOPSIS procedure, the next step was obtaining the positive and negative ideal solution based on the weighted normalized matrix computed before. Given that all criteria were defined as positive criteria, meaning that the better the level of performance, the better the rating, the positive ideal solution (PIS) and the negative ideal solution (NIS) will always follow Equation 25 and Equation 26, respectively.

$$PIS = A^+ = \{V_1^+(X), V_2^+(X), \dots, V_j^+(X), \dots, V_m^+(X)\} = \{max_k v_{kj}(x) \mid k = 1, \dots, n\}$$

Equation 25. Positive Ideal Solution Equation (Athawale, Mukherjee, & Chakraborty, 2009)

$$NIS = A^- = \{V_1^-(X), V_2^-(X), \dots, V_j^-(X), \dots, V_m^-(X)\} = \{min_k v_{kj}(x) \mid k = 1, \dots, n\}$$

Equation 26. Negative Ideal Solution Equation (Athawale, Mukherjee, & Chakraborty, 2009)

Having calculated the positive and negative ideals solutions, the next step consisted of figuring out the distance between each alternative to the ideal solution and to the negative solution. The core of TOPSIS relies on the separation of the alternatives from the positive ideal and negative ideal solutions. A graphical representation of two alternatives with two criteria is shown in Figure 41.
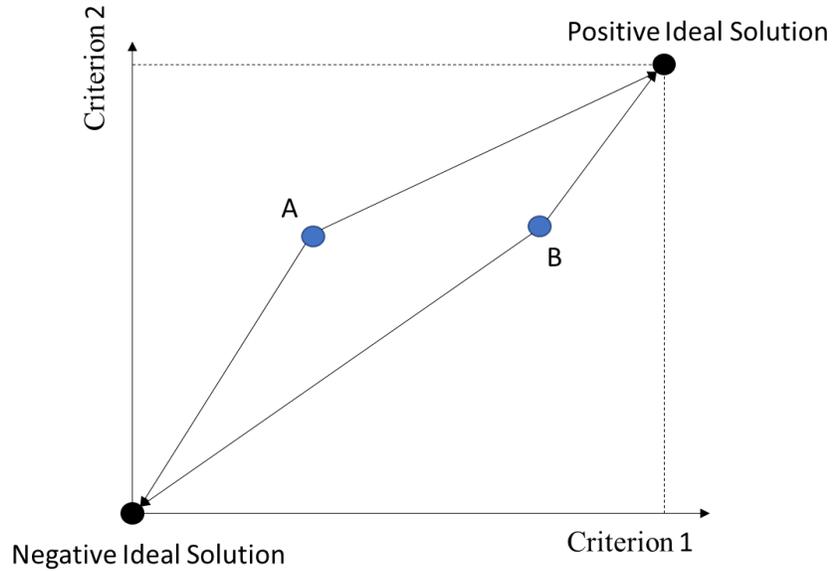
Figure 41. Generic TOPSIS Ratings Matrix for a Set of Alternatives A, a Set of Criteria C, a set of Ratings X and a Set of Weights W (Ishizaka & Nemery, 2013)

The distance of each alternative to the positive and negative ideal solution is computed using Equation 27 and Equation 28 respectively.

$$D_k^{+} = \sqrt{\sum_{j=1}^{m} \left[v_{kj}(x) - v_j^{+}(x) \right]^2}, k = 1, \dots, n$$

Equation 27. Equation for the Distance to the Positive Ideal Solution (Athawale, Mukherjee, & Chakraborty, 2009)

$$D_k^{-} = \sqrt{\sum_{j=1}^{m} \left[v_{kj}(x) - v_j^{-}(x) \right]^2}, k = 1, \dots, n$$

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Equation 28. Equation for the Distance to the Negative Ideal Solution (Athawale, Mukherjee, & Chakraborty, 2009)

The similarity of each alternative to the positive ideal solution can be calculated as a distance coefficient with the negative and positive distances computed before. To achieve this, Equation 29 is applied.

$$C^*_k = \frac{D_k^-}{D_k^- + D_k^+}$$

Equation 29. Equation for the Similarity Coefficient to the Positive Ideal Solution (Athawale, Mukherjee, & Chakraborty, 2009)

Once the similarity coefficient to the positive ideal solution has been computed, then the preference order can be obtained by setting the alternatives coefficients in descending order.

5.5.7   Supplier Selection Software Tool

The supplier selection tool (SST) is an application designed using the visual basic application module in Microsoft Excel. The tool is the software implementation of the structured AHP-TOPSIS models explained in prior sections. The SST allows practitioners from companies to obtain a ranking of the alternative suppliers that are being evaluated, enabling the personnel in the procurement and supply chain departments to identify the best suppliers to work with, so the company can increase the value received from purchasing.

As a selection tool, the SST can be used when the company needs to add a new supplier to its supply network and must decide between alternatives. As an assessment tool, it can be used to identify which of the current suppliers are adding more value to the company, which supplier a company should purchase from, with whom the company should pursue a stronger relationship, and which supplier or suppliers could be removed, if the company needs to reduce its supplier base. The following sections describe the main functions integrated in the SST based on the Hybrid AHP-TOPSIS model proposed.

5.5.7.1   Determination of the Relative Importance of the Criteria

The supplier selection tool provides a matrix for the user. The user must fill in the upper half of the matrix, comparing each criterion in the left column of the matrix to each criterion in the first row of the matrix. The lower half of the matrix will be calculated automatically by the tool. Each value in the matrix must be inserted using the Saaty scale, which is explained next to the pairwise comparisons matrix and is shown here in Table 39.

Table 39. Saaty Scales for Comparisons in the Supplier Selection Tool (Saaty & Vargas 2013)

Fundamental Saaty Scale for Comparisons	
Extremely Less Important	1/9
Very Strongly Less Important	1/7
Strongly Less Important	1/5
Moderately Less Important	1/3
Equal Importance	**1**
Moderately More Important	3
Strongly More Important	5
Very Strongly More Important	7
Extremely More Important	9

The values of the matrix represent how the criteria in the left column is compared to the criteria in the first row. For example, in Figure 42 when quality is compared to reputation, the value 5 in the position (1,6) in the matrix means, according to the Saaty scale, that quality is considered to be strongly more important than reputation. By contrast, when delivery is compared to technical capability, the value 1/7 in the position (3,7) in the matrix means that delivery is very strongly less important than technical capability or that technical capability is very strongly more important than delivery.

Once all the values have been entered in the matrix, the user will click the button "Compute Weights" as shown in Figure 42 to go to the next step, which is the assignation of rates for each supplier. In case of questions regarding the meaning of any of the criteria predefined in the tool, the user can click the button "How to understand criteria for a definition.

			Quality	Cost	Delivery	Financial Position		Relationship	Reputation	Technical Capability	Reliability	Geographic Location	Flexibility
Quality			1	1/3	3	1	▼	3	5	1/3	1	5	5
Cost				1	5	1/9	∧	7	5	1	3	3	7
Delivery					1	1/7 1/5		5	5	1/7	3	1	3
Financial Position						1/3 1		3	7	1	5	5	7
Relationship						3 5		1	5	1/5	3	1/5	3
Reputation						7	∨		1	1/9	1	1/7	1/5
Technical Capability										1	7	5	9
Reliability											1	1/7	1/5
Geographic Location												1	3
Flexibility													1

How to Understand the Critera

Pairwise Comparisons Matrix

Go Back **Compute Weights**

Figure 42. Determination of the Relative Importance of Criteria in the Supplier Selection Tool

5.5.7.2   Assignation of rates to each alternative

The user must enter the rates for each supplier and for each criterion considered in the ratings function table. The tool uses the Technique for Order Preference by Similarity to the Ideal Solution method to compute a global ranking for each supplier considered. The rates must be assigned according to the Saaty scale for level of performance, which is shown above the rating table in Figure 43.

Fundamental Saaty Scale for Level of Performance	
Excellent	9
Highly Satisfactory	7
Satisfactory	5
Below Satisfactory	3
Poor	1

	Weights	A	B	C	D	E	F	G	H
Quality	17.77%	5	7	7	1	7	9	5	7
Cost	25.14%	5	7	5	5	5	3	3	3
Delivery	3.47%	9	9	9	9	9	9	9	9
Financial Position	3.44%	5	5	7	3	7	7	1	5
Relationship	8.66%	5	7	7	1	5	5	7	7
Reputation	8.96%	7	7	7	1	5	7	7	7
Technical Capability	4.44%	7	7	9	5	7	7	5	5
Reliability	14.63%	3	7	9	3	5	7	7	7
Geographical Location	9.92%	3	9	3	7	5	3	3	3
Flexibility	3.56%	5	5	5	3	5	5	7	3

(Control panel buttons: How to Assign Rates | Supplier Performance Ratings | Go Back | Get Ranking)

Figure 43. Assignation of Rates to each Alternative in the Supplier Selection Tool

The user should click the button "How to assign rates" to review a predefined guide on how to assign the rates according to certain indicators defined for the quantitative proposed criteria. The guide shows the range of values for the indicators for level of performance, so the user can assign the rates properly.

5.5.7.3   Calculation of the Coefficient of Performance for each Alternative and Ranking

The ranking function in the SST is accessed automatically when the user assigns all the rates for suppliers and it can also be accessed from the control panel, whenever the user wishes to check any previous computed rankings. When the user clicks on the button "Get Ranking," the tool will automatically calculate a coefficient of performance and show a graphic with the final global ranking, an example is shown in Figure 44.
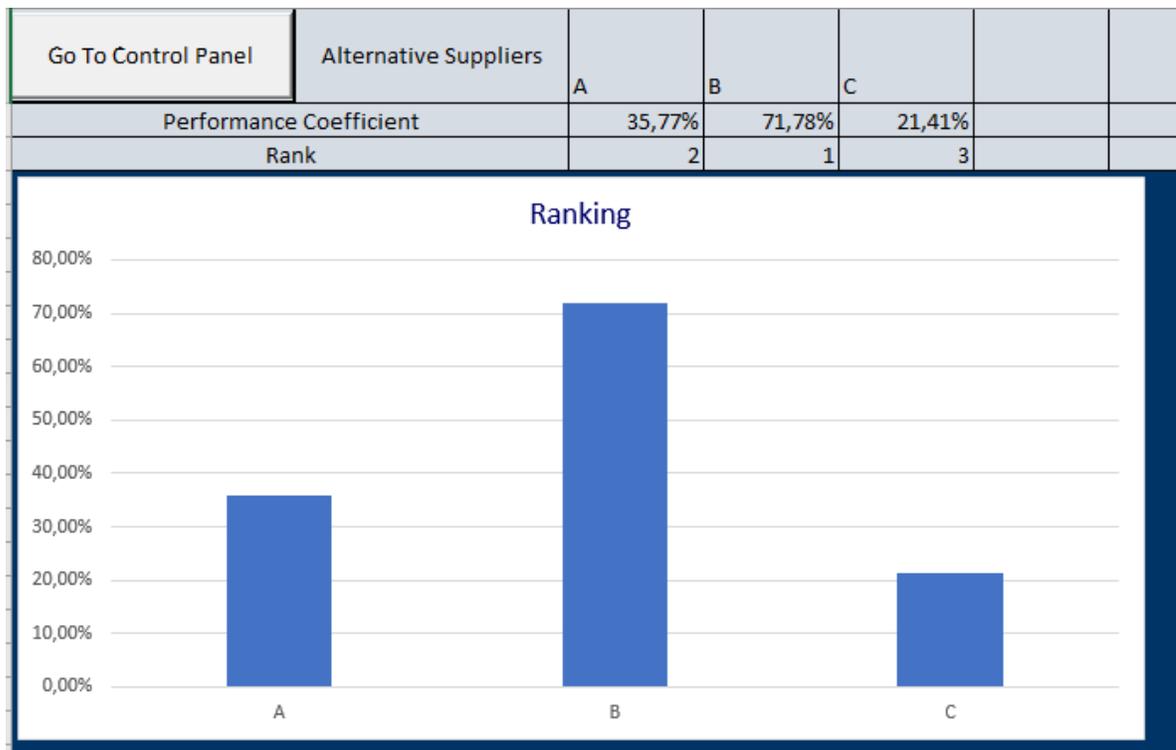
Figure 44. Assignation of Rates to Each Alternative in the Supplier Selection Tool

In the example shown in Figure 44, three suppliers A, B and C were evaluated. The results show a coefficient of performance of 35,77% for supplier A, 71,78% for supplier B and 21,41% for supplier C. The coefficient of performance indicates the degree to which the supplier evaluated is the ideal supplier, according to the whole group of suppliers.

If the user is unable to gather the quantitative information necessary to have a solid base when assigning rates for suppliers, then he/ she will have to rely on his/ her judgment or expertise on the matter, which might be detrimental to the accuracy of the tool results reflected in the actual supplier performance. It is important to point out that the results given by the tool will be as valid as the information available. The tool itself does not guarantee valid results.

5.6   Verification and Validation of Supplier Selection Tool

The verification and validation of the criteria was performed in order to fulfill the requirements of objective three. The verification consisted of manually computing the mathematical formulation and comparing the results to the ones obtained by the tool from one of the interviews conducted with industry as part of this research.

5.7   Verification of the Supplier Selection Tool

The verification of the supplier selection tool was performed by manually computing the results from an interview. A comparison between the output of the tool with the manual results was done and the tool was verified. The steps and results are listed below.

5.7.1   AHP Verification

5. The grades that were assigned by the interviewee (see Appendix E. Matrix for the Determination of Relative Importance of Criteria in the Supplier Selection Tool) were utilized to perform the pairwise comparisons between criteria. These grades were used as the input data to calculate the geometric mean of the i^{th} row of the matrix of pairwise comparisons (see Equation 21).

6. Once the geometric mean was obtained for every row of each criteria, the weight was divided by the value of the summation of all the geometric means to obtain the normalized geometric mean (see Equation 22).

7. The normalized geometric mean was multiplied by 100 to show the results in percentages.

The results of the geometric mean, GM_j (Step 1), the normalized geometric mean, W_j (Step 2), and the final weight percentage or normalized geometric mean (Step 3) are all in Appendix I. Results of AHP Proof.

5.7.2 TOPSIS Verification

7. By using the matrix obtained by the interviewee to rate every supplier against the selected criteria (see Appendix J. Matrix for Assignation of Rates to each Alternative in the Supplier Selection), the normalized rating matrix was obtained using Equation 23 and is displayed in Appendix K. Normalized Rating Matrix.

8. The weighted normalized matrix (see Appendix L. Weighted Normalized Matrix) was computed by multiplying each entry of normalized rating matrix by the corresponding weight for each criteria obtained in the AHP computation (see Equation 24).

9. The positive ideal solution and the negative ideal solution were obtained by using Equation 25 and Equation 26. The results are displayed in Appendix M. Positive Ideal Solution and Negative Ideal Solution.

10. The distance of each alternative to the positive and negative solution was computed using Equation 27 and Equation 28. The results are found in Appendix N. Distance of each Alternative Positive Ideal Solution and Negative Ideal Solution.

11. The similarity coefficient to the positive ideal solution was calculated for very alternative using Equation 29. The results are displayed in Appendix O. Distance of each Alternative from Positive Ideal Solution and Negative Ideal Solution.

12. Once the similarity coefficient to the ideal positive solution was computed and multiplied by 100 (see Appendix P. Similarity Coefficient to the Ideal Positive Solution), then the preference order was determined.

The results from both the AHP and TOPSIS sections were compared to the results obtained by the tool. The results from both procedures were the same therefore the tool was verified. For the AHP proof process Appendix Q shows the values that the interviewee submitted through the tool, these are the same found in Appendix H which are the values that were used to perform the AHP process mathematically by using the equations (manual procedure). When the values that were determined for the relative importance of criteria were computed manually, the results are shown in Appendix

I. These same results were obtained by utilizing the tool and are displayed in Appendix R. Therefore, the results of the AHP proof were consistent and therefore verified.

For the TOPSIS process the same methodology was used. Appendix R displays the assignation of rates to each alternative by the interviewee through the tool. These rates correspond to the rates to each alternative by the interviewee utilized in Appendix J, which are the values that were used to compute the TOPSIS proof manually. Appendix P and Appendix S display the final result of the TOPSIS proof by computing the values manually through equations and through the tool respectively. The results were approximately the same. Differences are caused by the number of significant numbers utilized in each method. Therefore, the TOPSIS portion of the tool was verified.

5.8 Validation of the Supplier Selection Tool

The validation of the tool was done through interviews performed with the forest product industry. The interview process was divided into two different interviews depending on the interviewee. If the interviewee was a consumer (paper mill or sawmill) then the interview process required utilizing the tool. If the interviewee was a supplier, then the interview focused on the criteria and how a multi-criteria decision making tool could alleviate the challenges in the supply chain. The following sections explain the interview process for both consumers and suppliers of the wood fiber supply chain. The validation of the tool was performed by interviewing seven companies within the forest products industry. The following sections describe the results obtained. The following section explains the results regarding the criteria from the supplier and consumer perspective.

5.8.1 Criteria

The criteria proposed for the model was reviewed by the participating companies. The group of companies consisted of two paper mills, two sawmills, and three loggers. Table 40 displays the overall results (approval or disapproval) for each industry segment. The majority approved the criteria. The only exception to the overall approval was one of the two sawmills interviewed regarding relationship and reputation as criteria for supplier selection.

Table 40. Results for Tool Criteria

Criteria Proposed for the Model	Paper Mill Perspective	Sawmill Perspective	Logger Perspective
Quality	✓	✓	✓
Cost	✓	✓	✓
Delivery	✓	✓	✓
Financial Position	✓	✓	✓
Relationship	✓	✓ X	✓
Reputation	✓	✓	✓
Technical Capability	✓	✓ X	✓
Reliability	✓	✓	✓
Geographic Location	✓	✓	✓
Flexibility	✓	✓	✓

5.8.1.1 Supplier Interview: Criteria

The criteria were approved by the suppliers participating in the interview. The main points of discussion centered on the following criteria: cost, quality, relationship, reputation, and reliability. Three different suppliers were interviewed. They will be referred to as: Supplier 1, Supplier 2, and Supplier 3. The suppliers (loggers) expressed approval of the criteria to evaluate and rate the suppliers. Nevertheless, there were important points that were discussed during the interview regarding the overall importance of each criteria and of current practices within the industry. The discussions of criteria are summarized below.

Supplier 1 deemed cost, quality, and delivery as the most relevant criteria that consumer companies use to select suppliers. The interviewee also mentioned that cost is significantly more important than quality or delivery. Cost has a far higher weight of importance than quality or delivery. Supplier 1 stated that relationship, reputation and reliability should be important, but these are only taken into account by consumer companies when they are in need of suppliers or need to be supplied (when they experience low inventory levels). Furthermore, Supplier 1 stated that if the criteria was used year-round, despite the market conditions, the criteria would help the consumer adequately compare suppliers amongst themselves and they would influence a purchasing decision. The utilization of the criteria year-round would improve the current supplier selection process.

Supplier 2 stated that the criteria selected could help the consumer properly evaluate and select suppliers but said that quality depends on a case by case scenario. Relationship was deemed of fairly high importance to both supplier and consumer companies. Supplier 2 considered relationship as beneficial for obtaining tonnage and loads from mills. The criteria were also deemed appropriate to adequately compare suppliers amongst themselves. Nevertheless, in Supplier 2's opinion, consumer companies would not follow all the criteria. Not following the criteria is in the consumer companies' best interest because having an overcapacity of suppliers helps drive the cost down. Supplier 2 did not agree with the statement that the introduction of the criteria would improve the current supplier selection process. The supplier stated that such a system could pressure every logger to a higher standard, and in return receive no competitive advantage over other suppliers. An analogy of this was discussed: if every logger had the master logger certification, then the certification would not give the supplier company a competitive advantage over other loggers, but would in return place a burden on the supplier company in order to obtain a master logger certification. In this scenario, the most favored would be the consumer companies not the loggers. Supplier 2 also stated that beyond needing a systematic approach for supplier selection for the wood fiber supply chain, relationships are far more important, but agreed that the main driver currently is cost.

Supplier 3 deemed the criteria as helpful in terms of helping consumer companies evaluate and select suppliers. The criteria would help them compare the suppliers amongst themselves but stated that the majority of loggers that belong to an association would comply with all criteria. The criteria could potentially level all suppliers, as currently some do not comply with all the state requirements, such as worker's compensation, but they still compete in the same supplier pool as those suppliers that do comply. Although the criteria might work to compare suppliers, Supplier 3 recognized that the market is entirely dependent on supply and demand. When the mills need wood, the suppliers gain market advantage. When inventories at consumer companies are high then quota is distributed amongst suppliers. Supplier 3 highlighted the importance of relationships for both the consumer companies and for the supplier companies. If there is a good relationship, then the consumer companies can count on loggers in times of need, and loggers can operate efficiently. An example of efficient operation is when a logger is given a timely notice on mill closure.

Overall, from the supplier's perspective, cost was far more important than all other criteria for the consumer mills. The predisposition of consumers to be driven by cost seems to be true until the consumer is in urgent need of suppliers in order to increase their inventory levels.

5.8.2 Supplier Interview: Evaluation of Tool's Potential Impact

Regarding the criteria selected, the loggers considered the criteria to be effective in comparing loggers amongst themselves and in influencing a purchasing decision of a supplier. However, from the supplier's perspective, the consumer companies wouldn't utilize the tool's criteria. The reason is that cost is the major driver impacting decision making. Evidence is found in market practices such as in quota distribution and price commitment. Quota is imposed when the wood yards have normal inventory levels. Meanwhile, when the market favors consumer companies, the suppliers are benefited. For example, commitment to price on behalf of consumers happens more often when inventories at the consumer's wood yard are at low inventory levels.

The introduction of the criteria formally into the supplier selection process had mixed responses. Supplier 2 mentioned that the introduction of such criteria might push all loggers to become more competitive. The loggers, in return, would not obtain a reattribution. Ultimately, this would benefit the consumer mills more than the entire upstream supply chain. Holding every logger in the competitive pool to a higher standard would not place any supplier at an advantage.

Supplier 3 deemed the criteria appropriate and had already compiled a significant number of responsible loggers. Nevertheless, there was a concern about loggers that didn't comply with imposed regulations (e.g. worker's compensation) but were still selected as suppliers to mills because of cheaper prices. Supplier 1 stated that the system would work if it were implemented all year, and might alleviate the challenges found in the supply chain.

According to Supplier 2, there is already a modified systematic approach implemented in the industry, although it is different from the one proposed in this study. Relationships were used to describe the systematic approach because they had a significant impact on quota distribution. In

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contrast, Supplier 3 stated that quotas didn't work in terms of loyalty. However, the logger did say that they recognized supplier's loyal actions and described these actions as promoting a mutually beneficial relationship between suppliers and consumers.

5.8.3 Consumer Interview: Criteria

The criteria were approved by the paper mills and the sawmills that participated in the academic exercise. The consumer interview was conducted with two sawmills and two paper mills. However, there were important differences in answers depending on the type of consumer interviewed.

5.8.3.1 Paper Mill

The paper mills interviewed agreed the criteria was valid for supplier selection. Each paper mill gave specific comments regarding some of the criteria. One paper mill deemed the delivery and the financial position to be of very high importance. The other considered cost and quality to be an important tradeoff between economic and performance criteria.

5.8.3.2 Sawmill

One of the two sawmills interviewed agreed the criteria was valid for supplier selection. The sawmill interviewee that agreed on all the criteria, worked for a lumber sawmill. The interviewee identified quality, cost, and relationship as key elements. The other participant sawmill interviewee agreed on all the criteria except on relationship and technical capability, stating that they were of no importance when selecting loggers.

5.8.4 Consumer Interview: Tool's Results and User Experience

The following sections explain what each consumer company interviewee provided as input in response to the questions that were asked regarding evaluating the tool's output and user experience (Table 23).

5.8.4.1 Paper Mill

Both paper mills found the tool applicable to their business and both interviewees were satisfied with the tool's output. One interviewee stated that the tool forces a decision. Both firms' interviewees stated that there was already an approach to the supplier selection process, selection criteria, and prioritization of selection criteria. One interviewee admitted that the supplier selection process was not structured or systematic, but that exercises with the same considerations (i.e. criteria) were already being done. Another respondent recognized that everyone had their own method of selecting suppliers.

One interviewee recognized the tool's capacity to help evaluate the tradeoffs between technical, economic, and performance criteria. The other paper mill interviewee specified they currently analyzed these tradeoffs by comparing the supplier cost per ton versus quality, and that decisions were based on the curve generated by these findings.

Each paper mill had different answers in response to the tool's consideration of different perspectives from different functional areas (i.e. procurement, sales, and production). One stated that a procurement department's customer is the paper mill and that production and sales were impacted by the criteria (e.g. quality and cost). The second stated that the supplier selection tool did not depict perspectives from different functional areas from a production and sales standpoint (i.e. by the time it is a sale, it is a commodity product) with the exception of quality.

The functionality of the tool was further evaluated in terms of adequacy to specified changes and computational complexity. The paper mills deemed the tool adequate to change alternatives or criteria in the following situations:

- When purchasing existing products from new suppliers.
- When purchasing new products from current suppliers.

Additionally, the computational complexity was approved in terms of the time required to gather information and the algorithm to compute results.

There were different results regarding the tool's bias on behalf of the buyers interviewed. One interviewee described the tool as a way to reduce bias, because it made the process objective and

forced organization. For example, without the tool's result, a strong personal relationship could overcome the lower level of performance in a supplier. The other participant said that the elimination of bias works to a certain extent but that it could not be eliminated completely.

Closely related to the tool's bias, imprecision was a concern for the paper mill firms. Both agreed that there was a significant amount of subjective evaluation in the tool. One interviewee identified the criteria of concern as: the financial position, relationship, reputation, technical capability, reliability, geographic location and flexibility. In some cases, the best guess was made, or assumptions were present in the evaluation. Therefore, the difficulty of assessing intangible aspects was confirmed. However, an interviewee stated that there were cases where the procurement department might be aware of intangible aspects because of the small community and geographical location, and that information of this sort could be obtained through informal communication.

5.8.4.2 Sawmill

The sawmills participating in the interview process found the tool applicable to their businesses. One sawmill interviewee was satisfied with the tool's outputs. The other described their satisfaction level as "somewhat satisfied" because of a concern regarding how the items were weighted. To be completely applicable, the user would have to modify the weights.

There were different results regarding the need for a systematic approach in the supplier selection process. An interviewee responded that a systematic approach would yield a positive result. The other interviewee stated that a systematic approach would not be applicable because situations vary constantly. The overall consensus regarding criteria was that it was already being used to select suppliers. Therefore, there would not be an improvement to the current supplier selection process. However, an interviewee from a sawmill said that there could be improvements in prioritizing the criteria and in evaluation of tradeoffs between technical, economic, and performance criteria.

The evaluation of the tool in terms of supporting changes of alternatives or criteria and computational complexity was positive. Nevertheless, the tool was considered biased and

imprecise because of subjective evaluation, lack of previous data, and the difficulty of assessing intangible aspects of supplier performance. The assessment of intangible factors and aspects of supplier performance was difficult. Imprecision was also a concern. Subjective evaluation by multiple decision makers might influence the tool's output. The information needed to evaluate the criteria was also a limiting factor when using the tool, especially in situations where a new supplier needed evaluation.

5.8.4.3   User Experience

The tool approved the criteria proposed to evaluate the user experience by the paper mills. Both sawmills interviewed found the tool comprehensive, but the rest of the criteria was not approved by both sawmills in the same categories. The participating sawmills had mixed responses (50% approval and 50% disapproval) in objectiveness, reliability, flexibility, and mathematically straight forward. The results are displayed in Table 41.

Table 41. Results of Evaluating the Effectiveness of the Tool

Effectiveness of the Tool	Paper mill Perspective	Sawmill
Comprehensiveness	✓✓	✓✓
Objectiveness	✓✓	✓X
Reliability	✓✓	X✓
Flexibility	✓✓	✓X
Mathematically Straightforward	✓✓	X✓

User experience was also evaluated in the interview process. Table 42 lists the characteristics, the sub-characteristics, the answers, and the questions used in the evaluation. The characteristics and sub-characteristics are defined in the ISO/ IEC 9126 (Jung & Kim, 2004).

Table 42. User Experience (Jung & Kim, 2004).

Characteristic	Sub-characteristic	Sawmill	Paper Mill	Questions
Functionality	Suitability	✓✓	✓✓	Is tool suitable for your business?
	Accuracy	✓✓	✓✓	Were the results obtained in the test run accurate?
	Interoperability	✓X	✓✓	Can the Excel Macros be easily used in different digital platforms?
Usability	Understandability	✓✓	✓✓	Are the instructions to use the tool easy to understand?
	Learnability	✓✓	✓✓	Is the process of operating the tool easy to learn?
	Operability	✓✓	✓✓	Is the tool easy to operate?
	Attractiveness	✓✓	✓✓	Is the interface attractive to use?
Efficiency	Time Utilization	✓✓	✓✓	Would the tool help make supplier selection decisions in a time efficient way?
	Resource Utilization	✓✓	✓✓	Would the tool help make supplier selection decisions in a resource efficient way?
Maintainability	Analyzability	✓✓	✓✓	Are the results easy to analyze?
	Changeability	X✓	✓✓	Are the scenarios depicted easy to change?
	Testability	✓✓	✓✓	Are the results obtained easy to test?

The user experience results were generally affirmative, except in the case of interoperability and changeability, each by a different sawmill participant. Interoperability refers to the ease of Excel Macros to be used in different digital platforms and changeability refers to the ease of changing scenarios within the tool. General appreciation of the tool was also received during the interview. One sawmill interviewee deemed the tool suitable to some extent but would need further analysis before achieving full functionality at the sawmill. The same participant also stated that the supplier selection tool could "possibly" make the supplier selection a resource efficient process

because you have to do business with the supplier before utilizing the tool. A paper mill company stated that, regarding resource utilization, the tool didn't need additional effort than the current process at the company to select suppliers.

5.9   Summary of Results

- The fulfillment cost for case study 1 firm (a paper mill) was estimated to be $10 million for a daily consumption of 1,122 tons/day. In this case the lead time was estimated as 85 days.

- The fulfillment cost of case study 2 (a sawmill) was calculated to be $10 million per year when consuming 2,134 tons/day. The total lead time for case study 2 was estimated as 61 days.

- The total cost of fulfillment of case study 3 (a logging operation) was estimated to be $18.2 million per year. This cost uses the logging cost for one supplier and the six wood/log yards that it delivers to. In this case the total lead time ranged from 97 to 112 days.

- The potential savings of the recommendations for case study 1 firm could lead to a cost reduction in the total cost of fulfillment of $306,232 annually.

- For case study 2, the implementation of recommendations could produce cost reductions of $312,085 in logistic activities.

- After implementation recommendations, the third case study could reduce fulfillment costs by $756,504 annually.

- The main differentiation factor in the lead time is the amount of inventory (stumpage + wood/log yard inventory) that is held in the wood fiber supply chain.

- Most of perfect-order execution metrics such as: quality, product, customer service, location, and quantity, are not tracked in the three case study firms.

- The main causes for waste include: lack of communication among supply chain partners, weak supplier collaborations, demand variability, quota management, and poor inventory management.

- The completion of a VSM aids in identifying communication gaps and disjunctions between different elements of the supply chain.

- The application of VSM to the wood fiber supply chain opens the possibility of improving collaboration and information sharing practices between the supply chain partners.

- The appropriate implementation of the supplier selection (SST) to get a ranking for alternative supplier candidates structures the way in which companies in the wood industry select and assess their suppliers and guarantee that the best alternatives are selected, thus increasing the chance of successful supplier-consumer relationships and increasing the value that the company gets from its supplier base.

- The suppliers approved the criteria proposed, but the cost was considered the most important driver for the consumer companies.

- The participating paper mill interviewees approved all of the criteria proposed. One of the sawmill interviewees approved all the criteria. The second sawmill interviewee did not consider relationship or reputation to be of importance when selecting suppliers, but approved the remaining criteria.

- The tool's effectiveness was approved by participating paper mill interviewees, but not by participating sawmill interviews. Both sawmill participants did consider the tool to be comprehensive but did not consider the tool to be: objective, reliable, flexible, and mathematically straightforward.

- The results on user experience were generally affirmative, both participating paper mills interviewees approved all the characteristics used to evaluate the tool on user experience. One sawmill interviewee accepted all the characteristics, while the other sawmill participant approved all except interoperability and changeability.

- Depending on stakeholder, there are major differences on how the procurement process is currently viewed. This reflects major discrepancies in the current supply chain dynamics. Consumer companies argue that a similar unstructured method to the proposed is already used. Suppliers state that the procurement process is mainly driven by cost. The differences are beyond the scope of the supplier selection model.

- The supplier's perspective in broad terms did not see the tool to be utilized by the consumer mills. The supplier's considered that the consumer mills were merely driven by cost, except when inventory levels are not at the targeted inventory levels.

- The consumer perspective saw the tool as a structured way to execute an otherwise currently unstructured current supplier selection process.
- Limitations to the tool were identified as: imprecision due to subjective evaluation and inexistence of previous data on supplier performance.

6. Discussion

Lean thinking provides a great opportunity to fill the gap on the use of tools that could help identify types of waste such as: over capacity of suppliers, loss of production due to market factors, reactive planning process, and the lack of impact based on consumer actions. Despite the popularity and success of lean thinking in recent years, the primary wood products industry has not widely exploited lean thinking to reduce the waste identified in the body of literature. Tools such as VSMs have not been widely applied to logistic operations within the upstream wood fiber supply chain. Therefore, the three VSMs generated are an innovative research effort to study logistic operations of an upstream supply chain.

The VSM allows to oversee the current state of the overall operation of the value stream selected. This entails coordination along with extraction and visualization of strategic information for decision making. Coordination refers to the information flows (e.g. wood procurement makes the decisions according to information based on historical and then sends weekly and monthly orders for supply). Across the three VSMs created (sawmill, paper mill, and logger) the communication channels don't have reciprocal feedbacks, so decisions are not taken with knowledge of strategic information from supply chain partners.

Visualization of strategic information for decision making is also abstracted through the VSM. In regards to strategic information it is important to distinguish that a significant amount of information in all three VSM created was assumed or extracted based on educated assumptions (e.g. the amount of incoming wood daily, minimum order quantity to be harvested from a tract of standing timber, average hardwood inventory carried and the average daily mill consumption). This signifies that important logistic information such as annual inventory and carrying cost, number of trucks transported per day, etc. are not known by each case study company which in return affects the capacity to take assertive decisions to improve efficiency and reduce costs accurately.

The VSMs reported waste that directly impacted logistics areas of operation, this could be a result of the lack of strategic information gathered and shared among supply chain partners.

Types of waste found include: inefficient use of human resources, unnecessary transportation, excessive movements, excessive waiting times, defective products, overproduction, etc. The amount of waste incurred could be reduced if suppliers and consumers worked closely together. The VSMs also visually depicted the lack of supply chain coordination by showing how discoordinated each value stream selected was. The disconnection was evident between suppliers and consumers because, in general, suppliers were not aware of important information such as: consumption, inventory levels, future mill supply needs, or foreseen changes with the potential to affect logger productivity. Furthermore, consumers were not aware of the quantity of standing timber their suppliers held, or the suppliers had no estimate of the consumer's inventory levels. This dynamic does not provide the foundation needed to synchronize the flow of material, hence waste is incurred in (e.g. carrying inventory cost, excessive movements, etc.). Similarly,

The VSMs applied also provided new insights in supply chain performance measurement and cost structure. Previous literature on the wood fiber supply chain had calculated the potential cost of lost production annually in the southeastern region. Meanwhile, the VSM tool, if applied correctly, could reflect the cost of fulfillment of the logistics operations of the desired supply chain elements, and the potential savings, if the recommendations were implemented. The following VSM metrics were developed: process time, lead time, days of inventory in the pipeline, transit time, carrying cost of inventory, and fulfillment costs. A cost structure to calculate the total fulfillment cost was developed and included the following items: harvesting, transportation, procurement, wood/log yard management, supplier and customer relationships, and inventory carrying costs.

Upon completion of the VSMs, a tool that would help the current separation between suppliers and consumers was developed. The separation between supply chain partners was attributed to the lack of formal supplier selection procedures. Most mills (consumers) did not use a structure to select and prioritize their suppliers. Research demonstrated that inefficiencies in communication carry additional costs that must be absorbed by the logging contractor or compensated for by the consuming organization, which increased the overall cost of production. The absence of structured methods to select and assess suppliers

propagated the fluctuating environment for suppliers. Previous research efforts have focused on inventory management in a reactive environment. Therefore, a tool that implements a hierarchy system to categorize suppliers was developed to fill the gap in supplier selection models in the wood products industry.

The result was an Excel tool that combined the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) method. The system was programmed using visual basic programming language for applications in Microsoft Excel. As a selection tool, the SST was designed to allow a consumer company to select the best suppliers from a given number of alternatives. The assessment tool was designed to allow practitioners to identify which of the current suppliers were adding more value to the company, to whom the company should assign a greater purchase, with whom the company should pursue a stronger relationship, and which supplier or suppliers could be removed in case the company needed to reduce its supplier base.

The adequate selection of suppliers is of strategic importance to the supply chain and involves a prioritization process based on quality, cost, financial position, technical capability, etc. Applying selection criteria promotes the strengthening of relationships and communication between strategic suppliers and the consumer companies. The assessment tool allows the consumer company to select the best suppliers from a given number of alternatives and make strategic decisions based on suppliers' specific rank. The hierarchy position (ranking), if used adequately, could determine the level of communication and the planning methodology between consumer and supplier companies.

A metrics-driven core logger system not only benefits the consumer company but also provides suppliers with stability. A formal identification of top suppliers provides the opportunity for appropriate communication channels, allowing suppliers to strategically plan operations ahead of time. Loggers that are only hired on a temporary basis (demand surplus) by a consumer company are aware of the situation and can plan accordingly. Improving the communication and cooperation with the suppliers can eliminate the inefficiencies that result from market and planning factors.

The validation process of the tool provided two very different perspectives of the supplier selection process. The suppliers considered cost as the most important decision driver to selecting supplier for consumer companies, therefore other criteria were not utilized for this purpose. The consumers saw the tool as a structured way to execute an otherwise unstructured supplier selection process (with all criteria considered). These two very different approaches to supplier selection prove that change is needed, but the tool is not sufficient. The supplier selection tool should be part of a broader change in the way that procurement departments in the wood industry think about their relationships with their suppliers.

The VSM described and discussed throughout this thesis provides the framework necessary to analyze the current status of upstream supply chain operations. The supplier selection tool provides an opportunity to benchmark current suppler selection methods. Both tools have the potential to start important discussions. The tools can provide important insights and promote communication and collaboration with supply chain partners, hopefully leading to a different dynamic between supplier and consumers.

Moreover, the results could be improved if the implementing party was closer to, and more familiar with, the company's processes in order to achieve greater benefits form the VSM implementation. Future research efforts should focus on applying both frameworks provided to the same supply chain, and the supplier selection system should be fully implemented. This would allow a much more in-depth analysis of the benefits and potential pitfalls of the framework and their repercussion to the wood fiber supply chain.

Implementation Considerations
The Lean logistic VSM requires an effort from all parties involved (i.e. supplier, transportation, consumer) in order to work properly and receive the greatest benefit. The very first consideration is to identify a point of contact from each supply chain sector involved. Each party should be ready to provide the information necessary, in a timely manner. A particular collaborator could be designated, but preferably a committee should be appointed

with representatives from each participating company to collaborate on the VSM. The next important step would be to determine the value stream to study. This is a major decision that should be determined based on quantitative justification. Appendix T lists the steps necessary to create the VSM. It is important to mention that participating companies may not have the information on hand to complete the VSM. In this case, they should be prepared to gather the data necessary. Data collection can include but is not limited to: time studies, maintaining traceability (e.g. historical information), and gathering percentages (e.g. perfect-order execution).

The supplier selection tool is easily applicable to a company's procurement operations. The tool only needs the procurement department's input in order to function. However, the procurement department can increase the quality of information utilized to rate the suppliers by gathering data to support each supplier rating. For example, quantifying each metric utilized can increase the accuracy of the tool's output. Furthermore, in order to improve the application of the tool, the procurement department can use the tool in a collaborative effort (e.g. as a team) to generate important discussions regarding supplier selection decisions. Nevertheless, it is up to the procurement department's discretion how to utilize the results provided by the tool.

7. Conclusions

- The VSMs implemented identified waste by extraction and visualization of strategic information. The main differentiation factor in the lead time is the amount of inventory (stumpage + wood/log yard inventory) that is held in the wood fiber supply chain, which are measured through ADOH (a non-value adding activity). Similarly, the creation of the VSMs identified that most of the perfect-order execution metrics such as: quality, product, customer service, location, and quantity, are not tracked in the three case study firms. The waste identified across the case study firms was: lack of communication among supply chain partners, weak supplier collaborations, demand variability, quota management, and poor inventory management. The lean logistics VSM demonstrated that through waste reduction initiatives in logistics operations cost reduction could be achieved in the three case study companies. The potential savings of the recommendations for case study 1 firm could lead to a cost reduction in the total cost of fulfillment of $306,232 annually. For case study 2, the implementation of recommendations could produce cost reductions of $312,085. After implementation recommendations, the third case study could reduce fulfillment costs by $756,504 annually.

- A computational tool was developed to prioritize suppliers in the wood fiber supply chain. The criteria determined for supplier selection and assessment was: quality, cost, financial position, relationship, technical capability, reliability, geographic location, and flexibility. A structured hybrid model that combines the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) was utilized to evaluate and rank suppliers. This tool provides practitioners in the wood industry with a simple structured way for selecting and assessing suppliers. The tool is user friendly and provides users with detailed explanations on how to use the application.

- The appropriate implementation of the supplier selection (SST) to get a ranking for alternative supplier candidates structures the way in which companies in the wood industry select and assess their suppliers and guarantee that the best alternatives are selected, thus increasing the chance of successful supplier-consumer relationships

and increasing the value that the company gets from its supplier base.Depending on stakeholder, there are major differences on how the procurement process is currently viewed. This reflects major discrepancies in the current supply chain dynamics. Consumer companies argue that a similar unstructured method to the proposed is already used. Suppliers state that the procurement process is mainly driven by cost. The differences are beyond the scope of the supplier selection model.

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Appendixes

Appendix A. Fulfillment Cost of Case Study 1

The fulfillment cost reflects the logistics impact annualized.

Wood Yard

The wood yard cost is divided into three different segments, personnel related to raw material handling, equipment associated with material handling, and overhead cost.

Personnel: Raw Material Handling

The personnel cost is calculated by multiplying the quantity of people related to raw material handling (Q_{RM}) by their annual salaries. The annual detail material moving workers' salary was established as $34,540, representative of an annual mean wage (U.S. Bureau of Labor Statistics, 2016).

$$Personnel\ Raw\ Material\ Handling = Q_{RM} * Annual\ Salary = 6 * \$34,540$$
$$= \$207,240$$

Equation 30. Personnel Raw Material Handling

Equation 30 is the annual salary for material moving workers. The material handling equipment is all the machinery necessary to perform the wood yard activities. The machine rate is divided into several costs that have been previously mentioned. The approach for calculating the machine rate and its transformation into material handling equipment cost is explained for this particular case study in the next subsection.

Machine Rate of a Machine at Wood Yard

Depreciation

The fixed cost in machinery is depreciation. There are different ways or methods to calculate this. However, it is advantageous to use a method that the company feels comfortable with, and could increase accuracy in calculations. The reported machinery in this particular case study was a wheel loader and two log stackers. Depreciation is a cost that takes into consideration the declining value of a machine. A reference value in the market was used as a salvage price, and a purchase price used was obtained from an industry source.

Komatsu WA600

The machinery used as a salvage value reference for the wheel loader was a Komatsu WA600 1997 model with 15,964 hours of usage. The salvage value price was $78,500 with 15,964 hours of operation.

$$Depreciation = \frac{(P'-S)}{N} = \frac{(\$250,000-\$78,500)}{15,964h} = \$10.74 \text{ per hour.}$$

Equation 31. Depreciation for Wheel Loader

Equation 31 above shows the depreciation per hour for a wheel loader with a mechanical life of 15,964 hours of operation, determined by the reference.

L90 Log Stacker

In addition to a wheel loader being used at the wood yard there were two log stackers. According to a sales representative in the industry, the pricing of a L90 log stacker depends on different options, but the base price of a New Generation Wagner Log Stacker L90 is currently $1,400,000. Therefore, the purchase price would be calculated with this value. The salvage price was obtained as a percentage of the value. Assuming that the machine loader falls under the description of a loader, medium, the hydraulic salvage value after 5 years is 30% (see Appendix F). The number of hours worked in 5 years is approximately 1,600 per year with an 8-hour usage per shift and an estimated 200 shifts.

$$Depreciation = \frac{(P'-S)}{N} = \frac{(\$1,400,000-\$420,000)}{1,600*5} = \$122.5 \text{ per hour.}$$

Equation 32. Depreciation for L90 Log Stacker

Operating Costs

Maintenance and Repair Cost per Hour

The maintenance and repair cost per hour is an operating cost, since it is proportional to the hours of usage. This may include simple maintenance, to the periodic overhaul of an engine, transmission, clutch, brakes, and other equipment. It is important to note that there are more valuable sources than a reference value, for example a company may estimate costs locally, or through the manufacturer, or past experience with similar equipment under similar working conditions (United Nations, 1992). For the purpose of this research the hourly maintenance and repair costs were obtained through a percentage of the hourly depreciation (see Appendix E).

Komatsu WA600

$$Maintenance\ and\ Repair = Rate\ as\ a\ percentage\ of\ hourly * Depreciation$$
$$= 50\% * \$10.74 = \$5.37$$

Equation 33. Maintenance and Repair Hourly Cost for Wheel Loader.

Equation 31 shows the percentage allocated for a loader with hydraulic grapple, multiplied by the depreciation rate per hour obtained previously for the wheel loader.

L90 Log Stacker

For the log stacker, the same percentage of a loader with hydraulic grapple is multiplied by the log stacker depreciation rate per hour previously obtained. The result is $61.25.

<u>*Fuel Consumption*</u>

Komatsu WA600

Fuel consumption was determined following the guidelines of the Food and Agriculture Organization of the United Nations. Equation 34 shows how to calculate the fuel consumption per machine hour. The kilogram of fuel per brake in horsepower over hour units ($K\frac{kg}{brake\ hp-hour}$), the weight of fuel in kilograms over liter ($KPL\frac{kg}{liter}$), and the load factor in percent (LF) were obtained from reference values (see Appendix D).This machine has a gasoline engine and a high load factor.

$$LMPH = \frac{K\frac{kg}{brake\ hp-hour}*GHP*LF}{KPL} = \frac{0.21\frac{kg}{brake\ hp-hour}*530hp*0.70}{0.72\frac{kg}{liter}} = 108\ L$$

Equation 34. Liters used Per Machine Hour Wheel Loader

L90 Log Stacker

The gross horsepower was obtained from the Wagner Log Stackers Manual (Allied Systems Company, 2016). Equation 35 shows the liters used per hour total 81.7 L, which is equivalent to 21.57 gallons, with a cost of $2.245 per gallon (EIA U.S energy Information Administration, 2017b). The fuel cost is obtained with the previous calculations, with a resulting gasoline cost per machine hour of $21.57.

$$LMPH = \frac{K\frac{\text{kg}}{\text{brake hp-hour}}*GHP*LF}{KPL} = \frac{0.21\frac{\text{kg}}{\text{brake hp-hour}}*400hp*0.7}{0.72\frac{kg}{liter}} = 81.7 \text{ L}$$

Equation 35. Liters used Per Machine Hour for L90

After all the calculations, each machine per hour is added together. The results are displayed in the following table.

Table 43. Machine Rate Per Hour

Machines		
Type of machine	Wheel Loader KOMATSU WA600	Wagner L90 Log Stacker
Depreciation	$10.74	$122.50
Maintenance and Repair	$5.37	$61.25
Gasoline Cost	$64.17	$48.43
Total	$80.28	$232.18

Each machine rate is multiplied by the number of hours of operation per year to obtain the annual machine cost (7.5 hours per day for 251 days per year).

Tonnage Out of Specification in 2016

The wood yard cost also considers the tonnage out of wood that did not meet quality specifications in 2016. This is calculated by multiplying an estimated 500 tons hauled out of the wood yard annually by the cost per ton hauled.

Material Ordering (Procurement Department)

This cost consists of the procurement cost or the personnel cost that is incurred in ordering and planning. A procurement cost per ton was calculated by dividing the procurement cost in 2016 by the number of tons (both pine and hardwood) that were obtained in 2016. A $1.56 cost per ton ($P_c$) was obtained, later multiplied by the amount of hardwood pulpwood (HWPW), which was the delimitation of this case study.

$$Procurement\ Cost = P_c*\text{Tons of HWPW} = \$1.56*285,279\text{tons} \cong \$445,935$$

Equation 36. Procurement Cost

Equation 36 reflects the procurement cost for the hardwood pulpwood obtained in 2016 from District A.

Inbound Logistics

Inbound Logistics represents the cost that is needed to transport the raw material to the company. The inbound cost is calculated multiplying the following variables:

- Number of incoming tons daily (T_i)
- Number of days worked per year (D)
- Cost per ton loaded[†††] (C_t)
- $Inbound\ Cost = T_i * D * (C_t) =$

$$1,122.5*251 days*\$8.50 = \$2,394,853$$

Equation 37. Inbound Cost

The inbound cost total is $2,394,853 for the year 2016.

Supplier Collaboration

The supplier collaboration measures the amount of investment in this area. This is determined by multiplying the number of hours (h_{sc}) invested by the procurement department and the hourly salary (S_h) , multiplied by the number of people dedicated to the activity within the department. This is unique to each company and the strategy used by each should be registered and accounted for. For example, in the present case study there were services to support loggers such as financing programs, these should be registered under the cost of fulfillment.

$$Supplier\ Collaboration\ Cost = \ h_{sc} * S_h * number\ of\ collaborators$$

Equation 38. Supplier Collaboration

Inventory Carrying Cost

[†††] Amount reported by the case study firm

The inventory carrying cost is associated with five components defined previously. These five components each share a percentage of the total carrying cost. For this particular case study, the division of the carrying costs are shown in Table 44. Inventory Carrying Costs.

Table 44. Inventory Carrying Costs (Martichenko & von Grabe, 2010)

Cost of Capital
Insurance
Inventory Damage
Inventory Obsolescence
Inventory Shrinkage

Appendix B. Fulfillment Cost for Case Study 2

Wood/log Yard Costs

Prices obtained from industry sources were used as references to estimate the machine rate costs.

Machine Rate of Machines at Wood/log Yard

Depreciation (Fixed Cost)

Fixed costs to consider in machinery are depreciation, interest, taxes, insurance, and, storage and protection. There are different ways or methods to calculate these. In this research, certain methods were used, but it is important to use a method with which the company is comfortable.

John Deere 2554 Track Loader (2008)

Depreciation is a cost that takes into consideration the declining value of a machine. A reference value in the market was considered as a purchase price. The machine used as reference was a 2008 model 2554 John Deere log loader, with a salvage value price of $75,000 and 16,001 hours of operation.

$$Depreciation = \frac{(P'-S)}{N} = \frac{(\$300,000 - \$75,000)}{16,001h} = \$14.06 \text{ per hour.}$$

Equation 39. Depreciation for Log Loader 2008

The depreciation value is $14.06 per hour of operation.

CAT 325D FM (2013)

The other machine was a 2013 CAT 325D FM. The value was obtained from an industry source and the hours of operation were calculated for 5 years. The salvage price is an estimation from the purchase price (salvage value is 10% of purchase price).

$$Depreciation = \frac{(P'-S)}{N} = \frac{(\$350,000 - \$290,000)}{2800hr} = \$21.43 \text{ per hour.}$$

Equation 40. Depreciation for Log Loader 2013

Equation 40 show the hourly depreciation for the 2013 CAT log loader totaling $21.43 per hour.

Operating Costs

Maintenance and Repair Cost

The maintenance and repair cost per hour is an operating cost, since it is proportional to the hours of usage.

John Deere 2554 Track Loader (2008)

The percentage allocated for a loader with hydraulic grapple, multiplied by the depreciation rate per hour is 50%.

$$Maintenance\ and\ Repair = Rate\ as\ a\ percentage\ of\ hourly * Depreciation$$
$$= 50\% * \$14.06 = \$7.03$$

Equation 41. Maintenance and Repair Hourly Cost for John Deere 2554 Log Loader

CAT 325D FM (2013)

For the 2013 CAT 325D FM log loader the same percentage of a loader with hydraulic grapple is multiplied by the depreciation rate per hour obtained for this particular machine. The result is $0.01.

Fuel Consumption

Fuel consumption was determined following the guidelines of the Food and Agriculture Organization of the United Nations. Equation 42 shows how to calculate the fuel consumption per machine hour.

John Deere 2554 Track Loader (2008)

The kilogram of fuel per brake is horsepower over hour units $(K\frac{hp}{hour})$, the weight of fuel in kilograms over liter $(KPL\frac{kg}{liter})$, and the load factor in percent (L) were obtained from reference values (Appendix D) for a diesel model.

$$LMPH = \frac{K\frac{hp}{hour}*GHP*LF}{KPL} = \frac{0.17\frac{hp}{hour}*177hp*0.70}{0.84\frac{kg}{liter}} = 25.075L$$

Equation 42. Liters used Per Machine Hour-John Deere

In the equation above GHP represents the gross engine horsepower at governed rpm, which was obtained from the manual for the 2554 model (John Deere, n.d.). The same source states that typical fuel consumption is $19\frac{L}{hr}$ to $28\frac{L}{hr}$, validating this value.

CAT 325D FM (2013)

The liters used per machine hour were also calculated for the 2013 CAT 325D (Gasoline). All the previous parameters where kept the same, except for the gross engine horsepower (GHP) which was obtained from the manual (Caterpillar, 2012).

$$LMPH = \frac{K\frac{hp}{hour}*GHP*LF}{KPL} = \frac{0.21\frac{hp}{hour}*204hp*0.70}{0.72\frac{kg}{liter}} = 41.65L$$

Equation 43. Liters Used Per Machine 2013 CAT 325D

The liters used for both machines were converted to gallons, with a cost per gallon of $2.47 dollars (EIA U.S energy Information Administration, 2017).Table 45 Totals the costs previously mentioned, which are then multiplied by the number of hours that the wood/log yard worked per year (4500 hours), to obtain the material handling equipment cost annually, which totals $435.789.

Table 45. Machine Cost per Hour

Machines		
Type of Machine	John Deere 2554 Track Loader (2008)	CAT 325D FM (2013)
Depreciation	$14.06	$21.43
Maintenance and Repair	$7.03	$10.71
Gasoline Cost	$16.39	$27.22
Total	$37.48	$59.36

Raw Material Handling

This cost consists of the material moving worker's salary. The annual mean salary was used as reported by the United States Department of Labor.

$$Raw\ Material\ Handling = 2\ Material\ Moving\ Workers * Annual\ Mean\ Wage$$
$$= 2 * \$34{,}540 = \$69{,}080$$

Equation 44. Raw Material Handling Cost

Material Ordering (Procurement Department)

This cost consists of the procurement cost or the personnel cost incurred in ordering and planning. The company reported that the foresters spent 100 hours. The median hourly salary from the United States Department of Labor was used.

$$Procurement\ Cost = 100\ hours * \$28.22 * 50\ weeks = \$141,100$$

Equation 45. Procurement Cost

Inbound Logistics

Inbound Logistics represents the cost that is needed to transport the raw material to the company. The inbound cost is calculated multiplying the next variables:

- Miles (one-way distance) (M)
- Number of Tons per Truck (T_T)
- Number of Loads per Week (L)
- Number of Weeks in a Year (W)
- Transport Cost Per Ton/Mile(T_M)
- $Inbound\ Cost = M * T_T * L * W *$

T_M=47.61miles*290trucks*28.15$\frac{tons}{truck}$*50weeks*0.13$\frac{Ton}{Mile}$≅$2,526,317

Equation 46. Inbound Cost

The inbound cost total is $2,526,317for the year 2016.

Supplier Collaboration

The supplier collaboration is meant to measure the amount of investment in this area. This was determined by multiplying the number of hours (h_{sc}) invested by the determined department and the hourly salary (S_h) ,multiplied by the amount of people dedicated to the activity within the department.

$$Supplier\ Collaboration\ Cost = h_{sc} * S_h * amount\ of\ collaborators$$

Equation 47. Supplier Collaboration

The supplier collaboration could not be determined.

Inventory Carrying Cost

The inventory carrying cost is associated with four components defined previously (see Table 44).

Appendix C. Fulfillment Cost for Case Study 3

The fulfillment cost for the logger consists of the costs related to carrying the stumpage, material ordering (which would be the estimated number of hours spent on procurement activities such as buying stumpage), company land, etc…, and outbound logistics.

Material Ordering (Procurement Activities)

The material ordering cost was determined by multiplying the number of hours (H) that were designated weekly to activities such as: buying stumpage, company land, etc…, by the logging company and the hourly wage (C_b) that is reported by the Bureau of Labor Statistics for buyers and purchasing agents (U.S. Bureau of Labor Statistics, 2016).

$$Material\ Ordering\ Cost = H * C_b = 200hours*\$29.18*50weeks = \$291,800\ annually$$

Equation 48. Material Ordering Cost for Logging Company

Harvesting Cost

The harvesting cost was determined by multiplying the harvesting cost[‡‡‡] by the amount of tons that were harvested in 2016 (600,000 tons delivered primarily to six facilities).

$$Harvesting\ Cost = \$12.50*2,000tons/day * 6\ days/week * 50weeks/year = \$7,500,000$$

Equation 49. Material Ordering Cost for Logging Company

Log Yard

The wood/log yard cost could not be estimated based on the information provided by the supplier company. Therefore, the wood/log yard cost from case study 2 was assumed in this fulfillment stream.

Stumpage Costs

The stumpage carrying costs are assumed to be 10% of the inventory value. This includes any cost associated with owning standing timber.

Outbound Logistics

Outbound logistics represents the cost that is needed to transport the raw material to the company. The outbound cost is calculated multiplying the next variables:

- Miles (one-way distance) (M)
- Number of Outgoing Trucks Daily (T_i)

[‡‡‡] Logging cost obtained from case study 2

- Number of Days Worked Per Year (D)
- Cost Per Ton Loaded Per Mile(C_t)

$$Inbound\ Cost = M * T_i * D * (C_t) * \frac{tons}{truck} + (F_a) = 60\text{miles}*70$$

$$\text{trucks}*6\text{days}*50\text{weeks}*(\$0.14)* 28.5 \frac{tons}{truck} = \$5,027,400$$

Equation 50. Outbound Cost

The outbound cost total is $5,027,400 for the year of 2016.

The fulfillment cost from stumpage to wood/log yard is noted in the following fulfilment stream. In this case, the material ordering, the stumpage costs, and the outbound logistics are detailed based on the information provided by the logger, and the wood/log yard cost considers the cost of six different wood yards (this cost was an estimate). The carrying costs are calculated as in previous case studies.

Appendix D. Weights, Fuel Consumption Rates, and Load Factors for Diesel and Gasoline Engines

Engine	Weight (KPL) kg/liter	Fuel Consumption (K) kg/brake hp-hour	Load Factor (LF)		
			Low	Med	High
Gasoline	0.72	0.21	0.38	0.54	0.70
Diesel	0.84	0.17	0.38	0.54	0.70

Source: United Nations

Appendix E. Maintenance and Repair Rates as a Percentage of the Hourly Depreciation for Selected Equipment

Machine	Percentage Rate
Crawler tractor	100
Agricultural tractor	100
Rubber-tired skidder with cable chokers	50
Rubber-tired skidder with grapple	60
Loader with cable grapple	30
Loader with hydraulic grapple	50
Power saw	100
Feller-buncher	50

Source: United Nations

Appendix F. Salvage Value

Machine category/description	Life (year)	Salvage value (%)
Chain saw	1	20
Tree shear, without carrier	5	50
Feller-buncher, small, rubber-tired	3	20
Feller-buncher, medium to large, rubber-tired	4	20
Feller-buncher, large, tracked, boom	5	15
Cable skidder, less than 80 Hp.	4	20
Cable skidder, medium, 80 to 100 Hp.	4	20
Cable skidder, medium, 101 to 120 Hp.	5	15
Cable skidder, more than 120 Hp.	5	10
Grapple skidder, 70 to 90 Hp.	4	20
Grapple skidder, more than 91 Hp.	5	25
Grapple skidder, large, tracked, bunk	5	15
Forwarder, shortwood	4	21
Slasher/loader, multistem	4	20
Delimber, iron gate	5	0
Harvester, combine	4	20
Loader, bigstick	5	10
Loader, small, hydraulic	5	30
Loader, medium, hydraulic	5	30
Chipper, small to medium, 12 to 18 inches	5	20
Chipper, large, over 22 inches	5	20
Crawler tractor, less than 100 Hp.	5	20
Crawler tractor, 101 to 200 Hp.	5	20
Crawler tractor, more than 201 Hp.	5	20

Source: (Emin Akay, 1998)

Appendix G. Planning and Communication: State of the Forest Industry and Opportunities for Improvement in the Wood Supply Chain. Authors: Brian Rodgers, Rein Visser, Robert Shaffer, et al. Year: 2002

Key Findings

Goal: Assess the current state of planning and communication in the industrial wood supply process and identify opportunities for improvement.

Current State of Planning:

- Extremely short planning horizons in the wood supply process characterize the industry; causes include uncertainty in the forest and logging industries, and traditional business practices.

- Not only is this short-term planning environment seen outside the companies, but inside as well. "Frequent, short-term changes in mill wood requirements, including delivery schedules, inventories, and specifications, drive many of the downstream constraints to planning in the wood supply system." (Rodgers et al., 2002)

- Although there is communication between loggers and wood dealers, and procurement personnel, the use of technology is a factor in reducing the planning horizon. They tend to micro-manage and control daily management goals, which affect weekly or monthly planning.

- 75% of the contract loggers interviewed are informed of the location and characteristics of the next tract they will harvest less than one week in advance.

- Compensation rates for logging contractors are primarily determined through:

    - Application of consumer's logging cost models

    - Dealer's established "market" rates

Models are based on projected "average" production rates that may not accurately reflect:

1. Quota restrictions
2. Unanticipated or mandated moves
3. Tract allocation 'mismatches'

Planning Opportunities

- Mill management and wood procurement personnel should collaborate in planning in areas such as: wood requirements, inventory, and delivery schedules on an annual

basis, and should communicate these plans to loggers in time, so they can conduct meaningful long-term strategic and tactical planning.

- Loggers should receive 30 days' notice from consumers regarding significant changes in wood requirements for effective short-term tactical wood supply planning; including tract allocation, wood flowing scheduling, and inventory management.

- Consumers and dealers should provide contract loggers with at least two weeks' notice of location, and characteristics of the next tract they will harvest for proper planning.

- Consumers should strive to provide consistent, stable markets and communicate wood supply plans that facilitate logger strategic planning and system development.

Ranking of Opportunities and Setting Benchmarks

The matrix summarizes the opportunities present and the part of the industry that could perform the recommendation. A monetary scale is associated as a possible outcome in terms of percent improvement in overall timber harvest and transportation efficiency. The key is as follows:

$-scope for a 1-3% overall gain
$$-scope for a 4-8% overall gain
$$$-scope for a 9-14% overall gain

Table 46. Key Planning Opportunity Matrix

Planning Opportunity	Mill Management	Procurement	Supplier
Wood Flow Planning	**$$$** Make available the annual wood consumption predictions and inventory requirements. Provide monthly updates on the wood supply requirements. Provide monthly updates on wood supply requirements, including log specification and shutdown information.	**$$** Convert long term wood supply into specific harvest plans. Project wood flow from individual tracts and adjust when assigned to supplier.	**$** Inform procurement of (a) purchased stumpage (volume and specs) and (b) expected changes in wood flow
Tract Allocation	**$** Avoid artificial budget constraints for procurement to purchase standing inventory.	**$$$** Match stand and terrain characteristics with the harvesting system. Allocate more than one tract at a time with adequate lead-time.	**$$** Determine harvest system efficiency for key stand and terrain parameters.
Communication	**$** Use modern communication systems to adjust existing plans, not replace planning. Provide enough information for planning to take a place.	**$** Provide timely information to suppliers regarding expectations and charges.	**$** Use communication to complete feedback loop by providing "procurement" with pertinent tract, move, and production information.
Rate Setting and Production Monitoring	**$** Guide price setting by discussing expected raw materials costs with procurement and suppliers.	**$$** Adjust matrix prices to account for lost production. Allow for discussion about cost calculations.	**$$$** Determine key productivity parameters for the harvesting system. Discuss changes anticipated in the harvesting system.
Truck/ Scheduling Coordination	**$** Keep mill turn time to a minimum.	**$$** Match trucking setup to haul. Minimize reactionary changes of delivery points.	**$$** Develop a trucking system to satisfy the majority of the tracts harvested.

Appendix H. Matrix for the Determination of Relative Importance of Criteria in the Supplier Selection Tool (AHP Proof)

Table 47. Matrix for the Determination of Relative Importance of Criteria in the Supplier Selection Tool

	Quality	Cost	Delivery	Financial Position	Relationship	Reputation	Technical Capability	Reliability	Geographical Location	Flexibility
Quality	1	1	7	3	3	3	3	1	1/3	3
Cost	3	1	5	3	3	3	3	1	3	5
Delivery	1/3	3	1	1	1/5	1/5	1/5	1/5	1/7	1/5
Financial Position	1/5	1/7	7	1	1/3	1/3	1/3	1/5	1/7	1/5
Relationship	1	5	1/3	1/7	1	1	3	1	1/5	3
Reputation	1/3	3	1	1	1	1	3	1	1/5	1
Technical Capability	3	1/3	1/5	1	1/3	1	1	1/5	1/5	1/5
Reliability	3	3	1	3	1	3	3	1	1/3	1
Geographical Location	5	1/3	1/3	1	1/3	1	5	1/5	1	9
Flexibility	1/3	1/5	1/5	3	1/3	1/3	1/5	1/3	1/5	1

Appendix I. Results of AHP Proof

Table 48. Results of AHP Proof

GMj (Geometric Mean)	Wj (Normalized Geo. Mean)	Final Weight Percentage
1.8852	0.1777	17.77%
2.6673	0.2514	25.14%
0.3681	0.0347	3.47%
0.3653	0.0344	3.44%
0.9188	0.0866	8.66%
0.9502	0.0896	8.96%
0.4707	0.0444	4.44%
1.5518	0.1463	14.63%
1.0524	0.0992	9.92%
0.3778	0.0356	3.56%

Appendix J. Matrix for the Assignation of Aates to each Alternative in the Supplier Selection tool (TOPSIS Proof)

Table 49. Matrix for the assignation of rates to each alternative in the supplier selection tool

Supplier	Quality	Cost	Delivery	Financial Position	Relationship	Reputation	Technical Capability	Reliability	Geographical Location	Flexibility
A	5	5	9	5	5	7	7	3	3	5
B	7	7	9	5	7	7	7	7	9	5
C	7	5	9	7	7	7	9	9	3	5
D	1	5	9	3	1	1	5	3	7	3
E	7	5	9	7	5	5	7	5	5	5
F	9	3	9	7	5	7	7	7	3	5
G	5	3	9	1	7	7	5	7	3	7
H	7	3	9	5	7	7	5	7	3	3
I	5	5	9	7	7	7	5	7	7	5
J	5	3	9	5	7	7	5	7	3	5

Appendix K. Normalized rating matrix (TOPSIS Proof)

Table 50. Normalized Rating Matrix

Normalized Rating Matrix	Quality	Cost	Delivery	Financial Position	Relationship	Reputation	Technical Capability	Reliability	Geographical Location	Flexibility
A	0.26	0.35	0.32	0.29	0.26	0.34	0.35	0.15	0.19	0.32
B	0.36	0.48	0.32	0.29	0.36	0.34	0.35	0.34	0.56	0.32
C	0.36	0.35	0.32	0.40	0.36	0.34	0.45	0.44	0.19	0.32
D	0.05	0.35	0.32	0.17	0.05	0.05	0.25	0.15	0.44	0.19
E	0.36	0.35	0.32	0.40	0.26	0.24	0.35	0.24	0.31	0.32
F	0.46	0.21	0.32	0.40	0.26	0.34	0.35	0.34	0.19	0.32
G	0.26	0.21	0.32	0.06	0.36	0.34	0.25	0.34	0.19	0.45
H	0.36	0.21	0.32	0.29	0.36	0.34	0.25	0.34	0.19	0.19
I	0.26	0.35	0.32	0.40	0.36	0.34	0.25	0.34	0.44	0.32
J	0.26	0.21	0.32	0.29	0.36	0.34	0.25	0.34	0.19	0.32

Appendix L. Weighted Normalized Matrix (TOPSIS Proof)

Table 51.Weighted Normalized Matrix

Weighted Normalized Matrix	Quality	Cost	Delivery	Financial Position	Relationship	Reputation	Technical Capability	Reliability	Geographical Location	Flexibility
A	0.036	0.058	0.020	0.018	0.026	0.034	0.025	0.019	0.020	0.020
B	0.051	0.081	0.020	0.018	0.036	0.034	0.025	0.044	0.059	0.020
C	0.051	0.058	0.020	0.025	0.036	0.034	0.032	0.056	0.020	0.020
D	0.007	0.058	0.020	0.011	0.005	0.005	0.018	0.019	0.046	0.012
E	0.051	0.058	0.020	0.025	0.026	0.025	0.025	0.031	0.033	0.020
F	0.065	0.035	0.020	0.025	0.026	0.034	0.025	0.044	0.020	0.020
G	0.036	0.035	0.020	0.004	0.036	0.034	0.018	0.044	0.020	0.028
H	0.051	0.035	0.020	0.018	0.036	0.034	0.018	0.044	0.020	0.012
I	0.036	0.058	0.020	0.025	0.036	0.034	0.018	0.044	0.046	0.020
J	0.036	0.035	0.020	0.018	0.036	0.034	0.018	0.044	0.020	0.020

Appendix M. Positive Ideal Solution and Negative Ideal Solution (TOPSIS Proof)

Table 52. Positive Ideal Solution and Negative Solution

	Quality	Cost	Delivery	Financial Position	Relationship	Reputation	Technical Capability	Reliability	Geographical Location	Flexibility
Positive Ideal Solution (V+)	0.07	0.08	0.02	0.02	0.04	0.03	0.03	0.06	0.06	0.03
Negative Ideal Solution (V-)	0.01	0.03	0.02	0.00	0.01	0.00	0.02	0.02	0.02	0.01

Appendix N. Distance of each Alternative from Positive Ideal Solution and Negative Ideal Solution (TOPSIS Proof)

Table 53. Distance of each Alternative Positive Ideal Solution and Negative Solution

Supplier	Distance from Si+	Distance from SI-
A	0.07	0.05
B	0.02	0.09
C	0.05	0.08
D	0.09	0.04
E	0.05	0.06
F	0.06	0.08
G	0.07	0.06
H	0.07	0.07
I	0.04	0.07
J	0.07	0.06

Appendix O. Distance of each Alternative from Positive Ideal Solution and Negative Ideal Solution (TOPSIS Proof)

Table 54. Distance of each Alternative Positive Ideal Solution and Negative Solution

Supplier	Similarity Coefficient to Positive Ideal Solution (PI)
A	0.45
B	0.80
C	0.62
D	0.29
E	0.57
F	0.55
G	0.45
H	0.50
I	0.61
J	0.46

Appendix P. Similarity Coefficient to the Ideal Positive Solution (TOPSIS Proof)

Table 55. Similarity Coefficient to the Ideal Positive Solution

Supplier	Similarity Coefficient to Positive Ideal Solution (PI)	Preference Order
A	0.45	44.57
B	0.80	79.82
C	0.62	62.15
D	0.29	28.59
E	0.57	56.86
F	0.55	54.51
G	0.45	44.87
H	0.50	49.88
I	0.61	61.48
J	0.46	45.69

Appendix Q. AHP Grades Assigned by User

Table 56. AHP Grades Assigned by User

	Quality	Cost	Delivery	Financial Position	Relationship	Reputation	Technical Capability	Reliability	Geographical Location	Flexibility
How to Understand the Critera										
Go Back / Compute Weights										
Quality	1	1	7	3	3	3	3	1	1/3	3
Cost		1	5	3	3	3	3	1	3	5
Delivery			1	1	1/5	1/5	1/5	1/5	1/7	1/5
Financial Position				1	1/3	1/3	1/3	1/5	1/7	1/5
Relationship					1	1	3	1	1/5	3
Reputation	0.333333333	3	1	1	1	1	3	1	1/5	1
Technical Capability	3	0.333333333	0.2	1	0.333333333	1	1	1/5	1/5	1/5
Reliability	3	3	1	3	1	3	3	1	1/3	1
Geographical Location	5	0.333333333	0.333333333	1	0.333333333	1	5	0.2	1	9
Flexibility	0.333333333	0.2	0.2	3	0.333333333	0.3333333	0.2	0.333333	0.2	1

Appendix R. AHP Weights Obtained by Tool Output

Table 57. AHP Weights Obtained by Tool Output and Matrix for Assignation of Rates to each Alternative in the Supplier Selection

Supplier Performance Ratings	Weights	A	B	C	D	E	F	G	H	I	J
Quality	17.77%	5	7	7	1	7	9	5	7	5	5
Cost	25.14%	5	7	5	5	5	3	3	3	5	3
Delivery	3.47%	9	9	9	9	9	9	9	9	9	9
Financial Position	3.44%	5	5	7	3	7	7	1	5	7	5
Relationship	8.66%	5	7	7	1	5	5	7	7	7	7
Reputation	8.96%	7	7	7	1	5	7	7	7	7	7
Technical Capability	4.44%	7	7	9	5	7	7	5	5	5	5
Reliability	14.63%	3	7	9	3	5	7	7	7	7	7
Geographical Location	9.92%	3	9	3	7	5	3	3	3	7	3
Flexibility	3.56%	5	5	5	3	5	5	7	3	5	5

Go Back   Get Ranking

Appendix S. TOPSIS Results obtained by Tool Output

Table 58. TOPSIS Results obtained by the Tool Output

Go To Control Panel	Alternative Suppliers	A	B	C	D	E	F	G	H	I	J
Performance Coefficient		44.07%	81.49%	61.86%	29.76%	56.59%	51.52%	40.43%	46.72%	57.64%	40.58%
Rank		7	1	2	10	4	5	9	6	3	8

Ranking

Appendix T. Steps to Generate a VSM for the Wood Fiber Supply Chain

In this appendix the following is presented the main steps, questions asked, metrics, calculations, and considerations on how a VSM for the wood fiber supply chain can be built. In the next chapters, the steps are applied to three case study firms. The scope of the case studies ranges from stumpage to the wood/log yard as shown in Figure 45. For this project, the supplier portion of the VSM refers to the logger or dealer moving the stumpage, the production process is logging operations, and the inbound logistics is the hauling operations of the raw material (wood) to the wood/log yard.
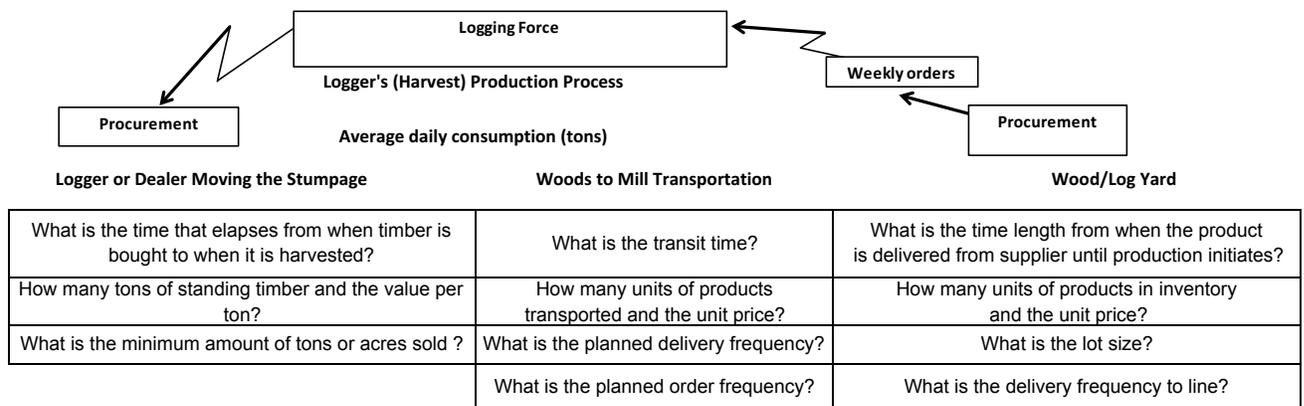

What is the time that elapses from when timber is bought to when it is harvested?	What is the transit time?	What is the time length from when the product is delivered from supplier until production initiates?
How many tons of standing timber and the value per ton?	How many units of products transported and the unit price?	How many units of products in inventory and the unit price?
What is the minimum amount of tons or acres sold ?	What is the planned delivery frequency?	What is the lot size?
	What is the planned order frequency?	What is the delivery frequency to line?

Figure 45. VSM in the Wood Fiber Supply Chain

To complete the VSM for a selected value stream the user needs to identify the proper value stream, the material and information flows, the main processes, and calculate the VSM metrics with the information that is available. Figure 45 shows a generic VSM with the necessary questions to accomplish such a task. In the following sections, the details of the required steps to complete the VSM will be explained.

Daily Consumption

The daily consumption is the quantity of product or raw material needed (it can be also expressed in weeks, months, etc…) and it is defined based on the needs of the consumer mill. The determination of the daily consumption is a fundamental aspect in VSM, since it is used to estimate the average days on hand (ADOH), which represents the amount of inventory available in days at the different inventory points of the value stream.

Supplier: Logger/ Dealer Moving the Stumpage

Figure 46 lists the questions that should be asked to gather the information needed to develop this section of the VSM.

What is the time that elapses from when order is received to shipment?
What is the quantity of product in inventory and the unit price?
What is the batch size?
What is the minimum order quantity?

Figure 46. Supplier

Order to ship time- What is the time that elapses from when the order is received until it is shipped?

How this section is used varies on the type of supplier. If timber procurement from landowners is done through a lump-sum procedure, the time that elapses from the bid being accepted to when the timber harvest is completed can be used as the order to ship time. A similar approach is used in a per-unit sale procedure, the time from when the sale is accepted (deposit is agreed upon and accepted by buyer and seller) to when the timber harvest ends. If the wood received at the company is gatewood and they have a specific timeframe that the supplier can deliver, that timeframe would be used. The order to shipment timeframe can be summarized as the time that elapses between the request for wood until it is available for delivery.

Value of inventory-What is the quantity of product in inventory and what is the price?

The value of inventory is needed to calculate the carrying costs the value stream incurs. The value of inventory can be determined by multiplying the amount of inventory units by the product price. If the supplier is a logger that purchases timber, the value of stumpage can be used as this value.

Batch size or minimum order quantity – What is the batch size or minimum order quantity?

The batch size is the number of items that will be produced or harvested, and might depend on company policies. For example, a logging company might decide that the minimum amount of wood (minimum order quantity) harvested from a site is 400 tons. In terms of transportation, usually the truckload size is used as batch size, or as the minimum order quantity.

Inbound/Outbound Logistics: Woods to Mill Transportation

Figure 47 lists the questions that need to be answered in order to complete the inbound/outbound portion of the VSM.

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| What is the transit time? |
| What is the quantity of product transported and the unit price? |
| What is the planned delivery frequency? |
| What is the planned order frequency? |

Figure 47. Inbound Logistics

Transit time-What is the transit time?

The transit time is the time that it takes to transport a truckload from the harvesting site to the wood/log yard. The VSM is a very flexible instrument; therefore, it can be utilized according to the company's interests. Transport times can be used for only one supplier, or an average of various suppliers, depending on the situation.

Value of inventory- What is the quantity of product transported and the unit price?

The value of inventory is obtained from the quantity of product transported and the unit price of the inventory. This can be narrowed down to the value of inventory moving at a determined moment, which can be obtained using the tons per day supplied, and multiplying by the days in transit, Equation 51. The time unit can vary.

$$Value\ of\ Inventory = \frac{tons}{month} * \frac{1\ month}{number\ of\ days\ work} = \frac{tons}{day} * \frac{cost}{ton} = tons\ in\ transit\ unit\ price = dollars\ in\ transit$$

Equation 51. Value of Inventory at a Determined Moment

The carrying cost incurred, by the the transportation company or the party financially responsible for the inventory in movement, is determined by calculating a percentage of the value of inventory that is being transported.

Planned delivery frequency and the planned order frequency- What is the planned delivery/order frequency?

The planned delivery frequency and the planned order frequency, if applicable, allows the transportation company or the responsible for the wood transported to determine the periods of shipments in detail if necessary.

Receiving Operations: Wood/Log Yard

Figure 48 displays the questions asked for receiving operations. A receiving operation may be a wood/log yard or any storage necessary before the production process. Receiving operations are an inventory point in which raw material, or material, waits until used for production.

| What is the time length from when the product
is delivered from supplier until production initiates? |
| What is the quantity of product in inventory and the unit price? |
| What is the lot size? |
| What is the delivery frequency to line? |

Figure 48. Receiving Operations

What is the time length from when the product is delivered from supplier until production initiates?

This question refers to the amount of days that raw material waits in receiving operations (for example wood/log yard) until it is received at the sawmill.

Value of inventory-What is the quantity of product in inventory and the unit price?

The value of inventory is calculated based on the unit price multiplied by the quantity. This follows the same principal throughout the tool.

Lot size-What is the lot size? /Delivery Frequency-Delivery Frequency to Line?

Some production lines might require a specific lot size for further processing. For example, the lot size in a truckload is just the amount of wood being transported. Usually sawmills and paper mills have continuous lot or batch sizes, but in some cases when there is a mix of products, a lot size is determined based on demand, capacity restrictions, or logistical limitations.

The Cost of Fulfillment

The cost of fulfillment is an important metric required in lean logistics, because it helps to understand the true cost of the supply chain, but it can also be used as a baseline to compare the current VSM against the future VSM (H. Quesada, 2016). It might be the case that the cost of fulfillment considers more than one firm, so that the total cost reflects the cost of the supply chain management and not the just cost for an individual company.

Once the current VSM is developed, recommendations and improvements are introduced to make a future VSM, and most likely these changes will impact the total fulfillment cost. The fulfillment costs include: harvesting costs, inbound logistics costs, wood/log yard operation costs, procurement costs, and supplier collaboration costs. The details on how to calculate the individual components of the fulfillment cost are explained in the following sections.

Harvesting Costs
In this project harvesting costs were not calculated from primary data. References and results of previous WSRI projects were used to estimate the harvesting costs in dollars per ton.

Inbound Logistics Costs
The movement of inventory to and from an organization is called outbound logistics and inbound logistics. The inbound logistics refers to the shipment of raw material inventory, and the shipment of the finished product translates into outbound logistics. Personnel required to perform these operations and the transportation costs associated are included under this section.

Receiving and Wood/log Yard Management Costs
Receiving and log yard management costs refer to the management of activities related to the organization's reception of raw materials, its handling and storage before production of the final goods. Wood/log yard activities might include receiving, storage, order picking, packing, marking and staging (Varila et al., 2007). Specific components that were considered in the case studies were the personnel required to operate the log yard and the material handling equipment (operating costs, fixed costs, etc.). Figure 49 explains what components make up machine rates.
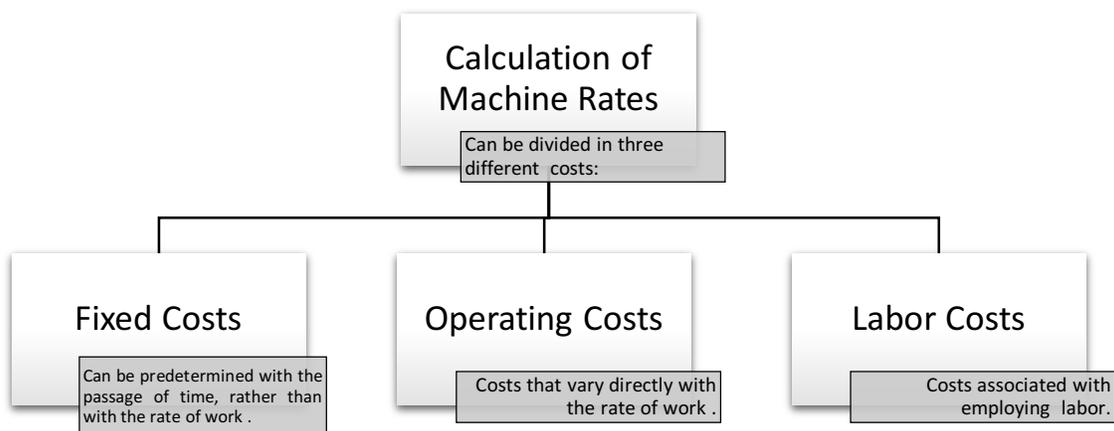

Figure 49. Calculation of Machine Rates

The calculation of machine rates can be divided in three different costs; fixed, operating and labor costs. Fixed costs in this report were considered the depreciation. Operating costs were the maintenance and repair cost, and the fuel costs. In the case studies presented, labor cost was

excluded from the machine rate because the annual salary for the wood/log yard personnel was presented separately. This is the raw material handlers not only devote their labor hours to operating machinery but also to other activities related to wood/log yard operations. Depreciation, the cost of machinery used over a period of time, is a fixed cost for this study. Depreciation is a long term asset, this refers to assets that take over one year, or an operating cycle, to turn into cash (H. Quesada, 2016). A commonly used method to calculate depreciation is the straight line method, displayed in Equation 52.

$$D = \frac{P' - S}{N}$$

Equation 52. Straight Line Decline Depreciation Method

P' is the purchased cost of the equipment? Usually this is the purchase cost including the standard attachments, optional attachments, sales taxes, and delivery costs. Depending on the situation the factory price, or the delivered price, applies. For example, the factory price is used when the company takes title of the equipment at the factory, and the delivered price is used if the title is taken after delivery. S represents the salvage cost, which is the price the equipment could be sold for, upon disposal. N is the period of time the machine can operate at an acceptable level of productivity, denominated as the economic life (in this study the economic life is determined in hours).

Procurement: Material Ordering

The material ordering cost is determined by multiplying the number of hours (H) that are designated weekly to procurement activities, by its corresponding hourly wage (C_b). If the costs are to be determined annually, the number of weeks worked per year should be multiplied in the following equation.

$$Weekly\ Material\ Ordering\ Cost = H * C_b$$

Equation 53. Material Ordering Cost for Logging Company

Supplier Collaboration

Literature states that strong relationships with key suppliers are advantageous to an organization (Stuart, 1997; Vollmann & Cordon, 1998). These relationships should be founded upon a clear business need and a convergence of interest (Bowersox, Stank, & Daugherty, 1999).

$$Supplier\ Collaboration\ Cost = h_{cc} * S_h * amount\ of\ collaborators$$

Equation 54. Supplier Collaboration

Supplier collaboration cost can be calculated as any resource spent on supplier collaboration. For example, if some personnel from the company (entity interested in defining the cost) are working on forming a strategic alliance with the supplier, the time in hours (h_{cc}) that collaborators spend on creating the strategic alliance, multiplied by the hourly salary (S_h) , and also by the number of collaborators would be the supplier collaboration cost (see Equation 54).