THE EFFECT OF TREE SIZE ON THE DELIVERED WOOD COST IN NORTHERN ONTARIO

by

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ABSTRACT

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Key Words: intensive silviculture, extensive silviculture, wood transport, delivered wood cost

To determine the effects that tree size has on the delivered wood cost, data was collected from existing literature on: average tree size (m3), average off road transport distance, volume per hectare (m3/ha), logging chance volume (m3) and average long-distance transport of wood in Northern Ontario. These variables were used to create three different modeled scenarios: Current (Extensive) Practices, Natural Regeneration with Thinning and Intensive Plantations. Of the three scenarios the Intensive Plantation had the lowest cost of wood at $39.18/ m3. While the Current (Extensive) scenario was the highest at $49.19/m3. For each a sensitivity analysis was performed on each variable to determine the variable with the most significant impact on the delivered wood cost. Through this it was found that the average long-distance transport distance played the most significant role and was capable of altering the final price by up to $12.04/m3. The average tree size was the second most significant contributing factor and was capable of altering the delivered wood cost by up to $3.82/m3. These results help define the effect intensive silvculture has on tree size and therefore on delivered wood cost.

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1.0. INTRODUCTION

Intensive silviculture is not a new concept in the province of Ontario. The idea of applying highly regimented forestry practices to the province's productive forest was first formally discussed during the1999 Ontario Forest Accord (Bell *et al.* 2000). The Ontario Forest accord was a response to Ontario's Living Legacy strategy which increased the amount of protected area in the province by 2.4 million hectares, and a subsequent predicted shortage of wood supply between 2020 and 2040 (Bell *et al.* 2008). However, the accord did little to change management styles and current practices in the province are still predominantly extensive, with little to no investments made into the regeneration or tending of stands (Bell *et al.* 2008). These practices have become common place due to the slow growth rates, long rotation and high initial investment costs, that render intensive silviculture, in many cases, impractical (Bell *et al.* 2008).

The lengthy 70-plus year rotations are attributed to a combination of relatively harsh climates, limited growing seasons and low site productivity (Bell *et al.* 2008). In addition to these factors much of the productive forest is located in remote areas far from communities or mills with very limited access (Bell *et al.* 2008). To compound the issue of access, most tree species in the province have low-yields and overall stem volumes.(Bonner and Nietmann 1987; Bell *et al.* 2008). This situation has a major effect on the final cost of wood since the transportation and road construction related to this can account for upwards of 65% of the total delivered wood cost (Pulkki n.d. a). Fforest managers can grow larger trees on shorter rotations and closer to mills by adopting more progressive and intensive silvicultural practices. These measures might reduce the potential for future roundwood shortages (Lautenschlager 2000).

1.1. OBJECTIVES

Northern Ontario forests are not known for growing large trees, but what the forests may lack in tree size it makes up for with vastness. Ontario has over 26 million hectares of productive forest (OMNR n.d.). Across this land base it has been argued that not enough is being done to maximize potential forest harvesting yields (Binkley 1997; Bell *et al.* 2000; Lautenschlager 2000; Bell *et al.* 2008). The adoption of intensive silvicultural practices could help mangers unlock the forests full potential . More specifically this paper will explore the effect growing larger trees, closer to mills via intensive silvicultre may have on the final logging cost of a cubic meter of wood.

To see how intensive silviculture can affect the final wood cost, three scenarios were simulated in a simple wood costing model: 1) current forest state (Extensive); 2) natural regeneration with thinning; and 3) intensive plantation silviculture. Then each of the scenarios will be subjected to a sensitivity analysis. The analysis will determine what variables have the greatest effect on the delivered wood cost

By determining which factors have the greatest effect on the delivered wood cost, forest managers can better understand how to reduce the cost of logging operations and increase the profit margins and returns on investment.

1.2. RESEARCH QUESTION

Does growing larger trees through intensive silviculture have any effect delivered wood cost? Furthermore, does the establishment of a plantation justify the increased cost of investment?

2.0. LITERATURE REVIEW

2.1 STUDY AREA

The Boreal forest of Northern Ontario is an area with rolling outcrops of Precambrian rock, lowland bogs and glacial deposits from the last ice age (Zoladeski and Maycock 1990). The soils are generally coarse and thin in upland areas, while the lowlands are boggy and consist of deeper peat deposits (Zoladeski and Maycock 1990). Tree species in this area are predominantly coniferous species of the genus *Picea, Pinus* or *Abies*, with some associated deciduous trees from the genus *Populus* and *Betula* (Zoladeski and Maycock 1990).

2.1.1 Tree Species

Black spruce (*Picea mariana* Mill.) is the most commonly found species, capable of growing in a wide variety of ecosites, though it is mostly found growing in the lowland peat bogs (Zoladeski and Maycock 1990). On sandy upland sites where competition for resources is lower and soils are thin, jack pine (*Pinus banksiana* Lamb.) is the dominant species, followed with some upland black spruce. These two tree species combine to dominate 49% of the harvestable area in Ontario (Sharma 2019). Other species found in Ontario’s Boreal forest are trembling aspen (*Populus tremuloides*

Michx.), white birch (*Betula papyrifera* Marsh.), balsam fir (*Abies balamea* Mill.) and white spruce (*Picea glauca* Moench.) to a lesser extent (Zoladeski and Maycock 1990).

2.1.2. Weather and Climate

The weather in in Northern Ontario varies throughout the year with warm, short summers and cold, long winters (Zoladeski and Maycock 1990). According to Natural Resources Canada (2020) the typical growing season across the region ranges from 80-120 days. Areas to the north east of the province typically have growing seasons closer to 80 days and the south west the season is closer to 120 days (Natural Resources Canada 2020). With only a third of the year suitable for plant growth, one would think it imperative that forest managers try and maximize the amount of growth. However, the vast majority of silvicultural practices in Ontario are extensive with occasional cases of thinning or human intervention (Bell *et al.* 2008)

2.1.3. Current Management Practices

For the purpose of this review the Dog-River Matawin Forest will be used as an example of contemporary forestry practices. Presently, the main silvicultural system used in Northern Ontario is clear-cutting. This system is used as a way to emulate the area's major natural disturbance of stand-replacing fires (Landres *et al.* 1999; McRae *et al.* 2001). Common regeneration practices on harvested sites vary according to site class, but are comprised two main approaches. The first is to allow stands to naturally regenerate from existing advanced growth, which is known as extensive silviculture (Bell *et al.* 2008; DRMF 2009). In this case nothing is done to the site after harvest and natural process are left to seed and succeed the site and takes place on just under 50% of the harvested areas in the DRMF (DRMF 2009). The other regeneration technique practiced in the DRMF is known as basic management, where seedlings are planted on harvested sites from local seed stock to help regenerate stands to more desirable commercial species. Sites a typically scarified, then planted with jack pine or black spruce and left to grow (DRMF 2009). In some cases the stands are subjected to chemical release from the competition on more productive sites, to help remove any competition to merchantable species (DRMF 2009). These techniques are considered acceptable so long as minimum stocking requirements are met and trees reach free to grow status (Bell *et al.* 2008, DRMF 2009).

2.1.4. Extensive Practices

The cycle of extensive silviculture begins once a stand is harvested and the commercial timber has been removed. The site is then scarified and left to naturally regenerate itself (Bell *et al.* 2008). Bell *et al.* (2008) found that this practice, while viable, can significantly lengthen the rotation age of a stand. This is because every year a tree spends trying to establish and free itself from the inter-specific competition is a year lost in producing commercial volume (Bell *et al.* 2008). More intensive practices can lower the times between harvests and increase volumes (Binkley 1997; Bell *et al. 2000*; Lautenschlager 2000; Bell *et al.* 2008).

2.2. INTENSIVE SILVICULTURE

Intensive silviculture is a part of intensive forest management (IFM) that looks to maintain wood flows to mills and improve wood quantity and quality (Lautenschlager 2000; Bell *et al.* 2008). More specifically it is defined under the NEBIE framework as the management activities that intended to control the quality and quantity of wood fiber grown on a site and the associated of inter-species and intra-species competition controls used in creating shorter rotation lengths and cutting cycles. (Bell *et al.* 2008) This management approach is common in many places such as Finland, Sweden and New Zealand, but in Canada the extent of this practice is mainly limited New Brunswick and parts of Quebec (Bell *et al.* 2008).

2.2.1. Intensive Silviculture in Ontario

In Ontario much of the silvicultural practices are considered to be extensive, looking to minimize the amount of money required to regenerate a forest. This works well but limits the quality and commercial volume of the final product when compared to more intensive practices (Bell *et al.* 2008). Intensive forestry has been applied in a few small cases in Ontario, but mostly for research purposes. The most notable sites are the Thunder Bay Spacing Trials, Legacy Forests and many red pine plantations further south.

2.2.1.1. Intensive Practices

The cycle of intensive silviculture is much more involved than that of a extensive prescription. Like the extensive system, the process begins after harvest and is followed by site preparation. The site is then planted with improved growing stock and subjected to chemical or motor-manual release treatments to remove any inter-species competition. Then at 20-30 year intervals, the site is thinned removing the poorest growth and creating more available space and nutrients for the remaining trees (Binkley1997; Lautenschlager 2000; Bell *et al.* 2008). A site will typically see thinnings 2-3 times, where the first is a pre-commercial thinning with little to no merchantable volume removed. This is followed by a second and third commercial thinnings yielding more merchantable volume, respectively (Bell *et al.* 2008; Lautenschlager 2000). This cycle is illustrated by Lautenschlager's 2000 study on the application of intensive silviculture in northern climates. Figure 1 is an illustration of what the cycle would look like in application.

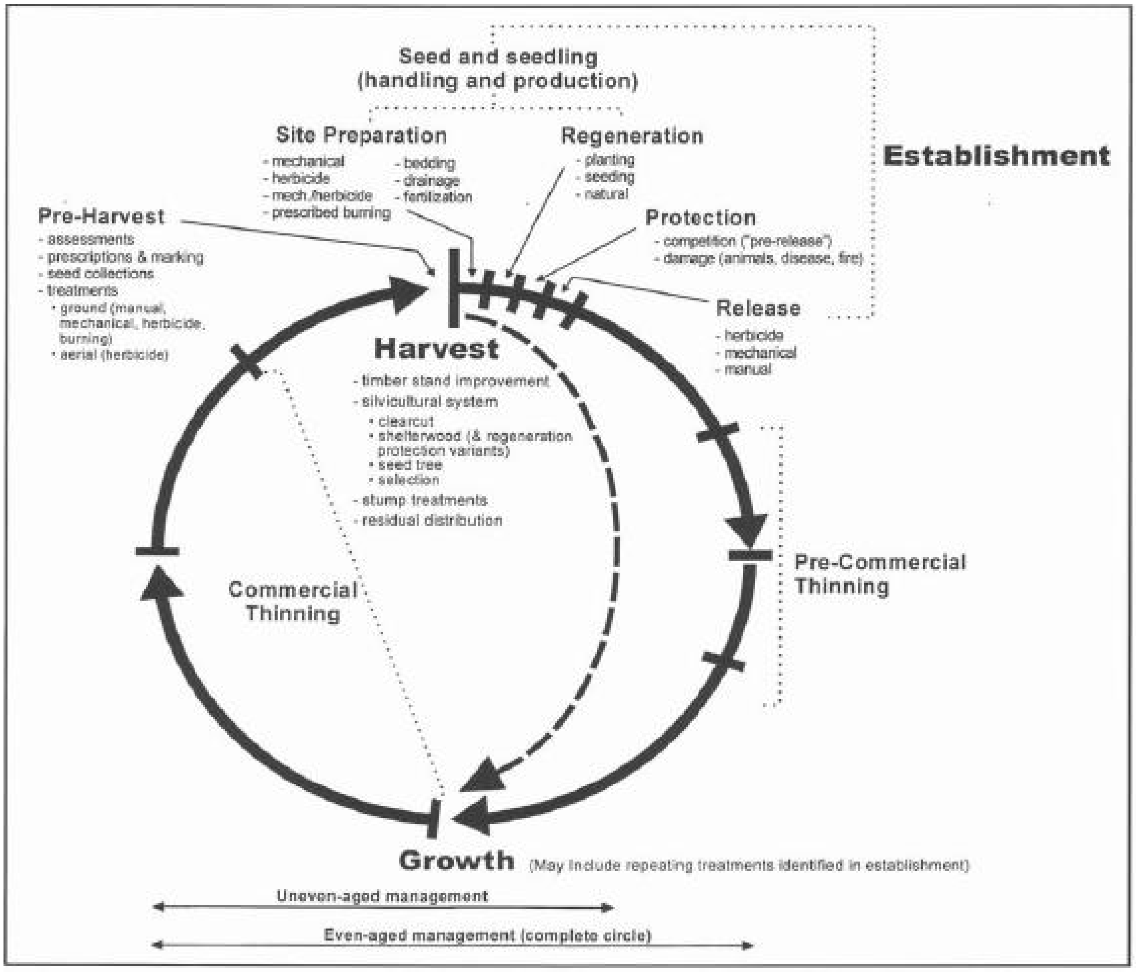

Figure 1. An illistration of the intensive silviculture cycle as presented by Lautenschlager (2000)

2.2.1.2 Tree Species

Another important factor of IFM that needs to be considered is the tree species used under the management regime. Choosing the most commercially valuable tree species can help reduce rotations and increase financial yields under IFM (Homagin *et al.* 2011).. In turn this can increase returns and reduced harvesting costs (Homagin *et al.* 2011). Species like red pine (*Pinus resinosa* Ait.) are ideal candidates for this type of forest management due to their ability to grow quickly, self-prune branches and maintain high strength properties (*Homagain et al.* 2011). Red pine is a well suited species for intensive applications because it is capable of growing at, at least, twice the rate of black and white spruce, and on average has greater yields than other commonly planted conifers in Ontario (*Homagain et al.* 2011).

2.2.1.3. 1999 Intensive Management Workshop

In 1999, Ontario addressed the lack of intensive silviculture in the province at the Intensive Forest Management (IFM) Workshop. The goal of the event was to find common ground on what IFM is and how it could be adapted for applications in Ontario's diverse forests (Bell *et al. 2000*). One of the driving factors propelling IFM to the forefront of Ontario's forest industry was the projected mid-range shortage of wood in 20-40 years (2020-2040) (Bell *et al.* 2000). IFM was chosen to addresses this problem because of its ability to increase the growth and yield of forests while simultaneously reducing rotation times; but this comes at a cost (Bell *et al.* 2000).

2.2.2. Economics

The advantages that can be gleaned from IFM takes investment and in some cases these investments can be expensive. J. D. Irving Limited (JDI) has practiced IFM for over 40 years in the province of New Brunswick and it has become an integral component of management success there (Bell *et al.* 2000; Montigny and Maclean 2006). At the IFM workshop, the company broke down its costs for intensive silviculture as follows: site preparation cost an average of $150 per hectare, planting cost $300 per hectare and chemical release of the planted stock averages $175 per hectare. Which brought the regeneration total cost to about $875 per hectare (Bell *et al.* 2000). These treatments are followed by several thinnings. Pre-commercial thinning costs an average of $650 per hectare, while commercial thinnings costs an average of $1400 per hectare (Bell *et al.* 2000) While these management practices are costly, the effects are substantial and JDI found that IFM has shortened rotations by 20 years (Bell *et al.* 2000). As well it allowed for a150-200% growth increase in early stages of development and increased overall volumes of commercial timber (Bell *et al.* 2000). These advantages translated into giving the company an 8% return on investment (Bell *et al.* 2000) .This equates to typical yields of 50 m_3/ha and average revenues of $800/ha for commercial thinning operations performed on intensively managed blocks. (Bell *et al.* 2000).

With the high costs of these practices and long waits for returns on investment, it is important to consider the economic values and implications of intensive forest management (Lautenschlager 2000; McKenny 2000). McKenny (2000) recognized that critics of the forestry industry think placing a dollar sign on forests can skew perspectives and hamper ecological protections and approaches. After all companies and governments need to make money. However, McKenny (2000) argues that the best way to manage the multiple uses of forests is to look at them with a common denominator. Placing a dollar value on all forest values helps build perspective of value (McKenny 2000). By allowing all the values within a forest to have a comparable value, managers and society as a whole can begin to see the true cost of forestry operations (McKenny

2000). The effects that harvesting may have on the balance of recreational, or habitat values can be comprehended. Then all the potential values can be compared in a cost benefit analysis (McKenny 2000). This type of economic analysis can then be applied to ensure that favorable economic and societal outcomes, like those at JDI, are obtained.

2.2.3. Influences on Non-timber Forest Values

Looking at forests as purely economic entities is not the proper or responsible thing to do. Therefore, today's forest management practices must look to accommodate forests for a plethora of ecological, economic and societal uses (Binkley 1997). Historically, in British Columbia (BC) extensive silvicultural practices have left a forest understocked and missing socially sustainable targets for environmental protection (Binkley 1997). These extensive practices have been mirrored in Ontario and lead one to wonder if it has left the forest in a similar state? Binkley (1997) believed that these past practices will cause a dislocation in future wood supplies and change the province's trajectory, and that intensive silviculture and land allocation need to become commonplace (Binkley 1997). If BC's forested lands were zoned into conservation reserves, ecosystem management areas and production zones, Binkley found that 18% of the productive forested land in BC would be needed to meet all current demands for timber (Binkley 1997). Having these zoned management areas would also create clearer management objectives and better balance land and resource use, while also reducing stakeholder conflict (Haas *et al.* 1987; Binkley 1997)

2.2.4. Concerns with Intensive Forest Management

With a focus on increasing the growth and yield of trees and shortening rotation times under IFM, Smith *et al.* (1997), Bell *et al.* (2000) and Lautenschlager (2000) found that concerns have arisen about the practice. These concerns circle around wood quality, the effects of IFM on fiber markets, the cost of investment into IFM and the overall sustainability of IFM. Smith *et al.* (1997) and Lautenschlager (2000) were concerned that the quality of wood grown in intensively managed plantations may be of lower quality. This is because when thinned the amount of juvenile wood in a tree is increased, which was found to have lower strength qualities than latewood (Smith *et al.* 1997). However, a study by Zhang *et al.* (2006) found when pre-commercial thinning is applied to a stand the resulting increase in growth has little effect on the strength quality of wood, but by when rotations of harvest are shortened below <59 years the bending properties of the wood are compromised (Zhang *et al.* 2006)

Another concern facing forests in northern climates is the demand placed upon them. With rapidly growing world populations the demand for wood has also seen rapid growth (Lautenschlager 2000). Because of this demand, IFM has been adopted around the world and with this comes fears that markets may become saturated with wood and diminish its value (Lautenschlager 2000). The increase of IFM may also have effects on sustainability and wildlife values in managed forests (Lautenschlager 2000; Bell *et al.* 2000). In Ontario, sustainable Forestry is based on the emulation of natural disturbances and the application of chemical release and thinning of plantations may not sufficiently emulate natural processes (Lautenschlager 2000). This is where some argue the TRIAD approach, which looks to zone management units into three different levels of intensive management, wood production zones, ecosystem management zones, and conservation reserves; can look to balance all social and economic values over the entire landscape, providing an equilibrium of production and protection. (Seymour and Hunter 1992; Binkley 1997; Montigny and MacLean 2006; Messier *et al.* 2009; Cote *et al.* 2010)

2.3. TREE SIZE

Tree size and growth can be extremely varied and is based on a number of different variables (Sherman 2005). Things like species, rainfall, sunlight, soil nutrients and topographic location can all have effects on tree growth and therefore the subsequent size (Sherman 2005). In Ontario, the two main merchantable species of black spruce and jack pine are no exception. Size of a tree is measured in three different ways, DBH (diameter at breast height), height in metres and volume (m_3). These measurements are important in determining the quality of a forest stand and many studies have been conducted on the area of tree growth and predicting future yields from stands (Polanski 1956; 1960; 1961; Parker and Wilson 2007; Sharma and Parton 2007; Penner *et al.* 2008; Sharma 2019)

2.3.1. Natural Forests

The most commonly known and used data on this topic comes from Polanski's yield tables (Polanski 1956; 1960; 1961; Penner *et al.* 2008) Polanski's tables were established in the 1950's and have been the base of many management decisions since then (Penner *et al.* 2008). However, in 2000 the Benchmark Yield Project run by the Ontario Ministry of Natural Resources began the process of updating these tables to ensure more recent and accurate data. (Penner *et al.* 2008). The project was published by Penner et al (2008), improved and validated Polanski's data from more than 3000 permanent sample plots across the province. These tables represented naturally grown trees and found that an average stand in Northern Ontario would have a density of 1750 stems per hectare, a gross total volume of 153.91 m$_3$ and an average tree size of 0.088 m$_3$ (Penner *et al.* 2008).

2.3.2. Effects of Pre-commercial Thinning

When pre-commercial thinning is applied to natural stands there are a number of changes that can be observed with regards to trees size and stand volumes. Tong *et al.* (2005) studied the effects that pre-commercial thinning had on jack pine stands in Northern Ontario. The study found that when a stand was subjected to pre-commercial thinning the average tree DBH increased, but reduced the gross volume per hectare, since trees were being removed in thinning operations. However, the thinning had a positive effect on the overall merchantable volume per hectare and increased the final product value of the wood by 19.6%. Pre-commercial thinning was also found to reduce the final harvesting costs, as there were greater merchantable volumes with less trees (Tong *et al.* 2005; Zhang *et al.* 2006).

However, the study also found that there can be downsides to pre-commercial thing, especially if it is down too intensively. Tong *et al.* (2005) found that if a stand is to aggressively thinned, the quality of the wood and its strength properties can be greatly diminished. Similar results were found by Zhang *et al.* (2006) when they studied the effects of pre-commercial thinning in New Brunswick, Canada.

2.3.3. Effects on Cost

By implementing IFM larger trees can be grown and by growing larger trees more profits can be made from the forest (Kluender *et al.* 1998; Bell *et al.* 2000; Lautenschlager 2000; Tong *et al.* 2005; Zhang *et al.* 2006). Kluender *et al.* (1998)

performed a study in United States to determine how tree size and harvest intensity effect the cost of logging operations. The study found that in order for an operation to break-even, trees needed to be a minimum of 8 inches (20.32 cm) DBH. It also found that the cost of operations were inversely related to the size of tree (DBH) and the intensity of the operation. This means that if larger trees were harvested with a clearcut system they would be more profitable than smaller trees under less intensive operations. (Kluender *et al.* 1998)

3.0. MATERIALS and METHODS

3.1 MATERIALS

The materials used to complete his study were heavily based on existing literature about growth a yield data for Boreal forest tree species, transportation of harvesting operations and site and stand characteristics in the Northern Ontario. This gathered information was then entered into a relative logging cost model and subjected to a sensitivity analysis. In total five different factors were used to determine the relative logging cost: average tree size (m_3), average off road transport distance, volume per hectare (m_3/ha), logging chance volume (m_3) and average transport distance of wood.

The data used to determine the average tree size and volume per hectare came from three sources and are based on two tree species, jack pine and red pine. Jack pine is used for the current extensive model (CEM), and natural regeneration with thinning (NRTM) model due to its abundance and common use as a merchantable species across Northern Ontario. While in intensive plantation model (IPM) red pine was used because of its superior growth qualities, relative to jack pine, making it a better tree for more intensive silvicultural practices. The sources used for these models are studies focused on the growth and yield infromation of Ontario's Boreal Forest which aligned with the three scenarios of this study. For the CEM, the average tree size (m_3) and volume per hectare (m_3/ha) data came from a study by Penner *et al.* (2008) that looked to update Ontario's growth and yield data base. The second, NRTM used a combination of data from Penner *et al.* (2008) and Tong *et al.* (2005) to determine average tree size and volumes. Here two sources were used because the Tong *et al.* (2005) study measured trees that were not at full maturity so the data need to be extrapolated and used in conjunction with Penner *et al.* (2008) data on fully mature stands. The final scenario in the study is the IPM, which focuses on intensive plantations and used data from a study conducted at the Thunder Bay spacing trials by Homagin *et al.* (2011). This data was based on intensively managed red pine measured at regular intervals over a 24 year period.

The average off road transport for all three scenarios was based on a similar study to this on by Park and Wilson (2007) and assumed a maximum off road transport distance of 250 m. The total logging chance volume, was determined based on two studies, McRae *et al.* (2001) and Alam (2012). Both studies looked at the average harvest area in Northern Ontario and provided important information needed for calculating the logging chance volume. Finally, the information used to determine the average cost of transport came from Alam (2012) and the basewood calculations excel sheet from Pulkki (n.d. c) (Table 2). The two information sets helped determine the base cost of transportation and in suit the basewood cost used in the model. All data sources were integral to completing the model and the three different scenarios within this study. The model used for the study came from Pulkki (n.d. b) . and ran in Excel to determine the relative logging cost. Within the model there were five variable inputs: average tree size, average off-road transport distance, volume per hectare, total logging chance volume and basewood cost. There were then six calculated values based on the five variable inputs. These were tree size effect, transport distance effect, volume per hectare effect, logging chance volume effect, overall weight factor and the final factored wood cost. The formulas used to determine these calculated values can be seen below (Table 1).

Table 1. Relative logging cost model variable inputs and calculated value formulas as seen in Excel.

	B	**C**
	RELATIVE LOGGING COST MODEL	
		Formulas
4	Average tree size (m3)	0
5	Average off-road transport distance (m)	0
6	Volume per hectare removed (m3/ha)	0
7	Total Logging Chance volume (m3)	0
8		
9	Tree size effect	=(123.8-438.9*C4+1033.2*C4^2-870.7*C4^3)
10	Transport distance effect	=(54.1+0.024*C5)
11	Volume/hectare effect	=(74.05-0.1075*C6)
12	Logging chance volume effect	=(98.1-0.1676489*C7+0.0002431264*C7^2-0.0000001167*C7^3)
13	Overall weighting factor	=(C9*2+C10+C11+C12)/5
14		
15	Base wood cost ($/m3)	0
16	Factored Wood Cost ($/m3)	=C15*C13/100

3.2. METHODS

The values of the five variable inputs were determined by two factors, the scenario of the model (current, natural regeneration or intensive plantation), and the tree species.

3.2.1. Current (Extensive) Scenario

The first scenario, was based on current extensive forestry practices in northern Ontario. Average tree sizes for this scenario came from Penner *et al.* (2008). The value for the average tree size was calculated to be 0.088 m_3/tree and came from Penner *et al.* (2008) validated growth and yield data for Northern Ontario. This same study provided the average stems per hectare for the area and when multiplied by average tree size, provided the value for volume per hectare. The volume per hectare was calculated to be 153.91 m_3/ha. Total logging chance value was then calculated by taking the average volume per hectare and multiplying it by the average cut block size in the study area. The value for average size of a cut block in Northern Ontario was assumed to be 50 ha, which was determined from the McRae *et al.* (2001).The study found that 46% of clearcuts in the Northern Ontario are 0-50 hectares in size. This was further validated by Alam (2012) in a Doctoral Thesis that used the same value for assuming the average cut block size. The final variable input determined for the model was the basewood cost.

The basewood cost value is based on a number of different variables such as harvesting costs, hauling cost and crown dues. However, for the purposes of this study the only variable of concern was the long-distance hauling cost. These values are all entered into the basewood cost breakdown (Table 2) which calculated basewood cost ($/$m_3$), based on all the input cost of each factor. The cost of long-distance hauling was determined to be $18/ m_3 for 150 km of travel, based on the below table from Pulkki (n.d. c) (Table 2) and the calculated value from Alam (2012). The average distance traveled per trip in the CEM scenario was 273 km, which was determined by Alam (2012) and applied to this study. To calculate the cost of hauling for this scenario the total distance was divided by 150 and then multiplied the base cost of $18.00/ m_3 to determine the cost of long-distance hauling for the current scenario to be $32.82/ m3. Once this was done the basewood cost was calculated to be $68.96 and entered into the costing model.

Table 2. The values of all variables used to determine the basewood cost used in the Relative Logging Cost models. Data from Pulkki (n.d. c).

Basewood Cost Breakdown

Factor	$/m3	% of Total Cost
Felling	5.15	9.5%
Skidding	3.88	7.2%
Delimbing	4.08	7.5%
Slashing	3.78	7.0%
Loading	2.25	4.2%
Hauling (150km)	18.00	33.2%
Roads & landings	3.25	6.0%
Plan,for,adm,ovhd	4.00	7.4%
Cont. profit	2.75	5.1%
Crown dues	7.00	12.9%
Total Basewood Co	54.14	100.0%

3.2.2. Natural Regeneration with Thinning Scenario.

The method for developing the second model was the exact same as the CEM scenario. The average off road distance stayed the same, as did the logging chance volume per hectare. The only difference was that the inputs for average tree size, and volume per hectare were changed to reflect the effects of thinning. The average tree size for this scenario came from data collected by Tong *et al.* (2005). The data was based on 36 year old natural regenerated jack pine stands that were subjected to pre-commercial thinning (PCT). Since the trees were not at full maturity this information would have to be extrapolated. This was done by taking the full data set from the study and determining the difference in growth between the PCT sites and the control. To do this the average tree size for each the PCT and control were found and the percent difference in growth was calculated. The PCT trees were calculated to have 43.61% greater volume than the control trees and this was then used in conjunction with the average tree size determined by Penner *et al.* (2008) to calculate an average PCT tree size of 0.1263 m$_3$. This was then multiplied by the average number of stems per hectare found by Tong *et al.* (2005), which was 2100 to calculate the average volume per hectare which was 265.14 m$_3$/ha. The hauling distance for this scenario was assumed to be the same as the extensive model since the only thing changing was the introduction of a pre-commercial thinning operation.

3.2.3. Plantation Scenario

The plantation scenario model was based on a forest that was subjected to intensive management practices and grown closer to a mill. The data needed to complete this model came from Homagain *et al.* (2011) on the growth and yeild of intensivly managed stands in Northwestern Ontario. The data is based on the growth of planted red pine, at 1.8 m spacing which had an average tree size of 0.314 m$_3$. The volume per hectare was 811 m$_3$/ha and was calculated by using the number of stems per hectare from the same stand, which was 2583 stems. The logging chance volume stayed the same at 1000 m$_3$/ha as did the average off-road hauling distance since the harvesing method was also the same. The hauling distance was changed however, since this was an intensivly managed stand the scenario assumed that trees were grown closer to the mill, making the average haul distance 200 km.

3.3. SENSITIVITY ANALYSIS

To determine the effect each variable had on the final factored wood cost a sensitivity analysis was conducted on all three scenarios. The sensitivity analysis used the same input values for each of the original models and subjected a variable one at a time, to a gradient of 10% changes ranging from -50% to 50%. This was repeated for all variables and the changed value of the factored wood cost was then recorded and entered into an Excel graph that plotted the change in value over the range of percent changes.

4.0 RESULTS

4.1. DELIVERED WOOD COST

The delivered wood costs were determined by changing the variable inputs within the factored wood costing model to reflect the values for each of the three scenarios. The scenario that resulted in the highest delivered wood cost was the Current (Extensive) Scenario at \$49.19/ m_3. This was followed by the Natural Regeneration with Thinning Scenario at \$45.30/ $m_3$and finally the Intensive Plantation Scenario \$39.19/ m_3 (Figure 2).

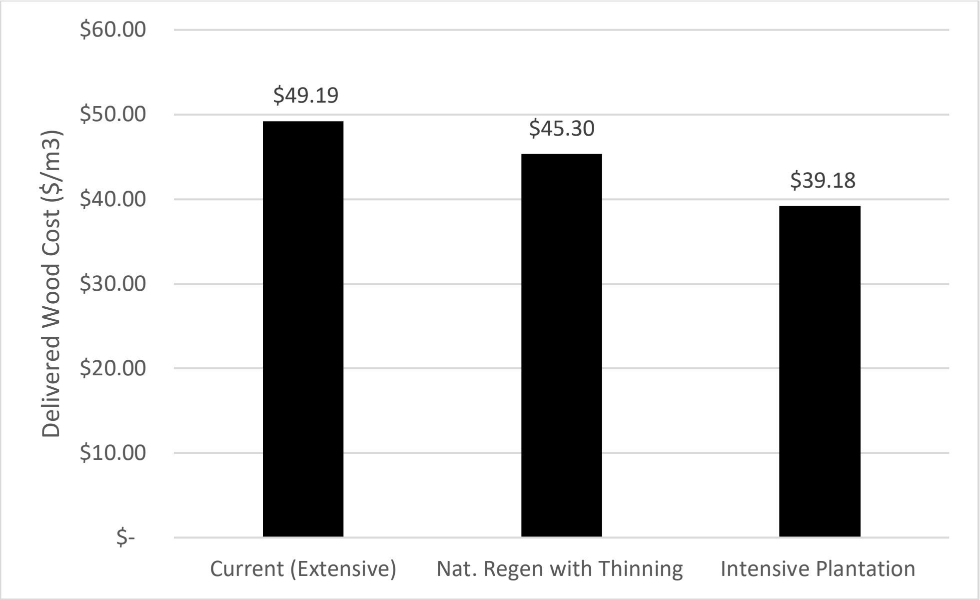

Figure 2. Delivered wood cost results of all three modeled scenarios.

4.2. SENSITIVITY ANALYSIS

Once the results for each model were gathered all three scenarios were subjected to a sensitivity analysis. The analysis subjected each variable input to a gradient of 10% change from -50% to 50% of the original modeled scenario. The resulting values were represented by the adjusted delivered wood cost and the difference in dollars per meter cubed ($/m3). The sensitivity analysis for all three scenarios shared a common trend. As the percentage of change went up, the overall factored wood cost went down for most variables. However, the opposite was true for distance to the mill and average off road distance. For these variables, as the value of these variables increased the factored would cost steadily increased and vice versa.

The below table (Table 3) shows the results of all the sensitivity analyses on the delivered wood cost for all three scenarios. The variables that had the greatest effect on the delivered wood cost were, distance to the mill and average tree size. Distance to the mill had the greatest effect on the factored wood cost out of any variable.

Table 3 The cost difference ($/m3) as a result of changing all variables for all three scenarios.

	Cost Difference from modeled scenarios ($/m3)										
Variable	-50	-40	-30	-20	-10	0	10	20	30	40	50
	Scenario										
	Current (Extensive)										
Average tree size (m3)	3.82	2.98	2.18	1.42	0.69	0.00	-0.66	-1.28	-1.87	-2.43	-2.96
Average off-road transport distance	-0.21	-0.17	-0.12	-0.08	-0.04	0.00	0.04	0.08	0.12	0.17	0.21
Volume per hectare removed (m3/	1.14	0.91	0.68	0.46	0.23	0.00	-0.23	-0.46	-0.68	-0.91	-1.14
Haul Distance to Mill (km)	-11.71	-9.37	-7.02	-4.68	-2.34	0.00	2.34	4.68	7.02	9.37	11.71
	Nartural Regeneration with Thinning										
Average tree size (m3)	4.66	3.59	2.59	1.66	0.80	0.00	-0.73	-1.41	-2.03	-2.60	-3.11
Average off-road transport distance	-0.21	-0.17	-0.12	-0.08	-0.04	0.00	0.04	0.08	0.12	0.17	0.21
Volume per hectare removed (m3/	1.78	1.42	1.07	0.71	0.36	0.00	-0.36	-0.71	-1.07	-1.42	-1.78
Haul Distance to Mill (km)	-10.78	-8.63	-6.47	-4.31	-2.16	0.00	2.16	4.31	6.47	8.63	10.78
	Intensive Plantation										
Average tree size (m3)	3.87	2.66	1.71	0.97	0.42	0.00	-0.32	-0.57	-0.80	-1.04	-1.35
Average off-road transport distance	-0.18	-0.14	-0.11	-0.07	-0.04	0.00	0.04	0.07	0.11	0.14	0.18
Volume per hectare removed (m3/	1.55	1.24	0.93	0.62	0.31	0.00	-0.31	-0.62	-0.93	-1.24	-1.55
Haul Distance to Mill (km)	-12.27	-10.91	-8.18	-5.45	-2.73	0.00	2.73	5.45	8.18	10.91	13.63

Increasing the hauling distance to the mill by 20%, increased the delivered wood cost by $4.68, $4.31 and $5.45 per meter cubed across the CEM, NRTM, and IPM scenarios respectively. While increasing the average tree size by 20% decreased the delivered wood cost by $1.27, $1.41 and $0.57 for the CEM, NRTM, and IPM scenarios respectively.

When the other two factors were subjected to the same 20 % increase similar results were seen but on a lesser scale. The volume per hectare decreased the delivered wood cost by $0.46, $0.71 and $0.62 per meter cubed and the average off-road hauling distance increased the cost by $0.08, $0.08 and $0.07 per meter cubed of wood for the CEM, NRTM, and IPM scenarios respectively.

5.0 DISCUSSION

The intent of this study was to determine the effects that tree size has on the delivered cost of wood in Northern Ontario and if so, can the increased investment capital applied to establishment of plantations be justified?. Through extensive research it was found that the overall size of the tree plays a significant role in the delivered cost of wood, and by investing in plantation silviculture larger trees can be grown in less time. Therefore, justifying the increased cost of intensive silviculture.

Within this study average tree size had the potential to change the delivered wood cost by -$2.96 when trees are larger to $3.82 /$m_3$ when trees are smaller at ± 50% of the current scenario These numbers may not seem significant when applied to a single m_3 of wood, but when a block may have thousands of cubic meters of harvestable wood the costs begin to rapidly change. This means that if a tree was even 20% larger than current growth, a savings of $1.28 could be realized per metre cubed. When this is applied to an average stand in Northern Ontario that has approximately 153 m_3/ha across a 50 hectare block there is a potential savings of $9850.24 based on tree size alone. These results are very similar to those found in a study by Kluender *et al.* (1998) where the size of the tree was directly related with the profitability of a harvest. Kluender et al (1998) found that when larger trees were harvested they were far more profitable then smaller trees, since the cost per unit (tree) was reduced and productivity of harvesting operations increased with an increase of diameter at breast height (DBH). This was again echoed by the two other modeled scenarios in this study, where the trees were larger and therefore the factored wood costs were lower (Figure 2). Tree size plays a major role in the final cost of harvested wood, and larger trees would much be more desirable to harvest with their inherent ability to reduce logging costs. However, to grow larger trees in an area like Northern Ontario's Boreal forest more intensive silvicultural practices need to be applied.

The effects that intensive silvicultre has on the growth of trees is well documented (Seymour and Hunter 1992; Binkley 1997; Bell *et al.* 2000; Lautenschlager 2000; Homagain et al 2011). The three different silvicultural scenarios explored in this study helped further the understanding that forest management can have of the final cost of wood. In Ontario extensive silvicultural practices are applied to the majority of stands, due to the initial investment being as low as $0 per hectare (Bell *et al.* 1999). While an investment into extensive silviculture is safe, it does little, if anything, to improve the stand (Bell *et al*. 2000; 2008). The results of this study showed that the initial savings from practicing extensive silviculture have a trickle-down effect on the delivered wood cost of extensive stands. As it dramatically increases the delivered wood cost, when compared to stands that were subjected to more intensive silvicultural treatments (Figure 2). The difference in calculated delivered wood costs between the CEM and IPM scenarios within this study was $10.01/ m$_3$. The CEM scenario had a final factored wood cost of $49.19/ m$_3$ while the IPM scenario was $39.18, this is a significant difference in price and when applied to an average stand that is capable of having several thousand cubic meters, where the cost savings would be in the tens of thousands of dollars.

The lower delivered wood costs come at a premium though, as the investment into intensive silviculture can be over $3000 dollars per hectare in the most extreme cases

(Bell *et al*. 2000). This is a serious draw back to the implementation of intensive silviculture and can make it hard to justify, especially when extensive silviculture can regenerate a forest back to a satisfactory state for much less. Intensive practices can also have adverse effects on the price of wood and lower the competitive advantage of areas with large forest expanses, where extensive silviculture is feasible (Benson 1988). In the case of Canada, extensive silviculture has been a luxury that we have been able to afford and the justification of more intensive practices is hard when the tree growth in the Boreal forest is around 1.7 m3/ha/year on an average site (Benson 1988). However, growth rates can be increased to mean annual increments (MAI) of 6-9 m3/ha/year with native species when intensively managed (Parker and Wilson 2007).The growth rate can be even greater on higher quality sites with faster growing species such as red pine, where MAI can be upwards of 9.2 to 16.0 m3/ha/year (Parker and Wilson 2007); and in the case of the Thunder Bay spacing trials MAIs for red pine have been seen at 14.5 m3/ha/year (Homagain *et al.* 2011).

The NRTM scenario from this study, may represent the middle ground between both intensities and may be the best solution to the steep cost of silviculture presented by intensive practices and the lower merchantable volumes of extensive practices. In this scenario the cost of applying pre-commercial thinning is only $650/ha (Bell *et al.* 2000), much lower than fully intensive practices, and the scenario yields greater merchantable volumes (265.14 m3/ha) than extensive practices (153.91 m3/ha). The delivered wood cost of $45.30/m3 is also $3.89 lower than the CEM scenario. This is again attributed to the increased piece size, as the model was run with all other variables equal to the CEM scenario. Only volume was a contributing factor to cost difference in this scenario and cost savins were still realised .

By increasing the volume per hectare and furthermore the utilization rate (m$_3$/ha/year) of a stand the average transport distance can be exponentially reduced. The figure below (Figure 3) shows the relationship that an increased utilization has with the average transport distance required to meet a harvest of 2 million m$_3$/year. As the utilization rate increases from 0.5 m$_3$/ha/year to 2 m$_3$/ha/year the average transport cost is cut in half from 159.6 km to 79.8 km respectively, for a half circle procurement zone.

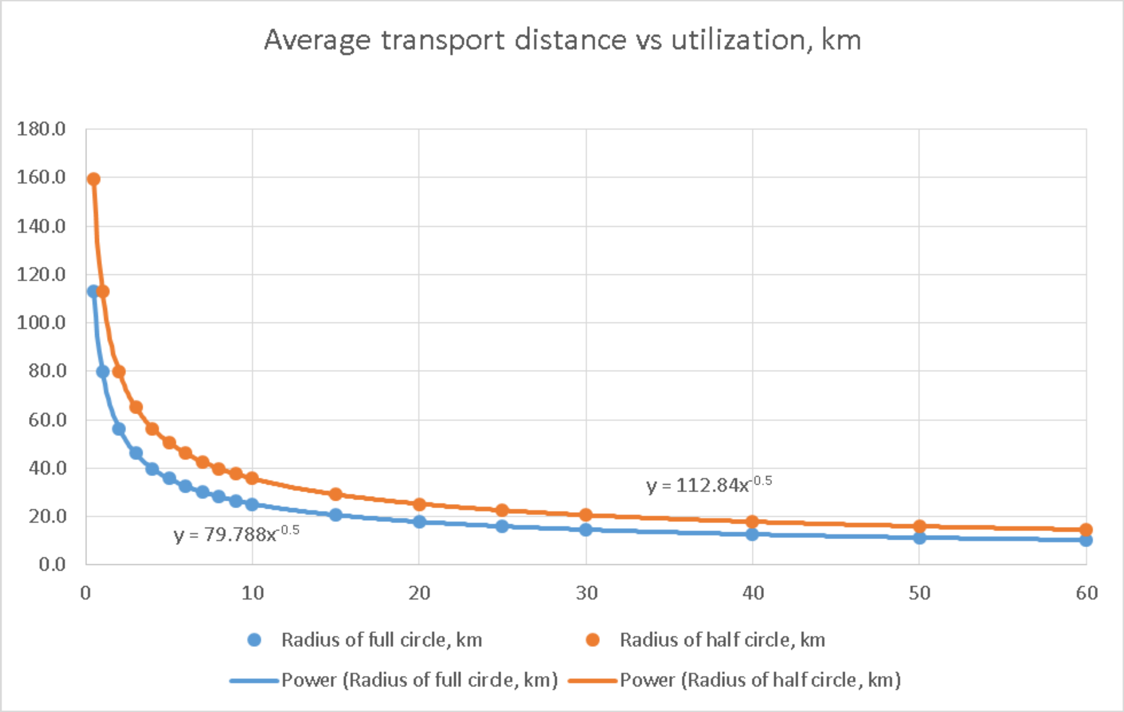

Figure 3. Illustration of the theoretical impact of increasing yield per ha on the radius of a circle and a half-circle from a central point of utilization.

This reduction in transportation distances is another benefit that can be seen from intensive silviculture, and was a contributing factor to the lower factored wood cost of the IPM scenario. It helps illustrate the effect that hauling distance has on the final factored wood cost an in this study it was found the impact was even greater than the impact average tree size. It was found that when trees are harvested further from mills the cost of logging can be increased by an average of \$12.04/ m_3, and when harvested closer to mills the cost can be reduced just as dramatically by an average of \$11.59/ m_3. This has major impacts on the final factored wood cost and when coupled with increased tree sizes can make major cost reductions. The model found that if distance to the mills in the current scenario were reduced by 30% (81.9 km) and tree size was increased by 30% the final factored wood cost could be reduced by \$8.62 or 19.2% per meter cubed.

Understanding the impacts that tree size and hauling distance can have on the delivered wood cost helps build a strong case for the use of more intensive practices like those used in the TRIAD management system. This approach while limited in real world application has been thoroughly studied by many (Seymour and Hunter 1992; Binkley 1997; Montigny and MacLean 2006; Messier *et al.* 2009; Cote *et al.* 2010). This approach to forest management has been most successfully applied this in New Brunswick, Canada by J. D. Irving Ltd and most notably on their privately owned Black Brook Forest (Montigny and Maclean 2006). Here the company operates on 188, 584 hectares of forested land, managed in a TRIAD inspired fashion. 60,000 hectares of the forest are dedicated to the intensive management of spruce (*Picea spp*.) plantations and increased timber yields. These intensively managed stands are capable of producing more than double the merchantable volume (365 m_3/ha) then extensively managed stands (180 m_3/ha) over the same rotation period (Montigny and Maclean 2006). In addition to this JDI, with the help of the World Wildlife Fund, set aside 7,000 hectares of “benchmark forest” as unharvested reserves; and the remaining forest is managed with an adaptive approach focused on extensive silvicultural practices (Montigny and Maclean 2006).In the Black Brook Forest, JDI is capable of meeting the diverse social and economic demands placed on the land with the integration of intensive management. Which in reality is the goal of sustainable forest management and if properly performed could have applications here in Ontario.

Limitations of this study stem from limited information and data used to determine the transport distances typical of Northern Ontario. The data used in this study only focused on a single mill (Resolute Forest Products, Thunder Bay), and did not account for any other mills or hauling distances. This limited the effectiveness of the study as the procurement radius of this particular mill is a half-circle since it is restrained by Lake Superior to east and the United States international border to the south. This half-circular shape means that the mill has to travel greater distances to meet their procurement demands then other mills in such place as Dryden, Hearst or Hornepayne that are located in the middle of fibre baskets and have circular procurement zones. Having determined and accounted for the average transport distance for the different mills in Northern Ontario a more accurate average transport distance could have been used for the model.

Another limitation of this study is the data used for the average tree size in the three models. These tree sizes were based on singular studies and therefore single data sets. Again if more information was used to determine the average tree sizes for the three scenarios greater accuracy could be obtained and more accurate results could have been presented. A recommendation for further studies into this topic would be to broaden the data set used to determine the values of the variables. As well increase the scope of the sensitivity analysis to include other contributing factors to the factored wood price. The basewood cost is comprised of 10 different variables and this study only analysed the effects of changing one, the long-distance hauling. Doing this may allow for further insight into how other variables may affect the final wood cost and deepen our understanding of the procurement system.

6.0 CONCLUSION

The information and results of this study provided insight into the effects that forest management can have on the reduction of final wood costs. By growing larger trees, this study found managers are capable of reducing the final wood cost by up to 6.2%/ m^3. In addition growing larger trees and increasing utilization of stands managers are able to move harvesting operations closer to mills, which in turn help further reduce the cost of wood and streamlines the productivity and profits from the forest. Reducing the average hauling distance to mills is capable of drastically reducing delivered wood costs by upwards of 27% /m^3. However, in order to obtain these types of cost reductions more intensive forms of silviculture need to be adopted in Northern Ontario. Additionally, contributing factors to such as steep investment costs, and satisfaction with the status quo may inhibit many from moving into this type of management. Never the less, some companies such as J.D. Irving Limited have decided to move beyond industry norms and have already adopted this type of management in Canada, helping push the boundaries and possibilities of forestry.

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