The UAV Logger as a Potential Alternative for Timber Transportation in the Canadian Boreal Forest

by

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Abstract

The Canadian boreal forest has substantial natural resources located in remote isolated areas that are of economic interest. Requirements of the log extraction operation are to minimize impact on the ecosystem and its inhabitants. Transportation is one of the largest direct costs of forestry operations and many potential harvest areas are left untouched because of the high costs to build and maintain logging roads and water crossings. Alternatives to the traditional surface transportation system could benefit the industry, the residents and the ecosystem.

The economics of a Lighter-Than-Air UAV Logger concept for log transportation is compared to the current truck and road build option using a cost comparison model and three harvest area case studies. At the engineered price estimate of $4.1 million, the results suggest that the UAV Logger is an uneconomic transportation alternative in the boreal forest at current product prices and supply availability. Conditions that favour the UAV Logger as a competitive economic alternative include small harvest volumes and high road build costs.

Acknowledgements

I would like to thank my advisor Dr. Barry Prentice for his vision and guidance. His passion for lighter-than-air technology and the use of airships to bridge the transportation gap to remote areas has been an inspiration. I look forward to the day that I can look to the sky and see his dream become a reality.

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Chapter 1
Introduction

1.1 Economic Problem

Canada's Boreal Forest is a playground for wildlife, explorers and residents alike, offering a "recreational and spiritual refuge" (Canada Natural Resources, 2007). It covers 35 percent of Canada's total land mass and accounts for 77 percent of the total forested land area. This forest is one of Canada's largest natural resources and is of great economic interest. The boreal forest provides direct employment to over 165,000 Canadians and its annual revenues exceed $38 billion (Canadian Boreal Forest Agreement, 2009a,b,c,d,e). Effective planning, responsible management and improved operating techniques help reduce the ecological footprint and allow the companies to deal with high costs involved to remain economically viable (Gibbons, 2007).

Transportation is a major cost in the forestry industry. Creating a road network through the boreal forest is costly because of the difficult terrain and the requirement to observe agreements and permits with stakeholders. All-weather roads for logging purposes cost on average $50,000 per kilometre, with maintenance costs upwards of $5,000 per kilometre each year. Water crossings further increase the investment in roads. These costs can average from a few thousand dollars for a culvert, to half a million dollars for a bridge crossing (Forester A, 2011).

Log transportation distances can vary between 200 and 600 kilometres (Gibbons, 2007). Lengthy trips over difficult terrain demand a sturdier, more robust truck and these vehicles are commonly associated with higher capital, maintenance and fuel costs. Other contributing factors to the high cost of transportation include the lack of basic road infrastructure beyond the lower third of most provinces, current weight and axle restrictions and the minimal opportunity for loaded back-hauls.

Access management of logging roads can be problematic. Although the roads are built and maintained by logging contractors, many of these roads have open access to the public for use free of charge. Upon completion of harvest operations, a decision must be made whether to strand the asset or to decommission the road.

Decommissioning, or land restoration, carries high cost but it reduces the ecological footprint in the area. This cost may be as high as the cost of building the road; however, removing it from service releases the logging company from liability of any injuries or accidents sustained on the road after the logging team has left the site (Gibbons, 2007). In addition to the direct costs of building the roads, many indirect costs and externalities are involved. The consideration and protection of wildlife and wetlands is a must, as well as re-planting the area upon harvest completion.

Climate change presents a new challenge to the industry and adjustment is costly. A main effect of climate change is the decreasing time period for safe use of the ice road network. Traditionally, the ice road season is 50 to 60 days long; however in recent years it has been inconsistent. Many ice roads open with restricted haul tonnages, while others do not open at all. Irrespective of the unstable ice road season, this network incurs high costs for building and maintenance for a short useable window. The shrinking window for safe use of the ice roads leaves some logging companies with less time to move their inventory out of the harvest areas. To move the same volume over a shorter period of time requires more trucks and drivers or may increase holding costs by stranding inventory at the harvest site for an additional season.

All of these factors and their potential combinations of scenarios make many harvest areas economically infeasible to harvest with the current market conditions for forestry products.

1.2 Business Problem

The forestry industry is affected by the rise of direct costs and the internalization of their negative externalities, such as environmental costs. Pressures from multiple stakeholders demand a further reduction of the logging industry's ecological footprint. Aerial alternatives to surface transportation could benefit the logging industry, the economy and the ecology of the Northern parts of Canada.

Limited utilization of the cable-balloon logging method has demonstrated the environmental advantages of lifting the payload from the harvest area without disturbing the integrity of the forest. Research shows that this method incurs less damage to the product compared to other logging systems (Ammeson, 1984; Curtis, 1978). However, cable-balloon logging requires close coordination that can be difficult, as well as the need to continually move the cable road. This involves clearing of the forest floor to set up yarders, anchors and cables.

The utilization of a remotely controlled powered balloon could provide an alternative economic solution. Hereafter, this is referred to as a UAV Logger, for Unmanned Aerial Vehicle. A UAV Logger would be to cable-balloon logging, what a cell phone is to a landline telephone. A UAV Logger would require no cables or ground limitations on its range or operations. This transportation system would assist the logging companies in meeting higher environmental demands, such as lower air pollution and minimal animal habitat disturbance. Using a UAV Logger to connect a harvest site to a main artery road would minimize or even eliminate the need to build additional logging roads for truck access.

There has been extensive discussion surrounding the use of airships for movement of cargo and passengers into regions without all-weather roads, as well as the use of unmanned airships for surveillance and military needs. These discussions centre on technology already available, while the proposed airship for forestry use would require innovation in regards to its design and operation. An unmanned airship puts no crew in harms way. A UAV Logger could use hydrogen, instead of helium, as the lifting gas. The weight associated with the human interfaces and crew can be eliminated, allowing maximum lift for the payload (Bock, Apel and Prentice, 2010).

Aerial logging in the boreal forest could have several advantages if it is economically competitive with truck-based logging. The UAV Logger would minimize the effects and relocation of wildlife and reduce open access to predators and hunters. This technology could assist interested parties currently promoting alternative cutting and land use strategies. The UAV Logger is aligned with the demands of the First Nations for sustainable forestry. For example, the Whitefeather Forest in Ontario has a land-use strategy that promotes minimal road construction and responsible logging within their boundaries (Pikangikum, 2006). Lastly, UAV Loggers would minimize the amount of marooned cutting areas, avoid the costs of decommissioning all-weather roads or stranding assets, and reduce the risks associated with an ice road network.

The design and operational considerations for a UAV Logger, as well as a primary development plan, have been drafted by Juergen Bock and Uwe Apel (Bock, Apel and Prentice, 2010). The direct costs and operational limits are assessed and compared, along with its effects on the externalities, to determine if the UAV Logger is a competitive alternative to current logging transportation in Manitoba and northwestern Ontario.

Research question: Is the UAV Logger a competitive economic alternative to the current surface transportation logging process within the Canadian boreal forest?

1.3 Research Objectives

The main objective of this research is to complete a cost comparison analysis to determine if the proposed UAV Logger is a viable economic alternative to the current logging truck-road build process in the Canadian boreal forest.

Other research objectives include:

a) to determine what special conditions need to be present in order for the UAV Logger to be competitive, and

b) to determine a target price range for the designers and manufacturers of the UAV Logger.

1.4 Research Scope and Method

The scope for the research encompasses logging within the Canadian boreal forest and does not include mountainous terrain. It is limited to the “last-leg” of the route, from the harvest site to an appropriate transhipment point located adjacent to an existing road network. The “last-leg” may be direct to the mill, for nearby harvest areas. The two types of road networks included are all-weather road networks and ice road networks. Harvest costs and processes are not within the scope of this analysis and are assumed to be unaffected. The UAV Logger design reference and operational data are provided by Juergen Bock and found in Appendices A, B and C.

The method of analysis is a cost comparison of the fixed and direct monetary costs. The relevant social costs and benefits are discussed but not quantified. Research information is collected from key professionals in the areas of forestry, transportation and road construction and from the designers of the proposed UAV Logger. Additional information is obtained from provincial and federal government departments and others studying forest management and the effects of logging.

Due to the sensitive material and confidentiality required, the forestry companies that have been contacted for assistance with this research remain anonymous and are referred to as Forester A and Forester B.

1.5 Thesis Outline

This thesis is organized in nine chapters. Chapter One introduces the business problem and outlines the research question and objectives. Chapter Two provides an overview of the forestry industry in Canada, including the current logging strategies. Also included is an introduction to airships and UAVs, with a brief history of the technology and current status of development. The different configurations with this transportation mode are discussed, with the focus on the UAV. Chapter Three discusses the economics of the cost analysis and current market trends in the lumber industry.

Chapter Four summarizes the current process for forestry road management, road decommissioning and outlines the basic costs to road build in the current environment.

Chapter Five explains the UAV Logger technology and estimates the capital cost of a 15 ton lift unit. Chapter Six describes and explains an economic cost comparison model between the surface truck and potential UAV Logger alternative. Also, the non-monetary costs and benefits are discussed. Chapter Seven applies the cost comparison model to three case studies that represent potential markets for the UAV Logger. Chapter Eight discusses the case study results and uses the current logging industry haul rates to estimate a price target for UAV Logger manufacturers. Chapter Nine concludes the thesis with a discussion of limitations and future research topics.

Chapter 2
Literature Review

2.1 Examination of Current Logging Strategies

The forestry industry in Canada is mainly found within the boreal forest eco-system which, as mentioned previously, covers 35 percent of Canada's land mass. Of this, eight percent is protected by legislation and less than one percent is harvested annually. In the provinces of Manitoba and Ontario, over 38 million hectares of forest is certified for harvest, however less than 0.4 percent is harvested annually (Natural Resources Canada, 2012).

Forest harvesting is a complex process that includes forest road construction, harvesting and log transportation. The Canadian forest industry builds approximately 15,000 kilometres of logging roads each year, half of which are temporary ice roads and unsurfaced summer roads (Wellburn, 2012).

2.1.1 The Basics of Logging Machinery

The common machinery used in forestry operations are the feller-buncher, skidder, delimber, slasher and loader. Some pieces of logging machinery combine more than one of the cutting, cleaning, sizing and moving functions. Refer to Appendix D for visuals of each machine.

The feller-buncher cuts the tree at the stump and lays the log on the ground in somewhat of an organized fashion. These machines can weigh approximately 27 tons (John Deere, 2012).

The skidder is responsible for the extraction of the logs from their cutting area to a landing or roadside for further processing. Two common types of skidders are cable-skidders and grapple skidders. Cable-skidders are advantageous when the machine cannot get close to the logs, however it requires a second operator to attach the cable to the logs, or for the operator to leave the cab to perform this operation. A grapple-skidder has a grapple claw at the end of a boom that can pick up the logs directly without human intervention. However, this skidder must be able to get in close proximity to the logs. The skidders drag the felled trees to a landing or roadside. These machines weigh approximately 10 to 17 tons (John Deere, 2012).

The processing steps include the delimbing and slashing of the trees prior to loading and transportation. The delimber removes all the limbs from the trunk of the tree. The slasher removes the top portion and cuts the trunk to predetermined lengths. The product is sorted according to type, length and quality and subsequently loaded onto secondary transportation to the mill. This can be by truck, railway or water.

The buncher-skidder combination is suited to harvesting areas in which the lengths, quality and types of logs do not have to be kept separate. These machines are lower in initial purchase price and training costs. This combination is suitable for general logging and chipping operations.

2.1.1.1 Processor and Forwarder Machine Combination

Processors and forwarders can be used in combination for higher efficiencies and fewer road requirements in the harvest block. The processor combines the feller-buncher, delimber and slashing operations. This machine has a header attachment that cuts the stem at the stump, removes the limbs, tops the tree and cuts to predetermined lengths in a single process step. It is ideal for pre-bunching of material (Forests and Rangelands, 2012).

Commonly paired with a processor is a forwarder. A forwarder is an extraction machine that replaces the skidding operation. Logs are lifted from the forest floor with a grapple head and placed in a "basket" for transport to the roadside. This machine can also load logs directly onto haul trucks, if required.

The processor and forwarder combination is most efficient where careful selection and the separation of tree types and cut lengths is important (Swanson, 2012b). The operator training for the processor is more intensive and demanding than that of any one single 'traditional' machine. These operators require good eye-hand coordination and good mechanical skills (Levesque, 2012).

Although these two machines are higher in capital cost and potentially in salary requirements due to increased training and specialization, the trade-off is lower fuel costs versus increased utilization of the whole tree (Ponsse, 2011). The cost to bring the product roadside is comparable between the processor-forwarder combination and the process using the multiple traditional machines (Levesque, 2012).

The processor and forwarder combination require fewer logging roads. The higher machine costs are therefore offset by the decrease in cost of the logging road network. The forwarder normally moves the logs distances greater than 600 meters, while skidding operations normally restrict their distances to 400 meters for full tree and between 500 and 800 meters for chipping operations (Forester B, 2012).

Other advantages to this logging machine combination include lower forest regeneration costs, fewer machines on-site and minimal or no slash disposal issues. There can be a gain of 20 percent more saw logs than with the other common logging methods (Levesque, 2012).

2.1.2 Logging Methods and Strategies

The type of logging method depends on the terrain, tree species and value of the lumber. Outlined below are three types of logging: traditional surface logging methods, helicopter logging and cable-logging, with an extension into the method of cable-balloon logging.

2.1.2.1 Traditional Surface Logging

The different traditional strategies for logging within a cut block depend on the end-product of the logs, the area's restrictions and conservation requirements. The common surface logging methods are as follows:

A) Tree-length logging:

Trees are felled, delimbed and topped in the cut block. The logs are then transported to a landing where they are cut to length and loaded onto a truck. An advantage of this method is that the slash remains on the forest floor which assists with soil and nutrient retention.

B) Full-tree logging:

The trees are felled and transported to a roadside or landing with the limbs and tree top intact. Further processing work is then performed and slash piles are accumulated. All parts of the tree are used in this method; the limbs and top are used for other by-products, such as hog fuel[1] or wood chips.

C) Chipping:

Chipping operations can be performed at roadside, on landings, or at the mill. When chipped in the harvest block, the trees are skidded to a landing for the chipping

[1] Hog fuel, short for 'hogged fuel', is a bio-energy made from wood residues and may include sawdust, planer shavings and coarsely ground pieces of bark and wood.

operation. Truckloads of chips are transported off the site. Chipping at the mill may incur higher transportation costs.

D) Cut-to-Length:

In cut-to-length (CTL) harvesting, the felling and processing steps occur at the stump. The processor and forwarder machine combination is widely used for CTL logging. Its advantages include less soil disturbance and a higher retention of nutrients because the limbs and tops are left on the forest floor. In addition, the wood is cleaner because the logs are not dragged from the cut site.

CTL operations can yield several different types of products, such as saw logs, lathe logs, small diameter roundwood and pulpwood (Ponsse, 2011). European companies utilize CTL as their primary logging method, while North America relies on the full-tree and tree-length methods.

The choice to use CTL versus other methods depends on the market demand. For commodity pulp and oriented-strand-board (OSB) markets, the alternative logging methods are acceptable because the high value does not necessarily have to be maintained outside the harvest block.

2.1.2.2 Helicopter Logging

Conventional helicopter logging is the most common aerial logging system. It is used to move groupings of logs short distances, from the cut block to a landing. A second type of heli-logging is single stem extraction, where the quality of the stem is more important than the quantity. Once the stem has been selected and de-limbed, a certified faller cuts it precisely so that it remains standing. The helicopter operator can break off the standing stem and fly the log to a landing site (Alternative Forest, 2005).

Helicopter logging creates the least amount of forest floor disturbance, however it carries high cost because of the specialized equipment and logging crew required, including trained heli-logging pilots. There is a high sensitivity to several weather conditions including low visibility, excessive winds and cold temperatures. Traditionally, helicopter logging is performed in mountainous or steep terrain.

Helicopter logging is profitable when the forest products are of high value and have significant volumes (Rauscher, n.d.). Conventional heli-logging reduces, or eliminates, the need for ground infrastructure and minimizes ecological effects. Standing stem harvesting pays because less of the stem is shattered from falling. Hence, it is suited for valuable tree species, such as the red cedar.

The focus of this research paper is in the province of Manitoba and northwestern Ontario where the terrain is essentially flat. Heli-logging is not included further in this thesis because it is not used for tree species like spruce, or jack pine, and cannot be justified economically.

2.1.2.3 Cable-Logging and Cable-Balloon Logging

Cable systems are a simpler and lower cost form of aerial logging than heli-logging, but appear to carry higher costs than traditional surface logging methods. Cable systems use winching machines, or yarders, and heavy wire rope to move forest products short distances, typically up to 300 meters (Wellburn, 2012). Essentially, the wire rope is cast down the hill and hooked to a log. There are also skyline cable systems where the wire rope is suspended in the air between towers and moves the product using a carriage between the cutting area and the landing (Rauscher, n.d.).

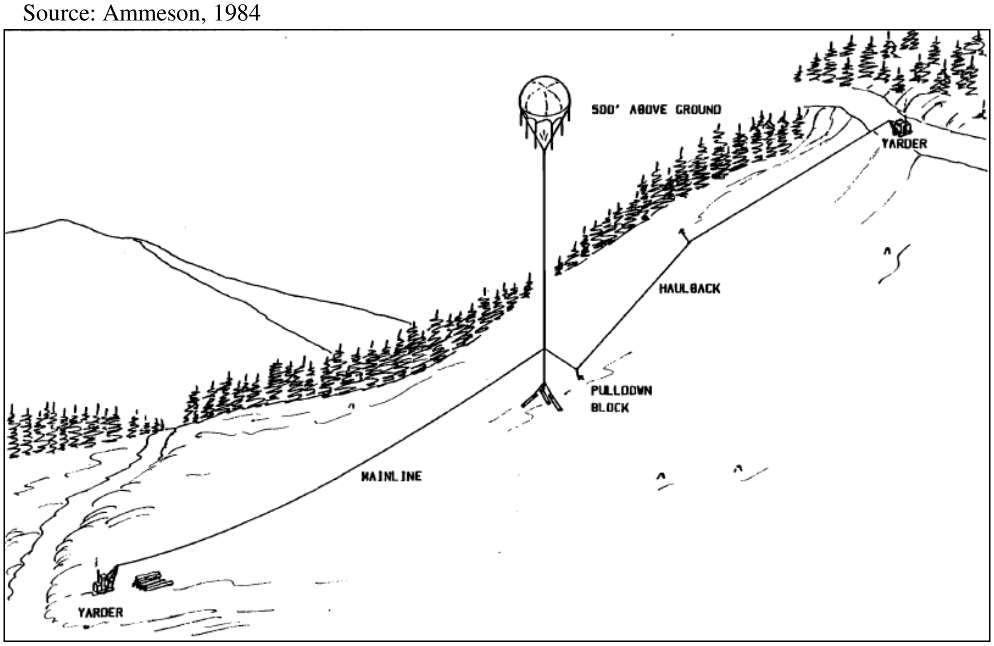
A further extension of cable-logging is cable-balloon logging where lift of the payload is derived from an envelope filled with helium (Wenger, 1984). There are three basic configurations of this system: haulback, inverted skyline and yo-yo (Wenger, 1984).

The haulback method uses a mainline to pull the balloon to the landing. Yarding distances can be approximately 1000 meters.

The inverted skyline method uses a balloon envelope attached to a carriage with a cable used to lift the payload. This system uses a mainline to move the balloon and logs, whereas the lift is from the balloon itself. Yarding for this system may exceed 1500 meters.

The yo-yo configuration uses two yarders, as seen in figure 1, one at the top of the unit and one at the bottom and can handle yarding distances of up to 2100 meters.

Figure 1: Yo-yo configuration: Cable-Balloon Logging
Source: Ammeson, 1984



Like heli-logging systems, cable balloon logging is sensitive to certain weather conditions. It is documented that winds in excess of 45 to 55 kilometres per hour cause problems with the control of the balloon during pickup and landing (Wenger, 1984). In addition to the landing area for the timber, other requirements for this logging system include an area for inflation, storage and deflation, as well as a transfer vehicle.

The disadvantage to the cable systems and cable-balloon systems is the need to create clearings to set up the yarders, associated anchors and equipment to create a cable road. Crews are required to move the cable road as the harvest progresses. Cable-balloon logging has an extra disadvantage because the tethered balloons are vulnerable to weather damage should a storm arise.

Research in cable-balloon logging was done at the Oregon State University during the 1970s and 1980s. They compared different systems' production rates using time study analysis. James Ammeson (1984) analysed the pendulum balloon logging system and the conventional version. He concluded that the pendulum option is more efficient for downhill logging applications with yarding requirements of less than 457 metres (Ammeson, 1984). However, he also observed the sensitivity along the inhaul portion to balloon positioning and the difficult requirement of close coordination of the lifting line, mainline and the haulback line in order to use the pendulum concept most effectively.

In 1978, Richard Curtis investigated production rates of several logging extraction systems. He opened his research by stating (1978, p.1), "the need to harvest timber from more difficult terrain has called for the use of more advanced logging systems". His study concluded that the yo-yo balloon configuration has lower total operation delays than the helicopter option and the short-span skyline systems. He also concluded that the balloon logging configurations offer longer yarding distances than the traditional cable logging methods but fewer logs yarded per productive hour.

Curtis's analysis (1978) showed that balloon logging could be competitive with conventional cable systems despite balloon logging's fewer turns yarded per hour and a lower volume of pieces yarded. The net merchantable volume per hour is higher with balloon logging than conventional cable systems because less damage is done to the logs during transport. The ratio of merchantable logs yarded versus the total number of logs yarded per day is 1.0 only for balloon logging and a mean range of 0.6 to 0.9 for both the traditional cable logging and for helicopter logging (Curtis, 1978, p.39).

Russia, which has large tracts of boreal forest in Siberia, is active in the investigation of alternative logging transport. Abusov (1999) states that in Far Eastern Russia, all of the areas beside main roads or rail lines have been deforested and that the remaining woodlands of value are located in difficult to access areas or in prohibited areas. Therefore, conventional logging techniques are unable to be used. The option to make partial cuts rather than the full clear-cut process is required. Cable-balloon logging is the focus of Abusov's (1999) investigation. Their attempt with helicopter logging was unsuccessful because of the high fuel costs, service costs and increased insecurity of the work.

2.1.3 Harvest Block Selection in the Boreal Forest

Choosing a harvest block requires analysis and data input, such as tree species, forest stand age and wildlife habitat. Forest management modelling programs are used to develop tactics that maximize the allowable sustainable harvest. The users of such programs set the criteria for harvest and the computer program picks the stands. Constraints must be added to these models to accommodate the reality of the lack of infrastructure in remote areas. This results in the selection of a smaller harvest block (Swanson, 2012b).

For example, the Strategic Forest Management Model (SFMM) is used in Ontario for the planning of future cut blocks and harvest strategy. This non-spatial forest modeling tool aides the users to consider the large forested areas at a broad, strategic level (Paragon, 2012). This analysis considers the tree size (ie. age), the total area in consideration, the types of eco-systems and frequency of historical cuts in the area. Taking all input in combination, the block size and mix of trees available is determined.

2.1.4 Cost to 'Bring Logs Roadside' and Stumpage Fees

In this research, the costs to 'bring logs roadside' from inside the cut block and the stumpage fees or timber dues are mentioned but not used in this thesis analysis. The assumption is that the harvesting methods are not affected by the method of transport[2].

The cost to 'bring logs roadside' is approximately $22.00 per cubic meter. This includes the machines being brought to the site and all processing and loading steps. A breakdown of costs associated with each harvesting process step can be found in table 1. The costs of skidding and loading are approximately 25 percent of the total harvesting cost. This $5.00 per cubic meter is the maximum that could be added to the transport cost for conventional methods.

Table 1: Harvesting process steps and approximate costs
Source: Forester B, 2012

Process Step	Cost per cubic meter ($/m^3)
Felling	$4.00
Skidding	$3.50
Delimbing	$4.50
Slashing	$4.50
Loading	$1.50
Overhead, Allowances, Misc	$4.00 approx
Total	**$22.00**

Stumpage fees are paid by the logger to the landowner for the right of harvesting the standing timber. In Manitoba, the timber dues are determined monthly by reference

[2] This is a conservative assumption. The length and cost of the logging road will be traded off against the cost of skidding the trees for collection. Aerial logging could pick up piles of payload wherever required.

to the commodity prices published in the *Pulp and Paper Weekly (RISI)* and *Random Lengths* (Manitoba Conservation Forestry Branch, 2012e). In Ontario, the stumpage fees are also calculated on a monthly basis and the dues are shared between the Consolidated Revenue Fund and the Renewal Trust Fund (Ontario Ministry of Natural Resources, 2012e). If the harvesting area is not found on Crown land, the landowner sets and collects the stumpage fee. Normally, their fee is in the same range as what the Crown charges.

2.1.5 Timing of Log Haul and Holding Inventory

Some operations and contractors choose to build inventory in the forest, others at their mill. The end-product or use of the logs at the mill dictates inventory location. For mill operations where freshness of the product is not required, or in fact not preferred, leaving the product in the bush and deferring the cost of transportation is common. Wood inventoried or seasoned, loses about 10 percent of it's weight through drying. Drier wood reduces haul costs because the volume per load increases. For example, Kraft paper production uses seasoned wood because the quantity of chemicals needed during the paper making process is lowered (Forester A, 2012). The raw product must be aged at least one year prior to use in production. In contrast, fresh or green wood is preferred for laminated strand lumber (LSL) production to maintain the quality of the end product. LSL is a an engineered wood product or 'composite product'. Because fresh wood is an important factor, LSL producers pay a premium to move the wood as soon as possible.

2.2 Brief History of Logging in the Manitoba and Ontario Boreal Forest

The conifer-dominated boreal forest stretches across Scandinavia, Russia, Alaska and northern Canada (Ontario Ministry of Natural Resources, 2012d). It has adapted to large-scale natural events like forest fires, wind storms and pest infestations. These disturbances affect entire stands of trees at one time and some boreal tree species, such as jack pine, require such disturbances for regeneration and growth (Ontario Ministry of Natural Resources, 2012d). The majority of the boreal forest in Canada is Crown land and is harvested in a sustainable way, with several levels of accountability, transparency and documentation.

Forest practices are regulated by the provincial natural resource authorities: Manitoba Natural Resources and the Ministry of Natural Resources in Ontario. Manitoba's forest land consists of approximately 75 percent softwood and 15 percent hardwood tree species (Manitoba Forestry, 2012d), while Ontario's forest land is composed of 56 percent softwood and 26 percent hardwood (Ontario Ministry of Natural Resources, 2012f).

Today, the majority of the logging that occurs in the Manitoba and northwestern Ontario boreal forest serves market demands of shortwood, wood chips and OSB products. Therefore, the buncher-skidder combination is widely used with the tree-length logging method (Forester A, 2011; Forester B, 2012).

Historically, local logging requirements increased in response to the demand for construction of homes and furniture. During the 1870's, the local lumber requirements quickly increased with the building of the transcontinental railway (Lakehead University, 2011; Manitoba Historic Resources Branch, 2000). Traditionally, logging patterns followed settlement patterns and transportation networks. Logging for commercial use was located near water or railways, due to the need for transportation of heavy goods and the water requirement to run the mills. In 1930, the American government passed the Smoot-Hawley bill under pressure from the American lumber manufacturers that set a duty on Canadian lumber and resulted in a decline in logging operations (Manitoba Historic Resources Branch, 2000).

Manitoba:

The Federal Government transferred control of natural resources and Crown land to the Manitoba Government in 1930 (Manitoba Conservation Forestry Branch, 2012f). It was not until the 1970's that the idea of managing the forests became an important factor to help secure a future for the timber industry. During the 1980's reforestation practices had started in an attempt to regenerate previously harvested areas and the acres lost to forest fires (Manitoba Historic Resources Branch, 2000).

To perform large scale forest harvesting in Manitoba, a Forestry Management Agreement with the provincial government must be signed. This agreement provides transparency to the company's timber harvesting plans, access management and forest renewal plans. Manitoba has three Forest Management Licences (FML). FML2, belonging to Tolko Limited, is the largest logging licence granted in Canada. It encompasses 17 percent of the province of Manitoba and includes two Provincial parks.

Recent developments have hindered the logging industry in Manitoba, such as the lowered demand for lumber in the United States. In addition, land withdrawals, mainly in the form of Treaty Land Entitlements, are on-going and are decreasing the Crown-owned land in which the industry operates.

In June 2009, the Government of Manitoba passed new legislation, Bill 3: The Forest Amendment Act (Manitoba Legislative Assembly, 2009). This Bill bans commercial timber cutting in Provincial parks and withdraws any existing timber cutting rights in Parks. The only exception to this Bill is the minimal removal of timber for forest research and also for forest fire threat reduction.

Ontario:

The allocation and licensing of timber on Crown land in Ontario is controlled by the Ontario Ministry of Natural Resources. Forest tenure can be granted as one of the following three types: sustainable forest licenses (SFL), forest resources licenses (FRL) and supply agreements. SFLs are long-term licences that are issued for up to 20 years and includes responsibility for sustainable forest management practices. FRLs are for smaller geographical areas than SFLs and are issued for up to five years. FRLs overlap SFL areas and only include the responsibility for harvesting operations and associated road build. Forest management activities remain with the SFL holder. There are approximately 40 SFLs granted in Ontario (Ontario Ministry of Natural Resources, 2012a).

The policy and legal framework for forest management on Crown land in Ontario is provided through the Crown Forest Sustainability Act (CFSA) and the Environmental Assessment (EA Act) (Ontario Ministry of Natural Resources, 2012g). Forest management plans provide the appropriate transparency and consultation with the public and Aboriginal communities.

2.2.1 Accessibility to Forest Lands

The northern parts of Manitoba and Ontario are largely undeveloped and lack basic road infrastructure. The majority of the population lives in the southern third of each province and is supported by existing road networks. Limited accessibility in the northern regions of Manitoba and northwest Ontario is a major challenge for communities and industries alike. Manitoba's northern region is comprised of 67 percent of the total provincial land mass, with a population density of 0.18 people per square kilometre (Statistics Canada, 2012). Ontario's northwest region covers 44 percent of total provincial land mass and has a population density 0.2 people per square kilometre (Statistics Canada, 2012). The terrain is categorized as the Canadian Shield, tundra and permafrost. This difficult terrain limits farming, as well as road infrastructure, even though there are numerous communities that exist within this geographical area.

The extensive road networks in the more populated areas of the province enable the logging process and assist with keeping transportation costs low because of the minimal need for additional road build and maintenance. Also, harvesting operations in these areas can use past logging roads that were not fully decommissioned. Due to these two factors, the cost for hauling log products is lower in the southern half than in the northern portion of the provinces where road build confronts muskeg, marshland and intermittent permafrost.

Large northern portions of Manitoba and northwestern Ontario are not logged. The current availability of suitable forest areas is sufficient to meet the demand of the markets served. The need to access the more difficult areas will result in higher transportation costs. Traditional surface networks may not be the most efficient or cost effective option because of the cost of building all-weather roads.

2.2.2 Recent Developments

Two recent developments have responded to the need for balance between the social, economic and environmental issues in Canada's boreal forest. Established in 2003, the Canadian Boreal Initiative (CBI) brings together governmental entities, First

Nations, industry and scientists. The CBI is a national convener for conservation and its mandate is to "link science, policy and conservation solutions across Canada's Boreal Forest" (2003).

The Canadian Boreal Forest Agreement (CBFA), signed on May 18, 2010, further addresses the challenge of conflicting views. The CBFA is a "unique collaboration between 21 major Canadian forest companies and nine leading environmental organizations"(2010). Participants in this agreement include Tolko Industries Limited, Weyerhaeuser Company Limited, the CBI, Canadian Parks and Wilderness Society (CPAWS) and Greenpeace (CBFA, 2010).

The CBFA states six main goals. The fourth goal is to reduce the greenhouse gas (GHG) emissions along the full forest products value chain. This goal includes the joint promotion and advancement of solutions to reduce the emissions and increase use of biomass and bioproducts.

The provinces of Manitoba and Ontario are home to 22 percent of the threatened Woodland caribou population. Immediate action from the CBFA (2010) was the suspension of log harvesting and logging road build in 29 million hectares of the boreal forest to allow for "intensive caribou protection planning". This suspension was in effect from April 1, 2009 until March 31, 2012.

These two developments were created so all users of the boreal forest can maintain a protected, sustainably managed forest while supporting a strong, competitive forest industry.

2.3 Introduction to Airships

An airship, also known as a dirigible, is a buoyant aircraft that can be propelled and steered through the air. This "lighter-than-air" (LTA) technology stays aloft by having a large cavity, or envelope, filled with gas of lesser density than the surrounding atmosphere. Many of the first airships were filled with hydrogen, however helium is the lifting gas of choice today because the majority of the designs are manned and hydrogen is flammable.

The first vehicle to float through the air was a hot air balloon, as the Montgolfier brothers demonstrated in 1783. In 1852, Henri Gifford installed a steam engine and propeller on a balloon. Keeping the aircraft aloft was a challenge because of the power to weight ratio of the steam engine. The Tissandier brothers introduced the installation of an electric motor in 1883, but they were also too heavy (Flynn, 1999).

These significant landmarks led to what may be the most memorable manufacturer in airship history; Luftschiffbau Zeppelin GmbH introduced the Zeppelin group of airships. In July 1900, Count Ferdinand von Zeppelin successfully demonstrated airship flight (Flynn, 1999), which not only marked what many call the "Golden Age of Airships" (Payne, 1991, p.187) but would also have the Zeppelin company lead the way with a highly efficient rigid airship design. Still today the term 'zeppelin' is used for airships despite the lack of association with the German company. As seen in figure 2, this design's main components are comprised of a cylindrical metal frame, fabric covered hull, large tail fins for stability and crew pods that hang beneath the hull.

Figure 2: The Graf Zeppelin
Source: www.pathe-scholen.nl

Airships were used for passenger transport and for military purposes. Most non-American airships were filled with hydrogen prior to World War II, because the United States had a monopoly on the helium supply and prohibited exports. In the late 1920s and 1930s, several successful transatlantic passenger flights were performed by Zeppelin airships.

These flights were halted on May 6, 1937, when the Hindenburg accident occurred at Lakehurst, New Jersey. Of the 97 people on board, 61 survived (Payne, 1991). Albeit tragic, rather than the death toll it was the betrayed confidence that sealed the fate of the airship. Reflecting upon the R101 airship crash that occurred in 1930, Lee Payne (1991, p.207) writes,

> "More men had died in ship sinkings and mine explosions than aboard the R101, yet ships still sailed and miners still dug in the earth. What was different about the airships?"

What buries a technology is not a betrayal of confidence, rather it is the introduction of a better alternative. In this case, it was the airplane that had become an economically viable alternative form of air transport (Payne, 1991).

During the second World War, the combined combatants built 500,000 airplanes. This technology benefited from billions of dollars of research and testing. Airplanes evolved from vehicles with a questionable safety record to high altitude bombers and jet engines. Soon after the war, civilian versions were produced and more investment proceeded as a result of the “cold war” competition.

2.3.1 Common Advantages of an Airship

The acceptance of the airplane as an alternative in the 1950s forced the airship and its recent failings to take a backseat in the air transport industry. The airplane demonstrated its ability for high speeds and flexible steering, however it was also accompanied by a requirement for large amounts of fuel and significant ground-handling infrastructure in every landing location. This includes airports, runways and all support equipment and personnel.

In comparison, airships utilize minimal fuel due to the lift from the gas and it is a relatively clean form of transport with low noise pollution and low exhaust gas emissions. Along with these economic and environmental advantages, airships require minimal ground handling equipment and are not limited by barriers of topography[3]. Airships eliminate the need for a runway and supporting equipment at every landing site. The only unique infrastructure need is a hangar, for the initial build and maintenance. Generally speaking, an airship hangar functions like a dry dock for ocean shipping. Ground-handling requirements are discussed further in Chapter Nine.

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[3] With the exception of mountainous terrain. Airships must trade off altitude for payload. Most airships operate below 1500 meters.

Airships have a high payload lift capacity and are capable of moving large, indivisible loads. Its capability to operate year-round could assist with economic development opportunities in remote areas that lack all-weather road transport. Reducing the cost of transportation to and from isolated communities could open access to better education, health services and opportunities for employment and earning capability.

Indirect advantages of using an airship come from the mitigation of several negative externalities. Road, port and air congestion can be alleviated by moving more cargo through the air with a cleaner transportation alternative. This would result in fewer trucks on the roads, ease air congestion by flying at a different altitude and reduce the number of ships arriving at the ports. In addition, door-to-door delivery of large, indivisible loads would be possible, which would also help avoid any weight restrictions on roads or of trucks and eliminate the frustration of attempting to manoeuvre a large or long load among streets designed for smaller vehicles. Lastly, climate change can potentially be mitigated, due to the environmental advantages of the airship.

2.3.2 Airship Designs

The four airship designs are rigid, non-rigid, semi-rigid and hybrid.

1) Rigid:

The rigid design consists of an internal framework that allows the envelope to retain its shape without depending on the pressure of the lifting gas. This framework houses the fuel, living and working space and the lifting gas cells. The framework is intricate in both its design and construction in order to achieve optimum load distribution.

2) Non- Rigid:

The non-rigid design is more commonly known as a blimp and is the simplest design of an airship. It consists of an envelope and a gondola. The envelope holds the lifting gas and the shape of the vehicle is dependent on the pressure of the gas, supplemented by adjustable internal ballonets filled with air. The ballonet(s) is used to maintain the external shape during ascent and descent and helps control the unit's levelness during the flight. The gondola contains the engine, the propulsion mechanism, the fuel, the cockpit, and the facilities for the crew, passengers and cargo (Airship Association, 2012).

3) Semi- Rigid:

The semi-rigid design contains components from the two configurations discussed previously. From the non-rigid design, the semi-rigid airship relies on the pressure of the lifting gas in the envelope to maintain its shape. It also incorporates a rigid keel, running the length of the ship which distributes the suspension load. Most designs have the engines and the gondola suspended from the keel. This type of build is commonly used for heavy lift cargo movement, because of the ability to better distribute the weight and increase efficiency of use (Airship Association, 2012). A modern semi-rigid is the Zeppelin NT that was introduced in 2000. This airship has a light internal frame that carries half the stresses and a pressurized, light-weight envelope that carries the balance of the load.

4) Hybrid:

A fourth classification is the hybrid design where the idea is to add aerodynamic lift principles, derived from the heavier-then-air industry (ie. airplanes and helicopters), to the LTA concept of aerostatic lift. Essentially, it attempts to increase manoeuvrability and lift by supplementing an airship's design with aerodynamic thrust (Airship Association, 2012). An example is the Aereon 26 in the early 1970s. It had a deltoid shape and designed to move various tonnages at various speeds without the trim requirements.

2.3.3 Current Status of Development

Airship technology was essentially abandoned for passenger transport following the Hindenburg incident. Modestly funded research and development was renewed in the mid-1970s following the oil crisis that began the upward surge of energy prices. These efforts focused on airships for advertising and surveillance uses because finances permitted only small vehicles. Currently, more than a dozen Tier 1 companies are actively designing and building prototypes or full units. In addition, Tier 2 companies concentrate on individual design aspects of the airship, such as the envelope material. Many components used in airships are identical to those used in other aircraft, such as the engines, avionics and autopilot. Although modifications may be required, no technical or material barriers preclude the development of modern airships.

Airships are most commonly associated with advertising and television camera platforms at major sporting events. With the depleting supply of fossil fuel, combined with increased requirements to lower GHG emissions to prevent climate change, many potential uses for the airship technology are recognized. These applications include eco-tourism, indoor and outdoor surveillance activities, and data collection and transmission. Further, airships have found a role in persistent presence for constant military surveillance or special events like the Olympic Games.

Recently, the U.S military awarded two contracts for large surveillance airships to operate at 20,000 feet. In 2010, Northrop Grumman in partnership with Hybrid Air Vehicles Limited in the United Kingdom, received a $517 million contract to produce three Long Endurance Multi-Intelligence Vehicles (LEMV) (Northrop Grumman, 2010). In 2011, a $211 million contract was awarded to MAV-6 to produce a conventional airship for similar purposes (Eshel, 2011). In addition, the United States Department of Defense DARPA (Defense Advanced Research Projects Agency) is funding a cargo airship demonstrator, the Aeroscraft, by Worldwide Aeros Corporation (Pevzner, 2008). The Aeroscraft is a rigid variable buoyancy air vehicle that is designed to have an internal ballast control system, vertical takeoff and landing (VTOL) and hovering capabilities at max payload (Aeros, 2011).

A reoccurring topic of discussion in Canada is access to isolated communities that depend on ice road networks affected by climate change. For the most part, the discussion evolves around the apparent need for an all-weather road network to be built to many of these communities. There have been studies proposing airships as an alternative (Prentice and Thomson, 2009). The use of a heavy-lift or cargo lift airship may prove to be the appropriate alternative which would lower the reliance on the ice road network and potentially translate into lower freight costs. Other applications may include mining and pipeline projects, where the supplies and their product can be moved to and from isolated project sites. Further, by minimizing the road network required to access the area, the amount of stranded assets would be minimized or eliminated once the resource of interest has been fully extracted.

2.4 Unmanned Aerial Vehicles

Unmanned aerial vehicles are machines that are controlled from a remote location or fly autonomously following a pre-programmed flight path. UAVs are used largely for military applications, more specifically for surveillance, reconnaissance and attack missions. With the concern for human loss, this technology was developed for use in hostile situations and often mimics the resemblance of a helicopter or jet aircraft. Several civil applications use this technology including commercial aerial surveillance, scientific research, search and rescue and non-military security work.

2.4.1 Regulatory Bodies

The majority of the UAVs in North America are used by the United States of America (USA) Military. The USA national regulatory body is the Federal Aviation Administration (FAA), and they are currently developing new policies, procedures and approval processes to address the increasing civil market for Unmanned Aircraft Systems (UAS) and requests for civilian operators (Federal Aviation Administration, n.d.).

UAS is a term emphasizing all components required to effectively operate the UAV. A typical UAS includes the ground control system, the control link, other support equipment and of course, the unmanned aircraft itself. Currently, all UASs must apply for a Special Airworthiness Certificate – Experimental Category, which requires the UAS to be safely demonstrated in a designated testing area and must cause no harm to the public (Federal Aviation Administration, n.d.).

Transport Canada (TC) has the responsibility to regulate civil UAV conduct in Canada. The Canadian Aviation Regulations (CAR) state that “a UAV is a power driven aircraft, other than a model aircraft, that is operated without a flight crew member on board” (Transport Canada, 2012). Transport Canada (2012) requires that any civil UAV “must meet the ‘equivalent’ levels of safety as manned aircraft” and that any UAV operator must have a Special Flight Operation Certificate (SFOC). The intention of the

SFOC is to ensure public safety and that of other users of the airspace. The information to be submitted with an application for the SFOC is outlined in Section 623.65(d) of the CARs and includes such requirements as the boundaries of the operation, the flight altitudes, a security plan for all areas to be traversed by this UAV in order to ensure no hazard is created and an emergency contingency plan in case of disaster (Transport Canada, 2012).

In addition to the SFOC, the risks of public liability must be covered with the subscription of the appropriate level of liability insurance. According to Section 606.02 of the CARs, an aircraft that has a maximum take-off weight of between 5,670 kilograms and 34,020 kilograms must subscribe for insurance that is not less than $2,000,000 (Transport Canada, 2012).

2.5 Airships for Logging Transport

There have been attempts to build a hybrid airship for use in the heli-logging industry to reduce costs and increase the economic radius of operations. Two examples are the Piasecki PA-97 Helistat (Holden, n.d.) and the Cyclocrane (Dunbar, 2008).

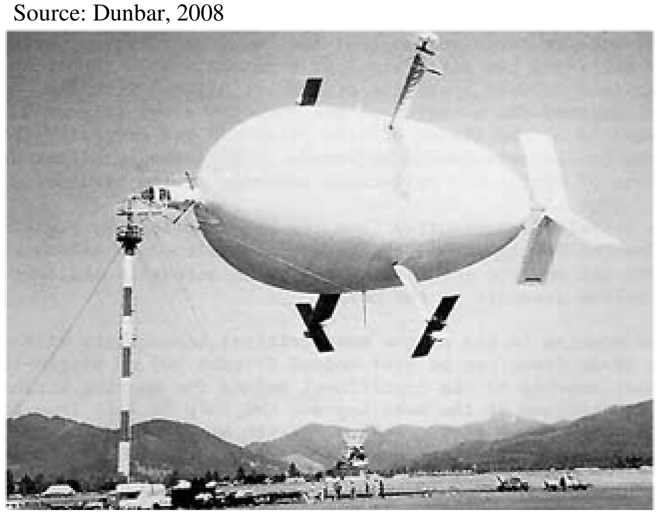
Invented by Frank Piasecki in the late 1970s, the Helistat attempted to combine the static lift of an airship with the dynamic lift of a helicopter. Seen in figure 3, this hybrid airship was filled with helium, had an aluminum open truss structure and four Sikorsky helicopters.

Designed for the specific function of lifting 25 tons of timber from inaccessible forest terrain, this hybrid airship was demonstrated in 1986 but was destroyed in an accident. Strong winds and helicopter ground resonance created instability that led to unbalanced lift leaving the helicopters to break free and crash (Holden, n.d.).

Figure 3: Piasecki PA-97 Helistat
Source: Holden, n.d.

The Cyclocrane was invented as a heavy load lifter capable of lifting up to two tonnes of felled timber from remote sites (Dunbar, 2008). This semi-rigid helium aerostat, seen in figure 4, was intended for the British Columbia logging industry and initially funded by five Canadian logging companies. In the 1980s, its proof of concept was used for 22 test missions. The drop in fuel prices with the collapse of the oil market in 1986 and budget cutbacks at the end of the Cold War both led to the abandonment of the Cyclocrane (Nicholson, 2000; Dunbar, 2008).

Figure 4: The Cyclocrane
Source: Dunbar, 2008



2.6 Academic Research

2.6.1 UAVs and Forestry

A search through high-impact forestry academic journals, such as the Canadian Journal of Forestry Research and Forest Ecology and Management, show few examples of research using UAVs in the forestry area. Several research articles discuss the use of NASA UAVs as tools for forest fire-fighting. Outfitted with thermal sensory equipment, the UAVs locate the heart of the fire for ground fire-fighting crews to extinguish (Johnson, 2008; Morris, 2006; Ollero, Martinez-de-Dios and Merino, 2006).

Other forestry research includes the use of UAVs for small-scale wildlife survey applications (Chabot, 2009) and to obtain various types of resource data of forest land through aerial photographic techniques (Draeger, 1967). Gundlach (1999), associated with the Virginia Polytechnic Institute and State University, designed a electric propulsion UAV to carry a 26 pound radiometer over the forest canopy to quantify various concentrations of forest data, including cellulose, sugar and lignin, for evaluation and planning purposes.

A trial design of a one-ton crane robot using VTOL technology was presented by a Tokyo research team at an American Institute of Aeronautics and Astronautics (AIAA) conference in 2006. The “CraneRobo” design is for transporting forest residues left behind from harvesting operations in steep Japanese mountain areas (Onda, et al., 2006).

Otherwise, evidence of research that involves UAV as heavy-lift airships in the area of forestry is not found and leads to the conclusion that the area is unexplored.

2.6.2 Forest Roads and Operations

Academic research of forest roads and forestry operations centers around the analysis and optimization of road planning and alternative management of forest areas. The majority of this research speaks to the spacing or planning function of roads to minimize their disturbance to the forest area. The effects of roads on the habitat and eco-tourism is prevalent in academic journals, however no alternative or suggestion to alleviate these effects is made. The negative externalities of roads is clearly stated but not of an alternative that would sustain the forest industry's economic activity and minimize ecological effects.

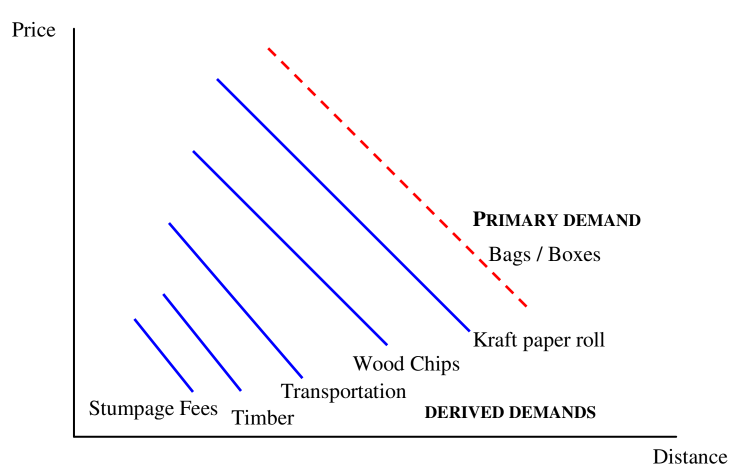
Examples of this research includes a trade-off analysis between skidding and road construction costs (Chung, Stueckelberger, Aruga and Cundy, 2008), tools to optimize the routing of forwarders (Flisberg, Forsberg and Rönnqvist, 2007) and the opportunity for backhauls in forest transportation (Carlsson and Rönnqvist, 2007). Engel, Wegener and Lange (2011) perform comparative research of the GHG levels for three different methods of harvesting spruce. They conclude that consideration should be given to the "use of more horses in forestry work in combination with forwarders" (Engel, Wegener and Lange, 2011, p.8).

Chapter 3
Economics of the Cost Analysis

3.1 Demand: Transportation as a Derived Demand

Derived demand moves upwards through the supply chain and depends on the primary demand of the end-product. For example, the primary demand for paper bags, cardboard boxes and OSB construction panels drives the demand for each step in the process from harvesting the timber and transportation, to end-product production. Figure 5 shows several different derived demands for multi-wall bags and boxes made from Kraft paper. The supply chain includes the harvesting and transportation of the logs, its breakdown into wood chips and subsequent transformation into Kraft paper rolls. Depending on the customers' specifications, the Kraft paper is made into the end-product.

Figure 5: Derived Demand Curves of Kraft Paper Bags



The price difference between the raw material (i.e. timber) and the finished good (i.e. bags) is the compensation for all processing activities in the supply chain, including transportation.

As a derived demand, transportation can be elastic or inelastic depending on the final demand. The elasticity of the derived demand follows the primary demand, such that if one is elastic then the other is too. The other determinant of the elasticity of the derived demand is its share of the total cost of the primary product. The greater the share of the final price, the more elastic the derived demand.

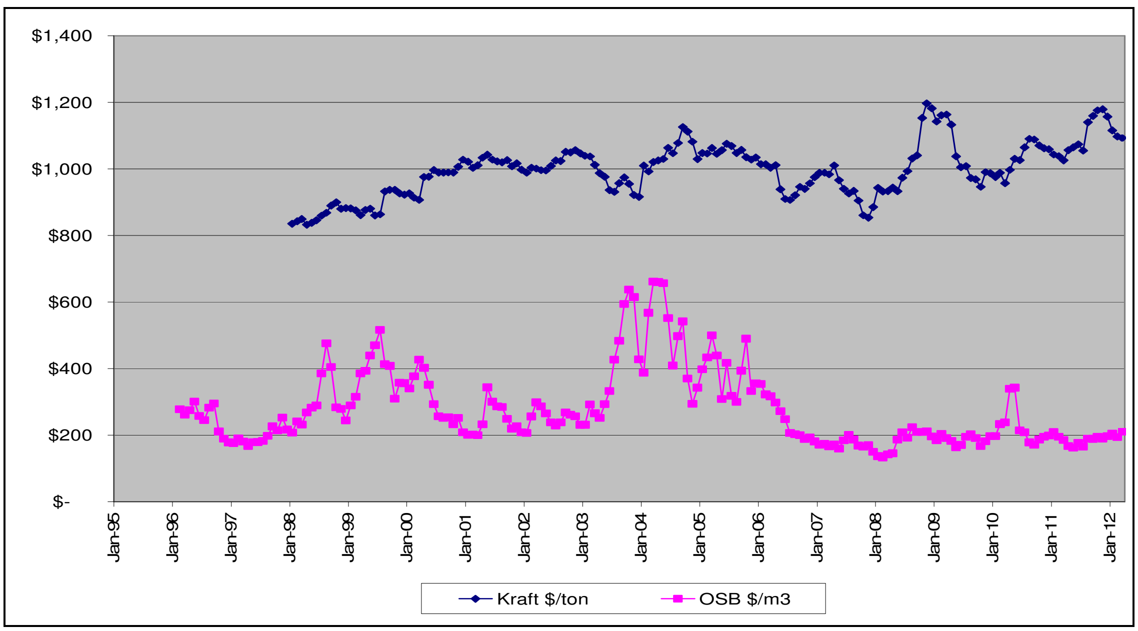
The demand for transportation in the logging industry is generally inelastic because of the lack of transportation alternatives. The primary demand may have more elasticity than the derived demand for transportation because of the higher number of substitutes in the market. Plastic bags can replace paper bags, metal studs can replace wooden 2x4s and aluminum doors can replace wood. In contrast, there are fewer options for the transportation of logs between the harvest area and mill. Consequently, the market for transportation may gain more from a shift in final demand than from a price change.

3.1.1 Current Wood Product Market Conditions

Leslie Preston (2011, p.1) expresses that "patience is a virtue in this beleaguered sector" and predicts an increase in lumber demand in 2013. The demand from China has increased Canada's softwood lumber exports and has assisted in maintaining an economic viability within the industry after several factors negatively affected the market. This overseas demand has allowed the industry to remain afloat in the medium-term (Preston, 2011). A recovery of US homebuilding is crucial to Canada's lumber industry and the low level of housing starts is insufficient to meet the replacement plus normal market growth.

The two types of wood products referenced in this research are Kraft paper products and OSB composite products. Seen in figure 6, current market conditions for the Kraft paper product are economically favourable and display a positive trend. This product is used as cardboard paper and to manufacture packaging material for agricultural (i.e. seed) and construction (i.e. cement) needs. Although there is a price drop around the year 2008, the Kraft paper market has been able to recover. The average price for March 2012 is $1,093 per ton. Factors that may affect the market price of Kraft paper are stimulus programs, currency exchange rates, the decline of paper newspapers and the increase in recycling.

Figure 6: Market price trend of Kraft Paper and OSB (CDN$) (1996 – 2012)
Source: Manitoba Conservation and Forestry Branch, 2012



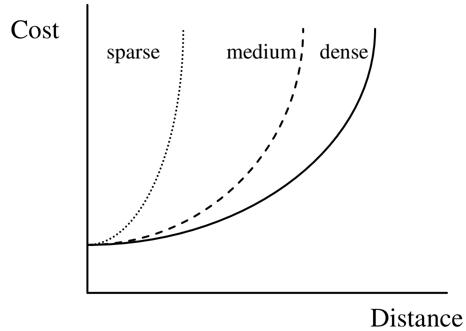
Also seen in figure 6 is a data line for the OSB price per cubic meter. OSB is largely used for residential construction and has maintained a relatively constant price level since 2006. The average price for March 2012 is $210 per cubic meter. The flat price trend does not show an expected improvement in market prices.

The peak of the mountain pine-beetle infestation in British Columbia occurring in 2005 (British Columbia Ministry of Forests and Range, 2007), the introduction of the Canada – US softwood lumber agreement and the housing crash beginning in 2006, all contributed to the OSB market price drop. Normally the low prices would curtail production, but climate change contributed to an opposite effect. With the increase in mountain pine-beetle infected areas, the allowable annual cut volumes have been increased. The logic was to recover economic value from attacked timber and to shorten the timeline to wood regeneration (British Columbia Ministry of Forests and Range, 2011). This increased the supply of wood and negatively affected the market price.

3.2 Supply: Economic Feasibility of a Harvest Block

The harvest volume of each cut block directly affects the associated haul rate. Figure 7 illustrates that a greater distance can be traveled, or road built, with denser resource availability. With distances being equal a denser harvest block will lower the haul rate by allowing the cost of road construction and maintenance to be spread across more cubic meters of payload.

Figure 7: Effect of varied resource availability on cost of collection

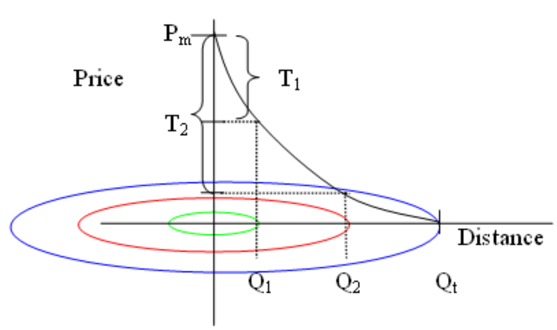


Transportation costs associated with a harvest block determine its value or economic viability. The demand and market price dictate transportation cost limits and guide harvest block selection based on current road networks and potential required road build. With the restriction of low haul rates long transportation distances are avoided, as are areas that require high capital road build.

The economic feasibility of a harvest block depends on the current market price, its accessibility and transportation haul rates. Areas with existing road infrastructure have lower haul rates for logs than undeveloped areas that require road access through difficult terrain and water crossings.

Using the location theory, it can be shown how the restriction of haul rates determines viable cut-blocks. This theory is based on the price difference between the market price and the site price of the good before transportation. Figure 8 demonstrates the location theory for two haul rates. With P_m being the price at the mill with no transportation costs, the curve shows how an increase in afforded haul-cost can determine the distance to economical cut blocks. Q_t represents the maximum distance before costs exceed revenue.

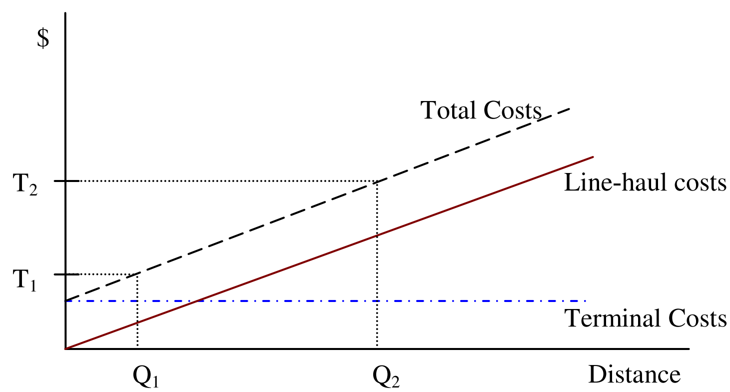
Figure 8: Location theory representation for two transportation rates (T)



At a haul rate of T_1, transportation can remain economically viable up to a distance of Q_1. With the ability to afford a higher haul rate (T_2), the distance to economical harvest areas increases to Q_2. With higher transportation costs and a fixed market price, there are fewer dollars left to cover other costs and for profit.

An alternative method of showing the effect of haul rates is the division between terminal and line-haul costs. The total cost curve is the sum of the fixed costs or terminal costs and the variable line-haul costs. Figure 9 shows the distance to, or the limitations of, economically viable harvest areas. With an increased affordability of transportation (T_2), a longer haul distance or the option to build access roads is viable (Q_2).

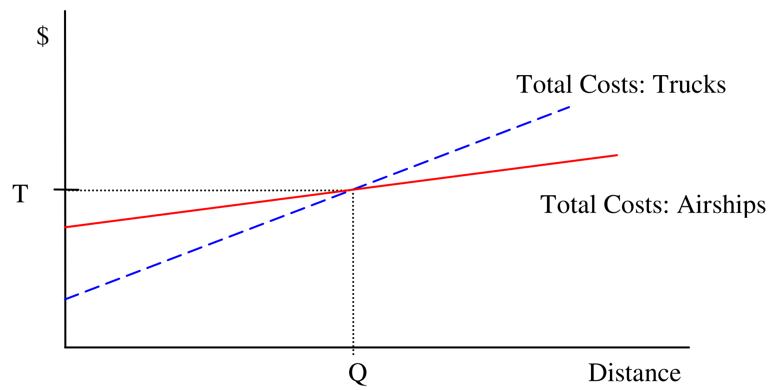
Figure 9: Effect of different transportation costs (T) on distance



The restriction of how much a company can afford to spend on transportation directly affects their area of operation. Limiting transportation rates to low levels essentially eliminates harvest areas further from the mill. Cut blocks that require road build for access are low priorities during depressed price periods. At higher product prices the forest industry can afford higher haul rates, additional road build costs and longer haul distances.

The distance-cost relationship can also be used to illustrate the competitive range for different transport modes. Figure 10 presents a hypothetical example of logging trucks and airships. The intersection of the two curves is the competitive boundary for direct costs. The fixed cost of the airship is its purchase price which is higher than that for a truck. However, the variable costs of the truck driver and fuel are higher per kilometre than for the airship.

Figure 10: Competitive boundary for trucks versus airships



The total cost curve described above only accounts for the private costs. If negative externalities were accounted for, the point of intersection would likely shift to the left. Carbon taxes would be lower for an airship and no remediation expenditures would be required to protect the surface environment or wildlife.

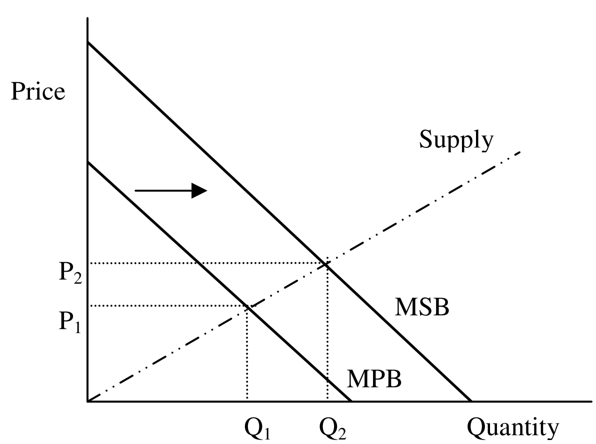
3.3 Externalities

The positive and negative externalities of a process are not measured in accounting ledgers. Negative externalities are categorized as social costs because they affect others around them, who may or may not have had any direct relation with their creation. If the environment is considered valuable to the society, then the externality is counted as a social cost, albeit an unintended by-product of an industry's economic activity (Prentice and Prokop, 2009). For example, roads into forest areas open up access for predators and hunters to Woodland caribou. The loss of the natural habitat due to the new road does not appear in a company's cost structure.

A positive externality of logging transportation is that access roads can be used for eco-tourism and to develop mineral deposits. Positive externalities are rarely maximized as a by-product of another activity. Rather, they commonly require public intervention in order to enhance the benefits beyond what is already present through the private market (Prentice and Prokop, 2009). A private logging road can sustain short term mining traffic and can potentially become part of the public road network.

A supply-demand graph can be used as a visual explanation of the effects of social costs and social benefits. Seen in figure 11, the marginal social benefits [MSB] are the sum of the marginal private benefits [MPB] and the positive externalities.

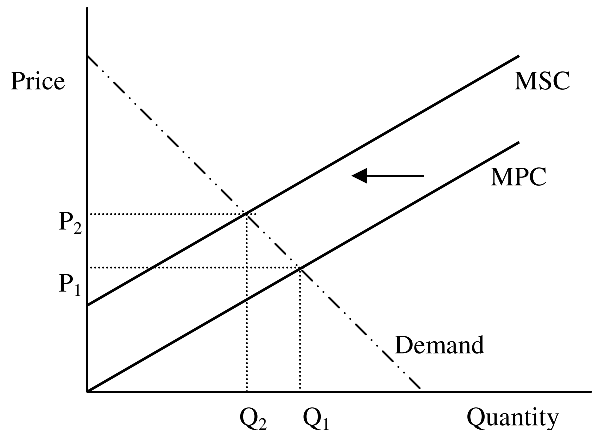
Figure 11: The effect of positive externalities



When the positive externalities are included and assuming an absence of negative externalities, more quantity is produced at a slightly higher price. This can relate to logging roads by increasing the users of the road, from Q_1 to Q_2 for a slightly higher build and maintenance cost (P_2).

Figure 12 demonstrates the marginal social costs [MSC] as the sum of the marginal private costs [MPC] and any negative externalities. When the negative externalities are monetized and assuming no positive externalities, the result is a higher price per unit for a lower quantity. As the price intersection shifts from the MPC to the MSC, the quantity produced shifts to Q_2 and the price per unit increases from P_1 to P_2.

Figure 12: The effect of negative externalities



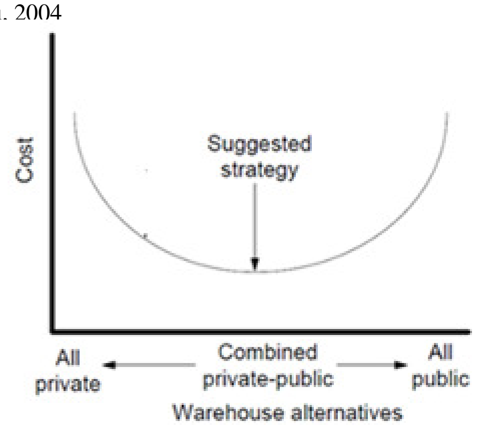
Following this reasoning, if the social costs of using the logging roads were included, such as the effects to the Woodland caribou and increased air pollution, there would potentially be fewer users of the logging road (Q_2) operating at the higher cost level (P_2). This increase in price may designate some harvest blocks that were previously economically feasible to be cost prohibitive and therefore not pursued.

3.4 Mixed Strategy versus Pure Strategy

A pure strategy is commonly thought to be a more efficient system, however the mixed strategy concept may have lower costs than a single, pure strategy. A mixed strategy allows for an optimal combination of services to be established for separate product groups, rather than extending a single average treatment among all product groups (Ballou, 2004).

The common example for this concept is with warehousing. If a company serves a market that extends throughout different cities or has large season savings in sales, it may be an advantage to mix storage options between private warehouses and rented space in public warehouses. This allows the company to achieve the lowest total cost combination for inventory, as seen in figure 13, while sustaining a constant level of customer service (Ballou, 2004).

Figure 13: Total cost curve for single and mixed warehousing strategies
Source: Ballou, 2004



A UAV Logger could provide the forest industry an opportunity to implement a mixed strategy for log transportation that is complementary to surface transport. Neither a pure surface transportation system, nor a pure UAV Logger system, may reap the full benefits or efficiencies within the harvest process. Where road or rail infrastructure is established, aerial logging is not competitive. When a road network does not exist, the UAV Logger could be used as an alternative to the high private and social costs of equivalent road construction.

Seasonal conditions of both logging transportation and of the market for the end-products create peak and off-peak periods of transportation and production. A mixed strategy for logging transportation could be to use the UAV Logger year-round for transporting logs to sustain a minimal supply of timber. Trucks on seasonal roads could be added to increase the log volume transported. Soft road conditions restrict surface transportation to approximately 220 days a year. The UAV Logger is not affected by the road conditions and could extend the transportation season.

A second mixed strategy example could be to use the UAV Logger to maximize the utility of necessary roads by offering feeder routes. A portion of a harvest block could be economically viable using the surface haul-truck option, while another part of the same harvest block may have a lower transportation cost by using the UAV Logger. Using the two alternatives together may make a harvest block economically viable, when otherwise it would be left uncut.

Chapter 4
Forestry Road Management

4.1 Background and Policy

Guidelines for forestry road management are specified by provincial governments. Provincial guidelines may differ, but share a common goal to manage the access for forestry operations while protecting the environment, addressing the sustainability of other resources and maintaining cultural values. This section examines the requirements in Manitoba and Ontario.

Three road classifications are used for forestry practice. A primary road serves as general access through the forest. Secondary roads create access to logging operational areas and tertiary roads provide the final link to the harvest blocks (Manitoba Conservation Forestry Branch, 2012c). Primary roads are built and maintained as all-weather, permanent roads. Secondary roads are not permanent, but usually exist for extended periods of time and are commonly an all-weather type of road. Tertiary roads are short term and usually seasonal roads.

The common forestry planning process includes a Forest Management Plan (FMP), Annual Operating Plans (AOP) and a Forestry Road Development Plan (FRDP) (Manitoba Conservation Forestry Branch, 2012c). These documents are revised and revisited as needed throughout the process of logging. Essentially, each document provides a layer of detail starting with the FMP that describes the company's long term general strategies and activities. The AOP details the annual harvest operation and road build requirements. Finally, the FRDP includes maps, tables and the description of all roads in each geographical area of the respective FML or SFL.

The FRDP identifies and discusses all possible negative effects and addresses the concerns of the Aboriginal communities and other communities in each area. This plan is the tool used for communication and mitigation of concerns and issues.

In Manitoba, the review of natural resource issues, approval of each plan and the on-going inspections of the forest operations is the responsibility of the Integrated Resource Management Team (IRMT) (Manitoba Conservation Forestry Branch, 2012b). Members of the IRMT come from the different areas of Manitoba Conservation. They represent Forestry, Wildlife, Lands, Parks, Fisheries and Water, as well as Regional Operations. In addition to satisfying the IRMT, the provincial transportation overseer must be consulted to gain approval for any road connection to provincial infrastructure.

The Manitoba Environmental Act requires that harvest blocks larger then 300 cubic meters must go through a process in which the plans are submitted for public review and comment prior to receiving approval and licensing from the Environmental Approvals Branch (Manitoba Conservation Forestry Branch, 2012a).

In Ontario, the Ministry of Natural Resources has a Class Environmental Assessment (EA) Approval that covers all forest management activities on Crown lands below the 51st parallel. Their conditions are integrated into the FMP process. This Approval, Declaration Order MNR-71/2, allows for the forest planning process to be streamlined, and minimizes the number of consultations required (Ontario Ministry of Natural Resources, 2012g).

4.2 Types of Logging Road Networks

Trucks are the main type of logging transport in Canada. Water and rail transport are used when they are available. While the bulk of the operational costs are incurred in the primary harvesting phase, the single largest component of the total stump-to-mill cost is with the secondary transportation (Rauscher, n.d.).

In the past, logging companies built and maintained their own road network. Modern logging companies are more specialized. They decide future cut-blocks, obtain the appropriate permits for construction and ensure due diligence with respect to public meetings and communication of their harvesting plan (Forester A, 2011). Receiving proper permission from all appropriate stakeholders can take up to five years. The majority of logging roads built in Manitoba and Ontario are contracted out to local companies specialized in building and maintaining the different types of roads required. The logging companies treat the purchase of these roads as a defined cost asset.

Once a harvest block is chosen, a road map is flagged and documented. Upon approval, the primary and secondary logging roads are commonly built ahead of the arrival of harvesting machinery (Forester B, 2012). Alternatively, secondary roads can be built, along with tertiary roads, as harvest commences by having the feller-buncher cut the road access and harvest the timber along the road line. This strategy allows the harvest to begin and minimizes the time between preparation for harvest and actual value-added harvesting.

The road requirements for a harvest block depend on the type of logging method used. There are two common types of harvest block road networks in the boreal forest (Forester B, 2012). The first type has a single road that winds throughout the operational area, allowing the skidding of trees to be a maximum of 400 meters. Once the product is skidded, if any further processing is required, it is done prior to loading for transport. This strategy requires more kilometres of roads. The second harvest block road network has a road through the centre of the operational area with a landing every 500 meters to accommodate the skidding distance for chipping operations. The chipping equipment is moved to each landing as the harvest progresses. The wood chips are transported by specialized trucks from these sites to the mill.

4.2.1 Ice Road Networks

Ice road networks help minimize the high cost of transportation by reducing the number of bridges and water crossings required. These networks are essential to access otherwise stranded areas. Ice roads are also used for the movement of essential goods, such as food, fuel, medical, building supplies and heavy machinery. On average, ice roads cost about $5,000 per kilometre to build, but are expensive on a tonne per kilometre basis because of low utilization and limited back-haul opportunities (Gibbons, 2007; Prentice and Thomson, 2004).

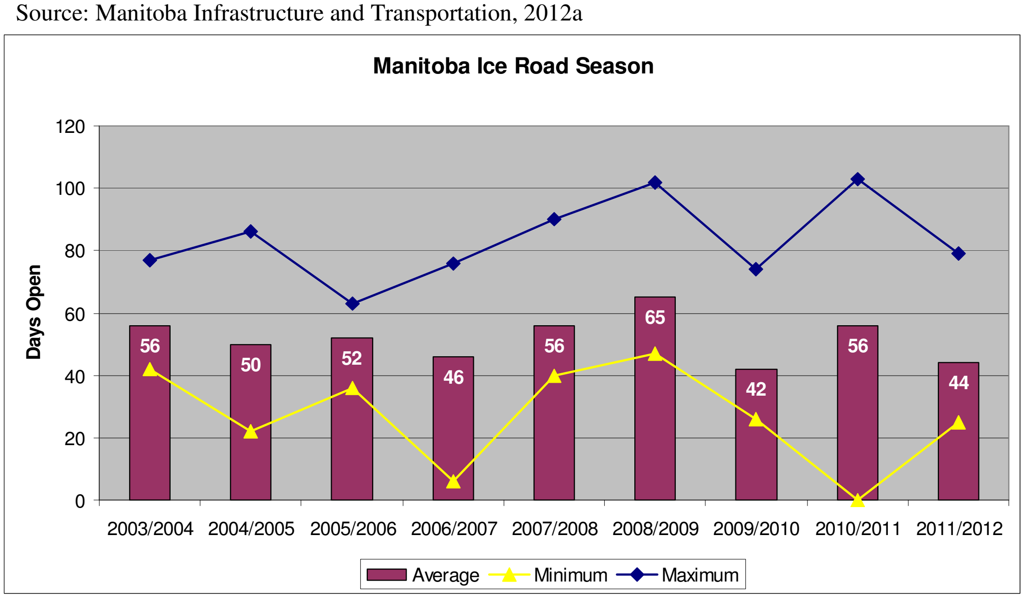
Ice road networks face challenges in construction, maintenance and use. They follow "the path of least resistance" (Manitoba Infrastructure and Transportation, 2012c) across muskegs, lakes, rivers and creeks. Ice roads can support loads up to 37,000 kilograms, with the restriction of a maximum speed of 15 kilometres per hour, and a spacing of one kilometre between vehicles (Manitoba Infrastructure and Transportation, 2012c). Exceeding the speed limits and spacing requirements can cause cracking, wave action or complete ice failures. These issues can place the drivers and their loads at risk, especially at the beginning and end of the season.

The principal challenge of the ice road network is its dependence on the weather. In Manitoba, the ice road network is planned for an eight-week period from mid-January until mid-March, but actual use can be cut in half depending on the weather conditions.

Climate change presents a new challenge to the industry and adjustment is costly. A main effect of climate change in the northern area is the decreasing period for safe use of the ice road network. Climate change in Manitoba is resulting in milder winters and more snow. This directly affects the ice road network by decreasing the time period in which ice is formed on the rivers and lakes, decreasing the ice thickness and increasing the amount of permafrost melt (CIER, 2006).

It has been predicted that Manitoba's average seasonal temperature could increase three to eight degrees Celsius by the year 2100 (CIER, 2006). The ice road season is on average between 50 to 60 days long in northern Manitoba, however many of the roads only open with lower tonnage allowances. Figure 14 shows that in recent years the ice road season has been inconsistent and some roads do not open at all.

Figure 14: Manitoba Ice Road Network Season
Source: Manitoba Infrastructure and Transportation, 2012a



The lost utilization increases the average fixed costs of these temporary roads. The shrinking window for safe use of the ice roads leaves some logging companies with less time to move their inventory out of the harvest areas. To move the same volume over a shorter period requires more trucks and drivers or may increase holding costs by stranding inventory at the harvest site for an additional season.

4.3 Road Decommissioning

With public safety and the long-term protection of natural resources in mind, there is an expectation of road decommissioning once the harvest is completed. It may involve the removal of water crossings and the re-vegetation of certain areas. In some cases, natural abandonment is acceptable (Forester B, 2012).

The strategic management of the road network is more complicated because they may become stranded assets. An asset is stranded if it becomes obsolete in advance of complete depreciation, and is therefore worth less in use than its balance sheet value. A stranded asset could be built for a specific reason, and abandoned when no longer needed. Examples are access roads to mines and a road put in place for the single use of building a new power line during the construction phase. The end of an asset's use may not be the end of legal responsibility of the owner.

Once the forest area has been harvested, a decision must be made to maintain or to decommission the road. If not decommissioned, the logging company is obliged to maintain these stranded assets as per the minimum standard required. Decommissioning a road releases the logging company from liability of any injuries or accidents sustained on the road after the logging team has left the site (Gibbons, 2007).

The logging roads may also be used after the harvest has been completed for re-seeding and regeneration purposes. For areas where poplar was harvested, little to no human intervention is required because they can perform their own regeneration. In areas with conifers, the roads may be kept and maintained for four to five additional years for seeding and spraying purposes during regeneration.

In a cost-benefit analysis, a capital investment usually has some positive residual value. The case of logging roads is unique to resource industries where land remediation is required for abandoned infrastructure. This means that the residual value of a logging road is negative. The shorter the useful life of the road, the higher the discount value.

In Manitoba and Ontario, the liability of logging roads built on Crown land and the responsibility for road maintenance is that of the logging company. Once the agreed upon decommissioning conditions have been satisfied, the provincial governments will waive any further requirements and liabilities. Alternatively, the Province may deem the road useful for other purposes as it may have become established for public, tourism or commercial use. In this case, the logging company is released from liability and maintenance responsibility (Manitoba Conservation Forestry Branch, 2012c).

4.4 Surface Transport Hauling in the Logging Industry

The cost to build, maintain and decommission roads is one of the main criteria used to decide whether or not an area will be harvested. The timeline from the application to the approval for the road build can be up to five years.

4.4.1 Basic Operation Costs and Information

Although logging operations differ slightly with respect to the chosen harvest method and the importance of the freshness and quality of the timber, the available annual window for harvest remains relatively constant. The harvest period depends on the weather and climate change, as previously mentioned, however general harvest operations run five days a week and the shifts are between 10 and 12 hours each. Depending on the volume to harvest and timeline for completion, there may be one shift a day, or toggled up to two. An annual operational window, on average, is 220 days (Forester A, 2011).

The transportation portion of logging does not directly follow the harvesting timeline. More haul is done in the winter months, taking advantage of the harder ground and the ice roads. Transport is limited or absent during the spring and fall months when soft road conditions occur. As an example, cutting may last ten months of the year and transportation activities only during six months. In some instances the haul occurs over the full 24 hours each day in the winter months and only over the day shift in the summer months (Forester A, 2011). The Department of Transport (DOT) has regulations in place that restrict each driver to 13 hours of driving per 24 hour period (Canada Department of Justice, 2012).

It is common for the harvest and transportation of logs to be contracted out by each logging company. Transport cost is expressed as a cost per hour for the truck and driver required to move the product. Current industry standard is $110 per hour for an eight-axle logging truck (Forester A, 2011; Forester B, 2012). Loading each truck is estimated to take 45 minutes and an unload is 35 minutes (Forester A).

4.4.2 Road Build Costs

The cost to build roads for logging depends on the type of terrain, the location and logging strategy. The cost for a winter block road is approximately $5,000 per kilometre and requires a buncher and a bulldozer for road build completion. In comparison, a summer block road costs approximately $10,000 per kilometre and requires an additional backhoe to create ditches for drainage. The gravel roads built for logging purposes range between $25,000 to $75,000 per kilometre within the boreal forest (Forester A, 2011; Forester B, 2012).

Water crossing costs can range from a few thousand dollars for a culvert to $500,000 for a full bridge. The cost for each crossing depends on its width and shoreline requirement (Forester A, 2012).

The cost for road maintenance is difficult to estimate because the needs and requirements are unique to each location. The common estimate for road and water crossing maintenance is approximately $5,000 per kilometre per year for roads that are only used for harvesting purposes. This maintenance cost includes the upkeep of culverts, snow removal and gravel. Should the road be used for additional purposes, such as tourism, recreation or community access, the cost per kilometre could increase significantly.

A summary of the costs, found in table 2, represents the averages for each of the items and is used for calculations further in this thesis.

Table 2: Road build data

Road Type	**$ per km**
Summer in-block	$10,000
Winter in-block	$5,000
Gravel (basic terrain)	$25,000
Gravel (difficult terrain)	$75,000
Maintenance (harvest use only)	$ 5,000
Bridge	$500,000 each

4.5 Externalities: the Effects of Roads

It is common to hear in the news about the negative externalities relating to the logging industry, particularly with regards to potential disruption of the Woodland caribou habitat or to the creation of roads in historically untouched terrain. Anna Baggio (2005, p.45), a director with the CPAWS Wildlands League Chapter, explains that roads not only fragment and isolate habitats but they create barriers for wildlife and disrupt watersheds. For animals that are not edge-dwellers, such as elk, wolves and caribou, a new 'edge' to their environment has been created and they are forced to move out of the area.

In addition to affecting spatial patterns, the presence of a road affects the water quality, concentration of flows and may re-route the water from its natural flow path. Further, it may exacerbate root diseases, through wounded or damaged trees and the incurred stress throughout the construction and use of the road. Roads also allow the movement of diseased wood to areas that were without, similar to how air and sea travel have spread many different human and animal diseases. Finally, tree growth is affected near roads due to the changes in the soil's physical properties, nutrient loss, increased erosion and soil compaction (Kennard, 2009).

With roads, comes traffic. Increased traffic leads to higher levels of noise and air pollution from fuel emissions. These increased emissions contribute to climate change, which may change the patterns of the ice roads required for accessing harvest areas and communities.

The Woodland caribou species in the boreal forest is sensitive to disturbances and is being threatened by the introduction of industrial developments and increased access for predators (Baggio, 2005). Their species is in decline mainly due to the changes to their habitat and reduced food sources (Baggio, 2005).

In contrast to the negative effects previously discussed, roads provide access for silvicultural activities that allow the quality of the forest to be controlled in order to meet diverse needs and values. Further, roads can arrest the spread of certain parasitic plants, such as true mistletoe, and can be used to intentionally separate a group of infected trees from another part of the forest to contain the infection.

From an economic viewpoint, the building and removal of all-weather roads provides a one-time stimuli to the economy. Winter roads and on-going maintenance of all-weather roads provide a recurring stimulus, as well as direct and indirect employment. Logging road networks may also support other economic activity such as mining, recreational activities, land management and firefighting.

Chapter 5
Lighter-Than-Air UAV Logger Concept

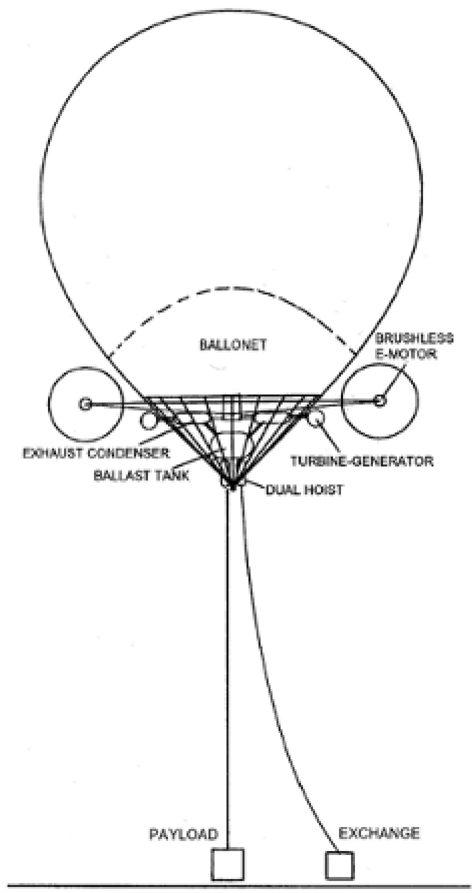
5.1 UAV Logger: Suspended Cargo Carrier

The primary focus of this research is on a short-range UAV Logger operation, concentrating on moving non-perishable products between two sites. An effective airship for short range operations is designed to maximize specialized tasks, such as logging (Bock, Apel and Prentice, 2012). This airship design needs maximum manoeuvrability and aerostatic lift, while adapting to the challenging terrain, in which minimal ground operations are required.

Juergen Bock of SLTA Engineering-Consulting, has designed a Lighter-than-Air UAV Logger concept, in which the UAV Logger "is an unmanned self-propelled cargo balloon conceived for operations […] at areas not prepared for aviation ground operations." (Appendix A, p.134). Description and design information is found in Appendix A. The design, as seen in figure 15 on page 61, incorporates payloads that are suspended externally and avoids any direct carrier footprint during pick-up and delivery by staying aloft at each operation's site. The spherical balloon design is equipped with two suspension cables, one for the externally suspended payload and a second for use during the compensatory ballast exchange process. The payload - ballast cable system allows the UAV Logger to maintain aerostatic equilibrium.

The upper portion of the spherical balloon is filled with lifting gas and the lower portion is an air ballonet. A "rigid upside-down conical cage structure" (Appendix A, p.134) is designed to fit at the lower end of the envelope, in order to disperse the weight of the payload to the entire balloon.

Figure 15: UAV Logger
Source: Bock; "UAV Logger: Baseline Definition" (Appendix A)



Advantages of this configuration for a logging application include a low centre of gravity that enhances flight stability and an externally suspended payload that allows for a quick and convenient exchange process. In addition, the lower point of the UAV Logger may accommodate a coupling device to anchor the unit during non-use periods. In colder climates, the shape of the UAV Logger allows for snow to slide off the surface. De-icing metal components can be performed as in fixed and rotary wing aviation technology (Bock, Apel and Prentice ,2012).

5.1.1 Propulsion and Control

The UAV Logger has two lateral propellers, six meters in diameter, mounted using lateral outriggers. These propellers are powered by a brushless electric motor and by two turbine generators. Differential thrust is used for directional control to permit precise landing manoeuvres.

5.1.2 Lifting Gas and Fuel

Hydrogen is the lifting gas for this application. Historically, helium is the common lifting gas of choice because of its inert characteristic. Hydrogen as a lifting gas is commonly dismissed because of its association with the Hindenburg accident. However, there has been 75 years of research and technology to safely handle hydrogen, as well as other flammable gases like propane and methane. The potential to put the public in danger is low, therefore hydrogen in a UAV is acceptable.

Hydrogen has both economic and practical reasons that make it the preferred lifting gas. It has eight percent more lifting potential than helium and allows for the highest lifting power for aerostats. It is less expensive than helium and can be produced on site by hydrolyzing water. A large part of the cost of helium is containerisation and transportation.

Hydrogen fills the upper portion of the balloon and is used as a component of the fuel system. The turbine generators use mixed fuel, combining the lifting gas with liquefied methane. The mixed fuel increases the available propulsion energy by 21 percent.

5.2 UAV Logger for Harvest Transport

The UAV Logger is well suited for the short range operation of primary transportation; moving logs from a harvest block to a landing. The UAV Logger's adaptability to adverse ground conditions and modular flexibility is advantageous and preferred due to the climate change challenges and environmental concerns.

The UAV Logger may be directly compared to other aerial logging systems, such as heli-logging. The UAV Loggers' advantages are lower carbon dioxide emissions from the use of alternative fuels and smaller engines, and the elimination of downwash at pickup and delivery points. Downwash is a nuisance to the ground workers and introduces the risk of flying hazards. Helicopters have higher airspeeds and do not require ballasting, however operating in icy conditions is dangerous. High fuel burn restricts their use to short ranges under payload. The high fuel consumption and maintenance costs preclude the use of helicopters except for the most valuable timber.

The UAV Logger can be guided using avionics and a telecommand system. These specifics have yet to be finalized. One idea is to create a tethered balloon communication platform with a relay system. A balloon at a height of 800 meters would have a 100 kilometre line of sight[4].

Other equipment required for the logging operation may include Doppler radar, a video link for the ground control centre and several monitoring and control systems for the fuel, gases, pressure, temperature and potential icing.

5.2.1 Operational Considerations

UAV Logger operational needs vary with each type of logging operation. With

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[4] Assumes the horizon is at sea level. The line of site was calculated by using the Pythagoras's theorem, assuming that the Earth is a perfect ball 6,378,137 meters in radius.

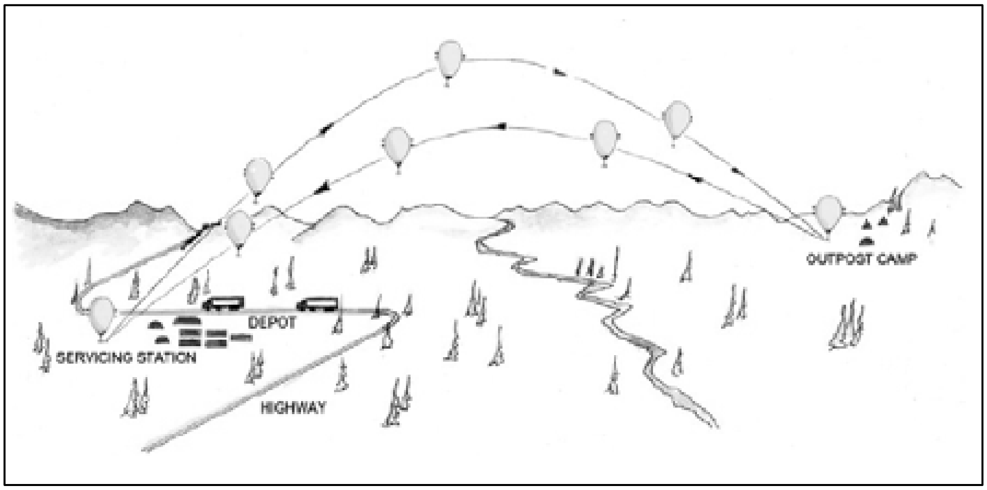
the use of hydrogen, the inflation may occur on-site. This may be necessary because of restrictions of flying the UAV Logger to the forest location from a ‘home base’. The airship hangar would only be required for larger maintenance and repair requirements, and for further research and development. The hangar may not be at the harvest site.

For efficient use of the UAV Logger significant pre-planning may be required with respect to the operational location and logistics of the ground operation. Pre-determined weights of ballast need to be available throughout the operation, whether it be water, earth, ice or other ballast material.

Due to the ‘unmanned’ component of the UAV Logger, the unit(s) require an Operational Control Centre (OCC) for monitoring, coordinating, dispatching and telecommand activities. This OCC may house the virtual cockpit and trained UAV pilot. Based on current or forecasted weather conditions, there would be the ability to adjust the flight path in order to avoid or minimize the exposure to adverse weather. Unforeseen conditions may require the specialized OCC crew to react quickly and guide the UAV Logger using human interaction.

Within the cut block, outposts or ‘field stations’ may be required to serve as a pickup point for the payload. The location of these outposts may continually shift with the progression of the harvest. Further to the field stations, ‘service stations’ provide a location for the storage of the hydrogen and methane, as well as any service items required to be moved to the harvest block. Figure 16 demonstrates a conceptual scenario in which UAV Loggers are used to transport logs from a remote harvest area, to a service station adjacent to existing road infrastructure. The service station serves as the intermodal connection between air and road.

Figure 16: Operational Scenario for Transport between an Outpost camp and a Service Station
Source: Bock, Apel and Prentice, 2010.



These service stations may have a type of mooring provision, in order to stabilize the UAV Logger for payload-ballast exchange and re-fuelling requirements. A dedicated crew is required to manage the incoming UAV Logger loads, perform ballast exchange and dispatch the UAV Loggers back to the cut-block. This may be accommodated by or in conjunction with the OCC staff.

5.3 Externalities

The UAV Logger presents several possible benefits. With the use of this alternative, the reliance on diesel fuel and its contributing air pollution is eliminated. Road congestion is reduced because haul trucks are minimized or eliminated. The UAV Logger may address the environmental groups' concerns about disturbing caribou habitat by minimizing forest disturbance during the harvest and transportation process. The cost and wait time for permit approval is eliminated because the need to disturb water crossings is removed.

Social benefits are increased by the reduced environmental impact through reduced GHG emissions, minimal disturbance to wildlife migration patterns and the elimination of access for poachers. The use of the UAV Logger could help the logging industry adjust to the increased Crown land withdrawals and minimize the amount of harvest land that was once deemed stranded and not economic for harvesting due to the costs associated with access.

The UAV Logger alternative would change direct and indirect employment. Employing a mixed strategy for log haul would result in a lower requirement for the expertise of crews for road construction and maintenance and the professionals responsible for building, maintaining and driving the log haul trucks. However, it would introduce a requirement for expertise in the field of airship build, maintenance and ground control. Employment and investment would be made with respect to the design, build and maintenance of the UAV Logger technology. This would have a significant effect on suppliers throughout the immediate and extended supply chain.

Although the UAV Logger shows many positive externalities, there are limitations that should be discussed. Ballast is required for the UAV Logger unit to return to the harvest area for a load of logs. It should be some type of natural, disposable ballast that can be handled in an environmentally acceptable way with regards to its' containment, accumulation and disposal. The trip from the docking station to the harvest area could also be an opportunity to move supplies and other items to the forest operation area, such as diesel fuel for the heavy equipment.

Another challenge for the UAV Logger is the lack of public trust in this re-emerging technology. The memory of the unfortunate Hindenburg incident makes it difficult to use hydrogen as the lifting gas. However, every situation has a tipping point, or a point where the public accepts an alternative to current technology. Research and development funds are available to help promote and demonstrate new technologies.

As new technology, the advantage of mass production of the UAV Logger can not be realized in the immediate future. An upfront investment is required to procure UAV Logger units. This research uses a ‘rental rate’ for the units to compare it to the cost of the truck-trailer combination. Later in this Chapter, the UAV Logger ‘rental rate’ is described and calculated.

5.4 UAV Logger Engineering Cost Estimate

Two important design assumptions are the maximum airspeed near ground at 60 kilometres per hour and an 80 percent propulsion efficiency. These two data points are critical to the fixed costs (ie. capital utilization) and variable costs (ie. fuel consumption). Key information from Appendix C is summarized in table 3.

Table 3: Key data of various sizes of UAV Loggers

Type #	Diameter m	Volume m^3	Components kg	Fuel* kg (methane)	Payload kg	Max Power kW
1	20	4,190	2,156	166	1,868	523
2	25	8,180	3,357	249	4,574	788
3	30	14,140	4,882	353	8,905	1,115
4	35	22,450	7,047	475	14,928	1,501
5	40	33,510	9,745	619	23,146	1,957

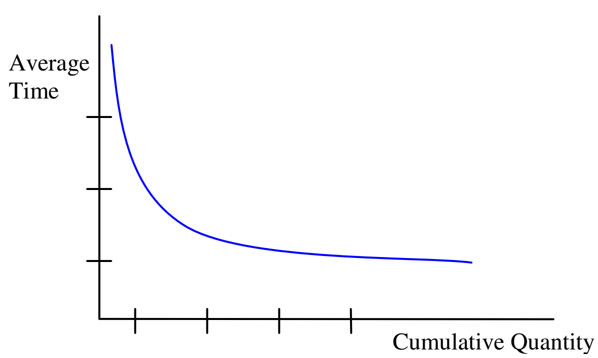
* at a 100 kilometre range

The lifting capability of hydrogen is essentially a 1:1 ratio for cubic meters to kilograms. Therefore, the maximum kilograms of lift for each UAV Logger size is equal to the ‘Volume’ data point in table 3.

Only one size of UAV Logger is considered for this thesis research and analysis. The Type 4 UAV Logger is assumed to have a payload lift capacity of 15 tons. The average speed over ground for the UAV Logger is 50 kilometres per hour. The fuel is a blend of liquefied natural gas and hydrogen. For a 100 kilometre distance, it is estimated that the Type 4 unit requires 475 kilograms.

For the purposes of comparison, the price of the UAV Logger unit is based on the cost for producing multiple units[5]. The first UAV Logger may take significant time and effort to manufacture, however as the number of units required increases, the hours per unit will follow a logarithmic curve, known as the learning curve effect (seen in figure 17). Efficiencies may lead to lower costs as the labour gains expertise, the standard work processes are implemented and supplier relationships are strengthened.

Figure 17: The Learning Curve Effect



An engineering estimate can be created by costing the main components of the unit, as represented in table 4. The costing of each piece is based on quotes from local Canadian suppliers and experts. The estimated total price includes a 10 percent

[5] The competing equipment (tractor-trailers) is mature and has long production lines. An experimental airship can not compete. Consequently, the research and development costs are included only as an intellectual property royalty.

allowance for profit and a 50 percent allowance for costs not considered.

Table 4: UAV Logger component pricing

Item #	Component	Cost ($)	Notes
i)	Engine	$1.5M	2400hp. (gen-set)
ii)	Envelopes	$240,000	Hot air balloon envelope, doubled.
iii)	Propellers	$60,000	6m long. $30,000 each
iv)	Autopilot avionics	$10,000	
v)	Actuators	$100,000	
vi)	Hydrogen	$434,632	Initial Fill. @$19.36/m3
vii)	Portable water tanks	$13,600	Helicopter water tanks.
viii)	MARK 3 Wajax pumps	$3,000	For ballast fill and dispersal
ix)	Cable system for payload-ballast	$75,000	Suspended cables and a grapple claw
x)	Communication platform	$100,000	Tethered balloon system for signal
	Sub-Total	*$2,536,232*	
	Estimated Type 4 Unit Cost	**$4,057,971**	**Added 50% for misc, 10% profit margin**

i) Engine:

The UAV Logger documentation calls for 1500 kW of power for the Type 4 unit. This converts to just over 2000 horsepower (hp). The equivalent engine is a 2400hp PT6 for a Dash 67 airplane. These engines cost approximately $1.5 million each (Gaffary, 2012). The Type 4 model is outfitted with the 2400hp engine for this cost estimate. The Canadian experts question the merit of the gas electric design that is more complicated than straight-forward turbo prop engines. This is an engineering question that is not explored further in this thesis.

Fuel cell technology presents an alternative source of energy. Current fuel cell design does not take weight into consideration because it assumes that the units are not lifted into the air. The units can weight 45 tons for a 1500 kW power requirement and cost $5.25 million (Ballard Power, 2012). The possibility of fuel cells is not considered further in this thesis.

ii) Envelopes:

The Type 4 unit has a 35 meter diameter balloon and a volume of 22,450 cubic meters. A hot air balloon company that manufactures balloon envelopes was approached to provide a quote. The price of an envelope this size is $120,000 (Sundance Balloons, 2012). The UAV Logger requires more gas tight envelopes. The design envisioned has two envelopes – a tough outer cover and an inner gas tight envelope to hold the hydrogen. This estimate includes $240,000 for two envelopes.

The Bock design calls for a ballonet, but this is not necessary for an airship that flies only above the trees. The current approach is more akin to the 21st Century Airship design that maintains its shape with an "inverse" ballonet. The pressure is sustained by air being pumped into the outer envelope.

iii) Propellers:

The propulsion system consists of two six-metre diameter propellers that are laterally mounted on a transverse outrigger structure. The estimated cost is $30,000 each (Gaffary, 2012).

iv) Avionics and Telecommand system:

To satisfy the auto-pilot functionality, a manufacturer, MicroPilot, was consulted with regard to the price of an appropriate unit for the UAV Logger. Its functionality includes several monitoring capabilities for fuel, GPS and weather. The estimated cost for the avionics autopilot is $10,000 (MicroPilot, 2012).

v) Actuators:

Actuators are required for purposes of engine regulation and several control functions, such as fuel, throttle, and propeller speed. To estimate the cost of these components, an aerodynamics and performance engineer was consulted. The estimated cost for the actuators required is $100,000 (Buerge, 2012).

vi) Hydrogen:

A compressed gas distributor was consulted for the price of hydrogen in quantities required for the UAV Logger. A costing per cubic meter of $19.36 for hydrogen is estimated and includes the cost of transportation (Bailey, 2012). This pricing exercise includes a total of $434,632.00 for the initial fill of hydrogen.

With the non-permanent operational areas and the large amount of hydrogen required, creating the gas on-site may be more effective. A type of mobile hydrolysis machine could be investigated. Minimal hydrogen quantities may be required to top-up the envelope due to gas leakage during regular operations.

vii) Portable water tanks:

The design requires an efficient payload-ballast exchange process. Water as ballast is the best option because it is generally available at zero cost. Ballast water could also assist with regeneration and silviculture activities. A heating system for keeping the water from freezing in winter is not included in the design.

Helicopter water shuttle tanks are commonly used in aerial fire-fighting operations. They are made of heavy duty reinforced polyvinyl chloride (PVC) construction and can be applied to the UAV Logger operation. Husky Portable Containment (2011) manufactures a 1800 litre (500 gallon) helicopter water tank that costs $1,700 each. Full tank weight is approximately 1915 kilograms. A 15 ton lift payload requires ballast of approximately 15,000 litres of water. The purchase price for eight of the 1800 litre tanks is $13,600.00.

viii) MARK 3 Wajax Pump:

Rugged portable pumps, similar to those widely used in fire-fighting efforts could be used to fill and disperse the ballast. An example is the MARK 3 Wajax Pump (Western Truck Exchange, 2012) that is the standard wildland fire pump in North America. It weights 26 kilograms and multiple units can be used in series, if required. The pump can move 350 litres per minute, at 20psi. The eight tanks, holding 15,000 litres of water, would take 45 minutes to fill. This time frame lines up with the assumptions for load cycles. Each pump is estimated to cost $1,500 and two pumps are used in this estimate.

ix) Cable system for payload and ballast:

The cable and grapple systems used in heli-logging operations cost between $20,000 and $50,000 and can lift payloads between three and six tons (Bear Creek Contracting, 2011; VIH Aviation Group, n.d.). The hydraulic components associated with the grapple claw are the most costly. Winches are not used in heli-logging because they are heavy and reduce available lift. For the purposes of this comparison a price of $75,000 is allocated, but it is acknowledged that the cable system is an area for further research.

x) Communication platform:

The 'unmanned' feature of the UAV Logger requires a form of communication tower. Operations occurring in remote areas currently rely on satellite telephones. As per discussed previously, the tethered balloon communication platform could be placed at a height of 800 meters for a 100 kilometre horizon site line. This platform could also provide cell phone service to the operational area and potentially lower the cost of phone communication. Included in the pricing is $100,000 for the communication platform and relay system.

Not included in the above pricing is the cost of insurance. Insurance for new technology traditionally has high costs because of the lack of data and assurance of its use. According to Transport Canada (2012) guidelines, airships require a minimum of $2,000,000 liability insurance for public protection.

The life expectancy of a UAV Logger is unknown. The life expectancy of the envelope depends on the fabric's ultra-violet (UV) levels. With a high UV stabilization number, the envelopes may last up to fifteen or twenty years. Use in the Canadian climate with less direct sun and UV rays could extend the expected life of the envelope. Other considerations include the dryness of the air, the protection of the UAV during idle time and how much abuse is put on the UAV during its normal operation (George, 2012).

The assumption for this research is that the UAV Logger remains inflated, upright and onsite. It is deflated for work in a hangar, or storage. The cost calculations are based on a 15 year life span, at which time the airship has zero salvage value. This is a conservative outlook because the engines and propellers could be sold. If any pieces are able to be sold or reused, this income can be considered as a bonus or additional revenue.

Based on the principle components of the UAV Logger, the estimated total unit cost is $4,057,971.00; or $4.1 million. The cost of ground control systems and required insurance are not included.

5.4.1 UAV Logger Cost Per Hour Breakdown and Calculations

For the cost comparison analysis, the cost of the UAV Logger is based on a 'rental' rate to compare aerial logging with the current truck-road build method. The cost per hour for a truck is based on an industry standard that includes the truck, the driver and the fuel cost. The calculation for the cost per hour for the UAV Logger includes the Unit, the ground controller and the fuel cost. Table 5 outlines the cost calculations for the three parts of the Total UAV Logger Cost per Hour and is equal to $88.64.

Table 5: UAV Logger Cost Per Hour calculations

Unit		
Estimated Type 4 cost	$4,100,000	per Unit
Life expectancy	15	years
Cost per year	$273,333	per year
Work Days per Year	220	days
Cost per day	$1,242.42	per day
# of hours in a day	24	hours
Airship Unit Cost per hour	**$51.77**	per hour
Ground Controller		
Annual Salary	$50,000	
Controller cost per hour	**$25.00**	per hour
Fuel		
Reference: table 3 - Type 4 unit:		
Kilometres (range)	100	km
Kilograms of fuel	475	kg
Estimated fuel cost	$0.05	per kg
Speed of airship	50	km/hr
Cost per km	$0.24	per km
Cost per hour	**$11.88**	per hour
Total UAV Logger Cost per Hour	**$88.64**	**per hour**

The cost per hour is based on the current annual logging transportation window of 220 days per year. The UAV Logger may operate as close to 24 hours per day as possible and night-time travel may be smoother and more efficient because of the calmer winds and even ground-temperature. Also, airships are safest when they are in the air.

The UAV Logger presents an opportunity to extend the annual log transportation window to 320 days. With the additional 100 days per year, the total UAV Logger cost per hour would be reduced by over 18 percent to $72.47. The decrease in cost is a result of the decrease in cost of the UAV Logger unit itself, reduced to $35.59 as opposed to $51.77 seen in table 5. The cost per hour of fuel and the ground controller remains the same.

Whether it is realistic to operate a UAV Logger for 320 days is an empirical question and is affected by weather conditions. These units may not fly on high wind days or in extreme cold.

5.4.2 Discussion of Profitability

This base rental rate is used as a first approximation of the cost. A profit margin would be required to keep the contractor and manufacturers economically viable and the business risk acceptable. The ‘rental’ calculation for the UAV Logger does not incorporate a profit margin or allowance for miscellaneous risks, other than the 10 percent added to the total Unit cost.

Chapter 6

Cost Comparison Model for Truck versus UAV Logger Alternatives

6.1 Introduction

Measureable costs and benefits can be used to analyse the economic feasibility of different alternatives using the cost benefit analysis (CBA) method. It weighs the total expected costs versus the total expected benefits on common basis, in terms of 'present value'. A source of inaccuracy in a CBA is the inability to estimate or incorporate a complete list of costs and benefits.

A CBA is a multi-step process that is presented as a business case and may include a feasibility analysis that objectively and rationally determines the strengths and weaknesses of a proposal. The feasibility analysis also discusses externalities to determine if it makes economic sense to proceed with the proposal.

6.1.1 Cost Comparison Analysis

This research compares the transportation portion of alternatives and assumes that the process before and after transportation remains status quo. Benefits that may be found in improving the overall process and supply chain are not identified within the scope of this thesis. A cost comparison analysis is better suited for this research because it will take into account the costs to road build and potential avoided costs with the use of the UAV Logger as an alternative haul strategy.

The logging industry determines harvest block economic feasibility by considering variables such as harvest size, haul distance, existing road infrastructure and potential new road build requirements. Roads can be used for up to twenty years and the costs of decommissioning are not included when calculating the transportation costs. These factors make it a challenge to properly and fully compare the two alternatives because of the delayed costs and long road life.

6.2 Cost Comparison Model

A base costing model that keeps the variables constant is developed to compare the UAV Logger alternative to existing trucking practices. The model calculates the total cost for full harvest. In the case of the trucks, this total cost includes the cost of hauling logs and road construction and maintenance. For the UAV Logger, the total cost includes the cost of hauling the harvest out of the cut block to a designated area.

The parameters of the base model are as follows:

- The volume of available harvest is 500,000 cubic meters.
- The span to be crossed is 100 kilometres. This span is undeveloped terrain, found in the northern sections of the boreal forest.
- The cost to build an all-weather, gravel road is $50,000 per kilometre.
- The cost of road maintenance is $1.00 per cubic meter.

Haul-Truck parameters:

- A loaded truck can travel at speeds of 50 kilometre per hour on this constructed road.
- Each haul is comprised of a maximum of 50 cubic meters.
- Each truck can be contracted at $110.00 per hour, which includes the equipment, fuel and driver.

- Every haul cycle includes 1.5 hours for all load, unload and fueling functions.

UAV Logger parameters:

- The UAV Logger travels at 50 kilometres per hour near-ground speed.
- Each haul can have a maximum payload of 15 cubic meters.
- Each UAV Logger Unit can be contracted at $88.64 per hour.
- Every haul cycle includes two hours for load, unload, ballast exchange and fueling functions.

Table 6 summarizes the truck-road build option for harvest and calculates the total cost for full harvest.

Table 6: Model example: Truck and Road Build costing

TRUCK		
Harvest size	500,000	m^3
Distance over terrain	100	km
Truck speed	50	km/hr
Road build cost	$50,000.00	per km
Maintenance costs	$1.00	per m^3
Truck Rental	$110.00	per hr
Load per haul (cycle)	50	m^3
Travel time (round-trip)	4	hours
Load / Unload	1.5	hours
Total time per cycle:	5.5	hours
# of hauls (full harvest)	10000	trips
# of hours for total hauls	55000	hours
Cost of Truck for full harvest:	**$6,050,000.00**	
Cost of Road Build:	$5,000,000.00	
Cost of Road maintenance:	$500,000.00	
Total Cost for Harvest =	**$11,550,000.00**	
Cost per cubic meter =	**$23.10**	

Table 7 summarizes the UAV Logger option for harvest, and calculates the total cost for full harvest.

Table 7: Model example: UAV Logger costing

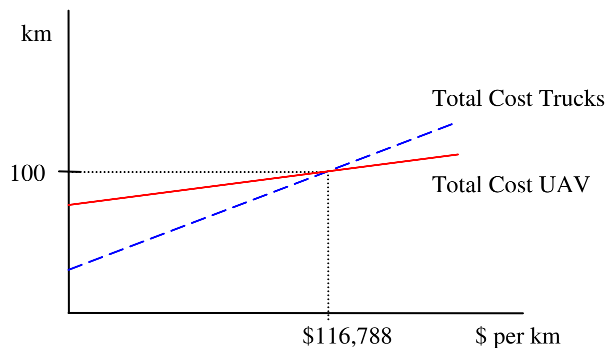
UAV LOGGER			
Harvest size		500,000	m^3
Distance over terrain		100	km
UAV Logger speed		50	km/hr
UAV Logger rental		$88.64	per hr
Load per haul (cycle)		15	m^3
Travel time (round-trip)		4	hours
Load / Unload		2	hours
	Total time per cycle:	6	hours
# of hauls (full harvest)		33334	trips
# of hours for total hauls		200004	hours
	Total Cost for UAV Logger Harvest =	**$17,728,889.92**	
	Cost per cubic meter =	**$35.46**	

The results from this example show that the truck-road build option has a lower total cost. Its cost per cubic meter is $23.10 which is 34 percent lower than the UAV Logger alternative that is $35.46. All combinations of variables are not used in this example, however this demonstrates that with the specified parameters and without the consideration of externalities, the truck haul option is the more cost effective.

Road build in the boreal forest rarely occurs without water crossings or bridges. These additional obstacles increase the road construction and maintenance cost. An area with many swamps and water crossings may make the UAV Logger alternative more competitive.

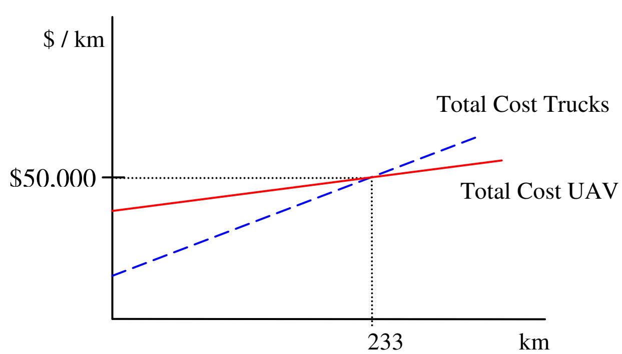
The UAV Logger alternative would start to be the lower cost option when the total cost for road build and maintenance exceeds the difference between the total truck haul cost and that of the UAV Logger. For this example, the difference equals just over $11.6 million. Therefore, the cost per kilometre for road construction and maintenance of the 100 kilometre road can be up to $116,788.00. Figure 18 shows that at any higher cost for construction and maintenance, the UAV Logger alternative is the lower cost option.

Figure 18: Model example: Break-even Cost ($ per Km)



Alternatively, by maintaining the cost of $50,000 per kilometre of road build, the span that can be crossed would be up to 233 kilometres, as seen in figure 19. It should be noted that the cost of maintenance is not included, which would slightly decrease the number of kilometres of build.

Figure 19: Model example: Break-even Distance (Km)



6.3 Increasing the Annual Transportation Operational Window

If the UAV Logger were priced using the increased annual operational window as previously discussed, the hourly rate for the unit would be $72.47. At this rate, the UAV Logger option cost per cubic metre is $28.99, demonstrated in table 8. The truck-road build option cost of $23.10 would still be 20 percent lower than this UAV Logger alternative.

Table 8: Model example: UAV Logger costing (320 days)

UAV LOGGER			
Harvest size		500,000	m^3
Distance over terrain		100	km
UAV Logger speed		50	km/hr
UAV Logger rental		$72.47	per hr
Load per haul (cycle)		15	m^3
Travel time (round-trip)		4	hours
Load / Unload		2	hours
	Total time per cycle:	6	hours
# of hauls (full harvest)		33334	trips
# of hours for total hauls		200004	hours
	Total Cost for UAV Logger Harvest =	**$14,493,345.42**	
	Cost per cubic meter =	**$28.99**	

In this scenario, the intersection point for break-even costs is at approximately $84,000 per kilometre for construction and maintenance or at 168 kilometres while maintaining the $50,000 per kilometre cost.

6.4 Discussion of Results

The cost per cubic meter in the UAV Logger options is not dependent on harvest volume. With a change in harvest volume, the cost per cubic meter for remains at $35.46

for the 220 day operational window. However, if the cycle time changes because of variations of speed, distance or with a change in ground-handling requirements, the cost per cubic meter is affected.

In contrast, the harvest volume directly affects the total cost for the truck-road build option. The change in harvest size proportionally alters the cost for hauling the full harvest off-site. While the cost for road build remains constant, larger harvests allow the cost contribution per cubic meter to be decreased because of higher utilization. A similar logic could apply to the length of the road build. Cost per kilometre being constant and the harvest volume changing, the cost per cubic meter increases or decreases with the haul distance.

The cost comparison model is applied to three case studies that exemplify three different potential harvest situations in the Canadian boreal forest. These examples will help determine if the UAV Logger is an economically competitive alternative to the truck-road build option.

Chapter 7

Case Studies

Three harvest areas in the Canadian boreal forest are examined as case studies to assess the practical application of the UAV Logger (see figure 20). Each case study concludes with a discussion of the UAV Logger's potential as a viable alternative. The main assumption in each case is that the UAV Logger is available and on the market for the estimated price described in Chapter Five.

Figure 20: Overview of Case Study Locations
Source: Natural Resources Canada, 2012

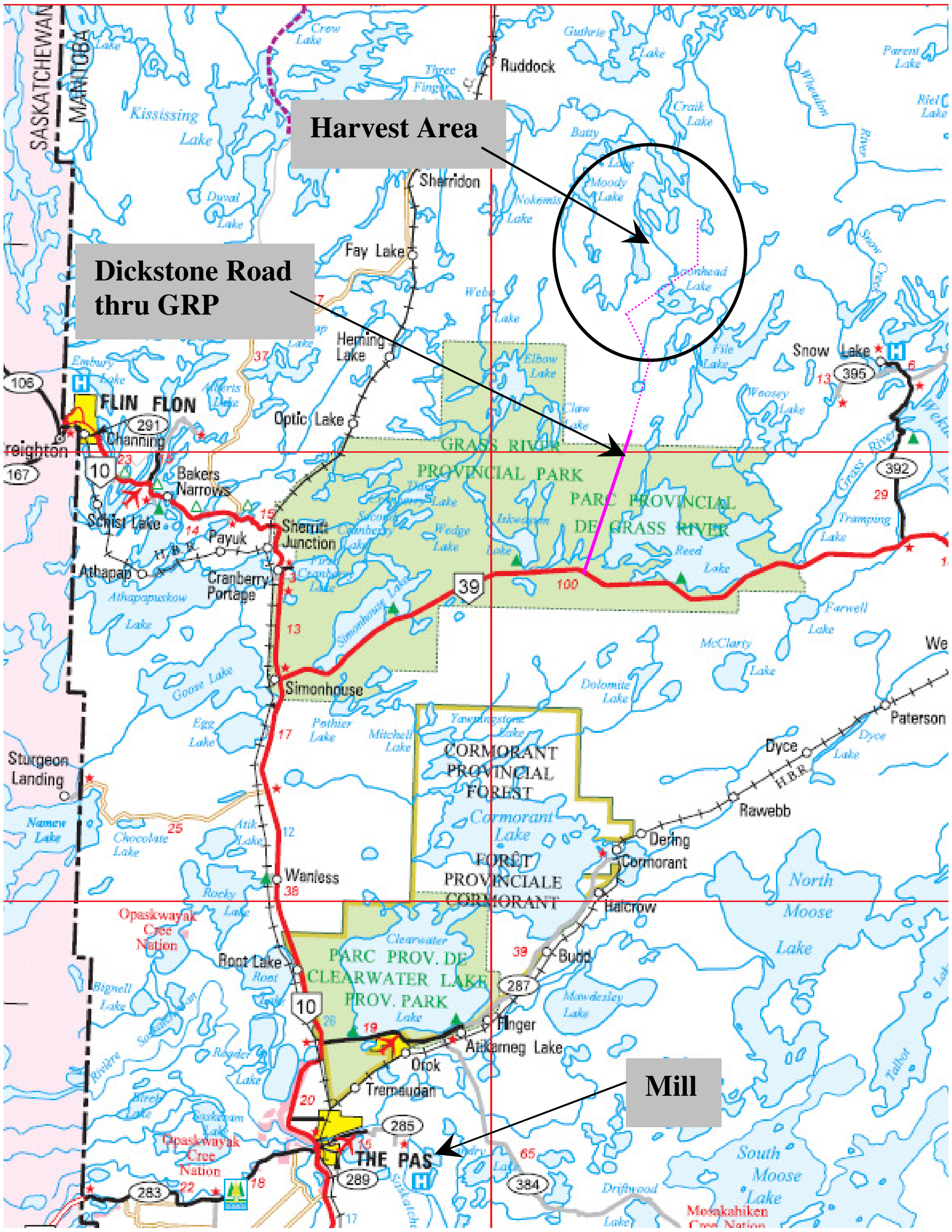
7.1 <u>Case Study 1:</u> Log Hauling through a Provincial Park

Grass River Park (GRP) is a Provincial Park located in northwestern Manitoba. Its terrain transitions between the Manitoba Lowlands with dolomitic rock and that of the Precambrian Shield characterised by granite rock (Manitoba Parks, 2012). This park is found within FML 2, held by Manitoba Woodlands (Tolko Industries Ltd). Manitoba Woodlands is located in The Pas, Manitoba, approximately 75 kilometres south of GRP. They have two divisions, Kraft Paper production and a Solid Wood mill.

With the introduction of the park logging ban (Bill 3), the forested area in this park has been removed from the logging licence. However, three million cubic meters of potential harvest operations lies north of the GRP. This area represents approximately 20 years of forest harvesting. The Dickstone Road, proposed by Manitoba Woodlands, creates the lowest economical delivery route option (Tolko Industries Ltd, 2012c).

Figure 21 locates the harvest area in Manitoba with regards to the GRP and the mill. Seventeen kilometres of this road would traverse the GRP and essentially bisect the park. This has caused serious debate and legal proceedings to determine whether or not the road building and hauling of logs on this road constitutes "logging". The main concern of the opposition is the potential effect the road build may have on the Woodland caribou habitat. The forestry company observes that any alternative routes would increase the costs of road construction, the fuel required and the haul time for each load (Tolko EA Submission, 2012c).

Figure 21: Location of GRP and Case 1 Harvest Block
Source: Manitoba Infrastructure and Transportation, 2012b



7.1.1 Operational Costs

The estimated cost to harvest and deliver the timber is $55 per cubic meter (Forester A, 2011). This includes the overhead and depreciation. The harvest area is in the 'medium distance dues rate' category and therefore, timber dues for timber used to make

Kraft paper is at $2.27 per cubic meter (Manitoba Conservation Forestry Branch, 2012e). These timber dues are considered to be a part of the overhead costs of the operation (Forester A, 2011).

The expected total cost of the Dickstone Road is $10 million with a maintenance cost of $100,000 per year (Forester A, 2011). Additionally, one bridge is required to be built, at a cost of $500,000. In addition to the main all-weather road, additional in-block roads are required for access within the cut-blocks, and adjoining with the Dickstone Road outside the park.

Of the six routes analysed for the haul of this timber from the operating area to the mill in The Pas, the preferred option that uses the Dickstone South Road has an estimated transportation cost of $19.36 per cubic meter (Tolko Industries Ltd, 2012c). This haul cost includes the loading and hauling of the timber, as well as the gravel road maintenance and capital road and bridge depreciation (Forester A, 2011). The five other options range from between $22.47 and $31.38 per cubic meter, with additional costs being incurred for improvements to existing infrastructure, the need for additional water crossings or the restriction of roads with lower weight maximums. Choosing among these five alternatives would incur an additional cost of between $9 million to $36 million (Tolko Industries Ltd, 2012c).

7.1.2 Haul Distance and Operational Information

The one-way haul distance from this harvesting area is between 160 and 200 kilometres. The highway portion of this haul is 110 kilometres and the remaining is a logging road, mainly consisting of the proposed Dickstone Road. Speed is restricted to 50 kilometres per hour on the logging road when loaded and 60 kilometres per hour when empty (Forester A, 2011).

The winter season is from November to April, or whenever the spring thaw makes the roads too muddy and wet for use by heavy machinery and haul trucks. The summer season is from June to September. Approximately 2700 truck loads are transported per year; 2200 loads in the winter and 500 loads in the summer (Forester A, 2011).

No timber is hauled in the spring and fall seasons because soft road conditions make the terrain unfit for the weight of the haul trucks. In the winter months, trucks haul timber over the entire 24 hours to take advantage of the hard surface. During the summer months, hauling normally occurs only during a single day shift. In addition to the restrictions that truckers must follow for rest periods and maximum driving hours per day, there is a one hour allowance for load, unload and re-fueling per trip.

7.1.3 Application of the Cost Comparison Model

The estimated haul rate assumes that each load leaves the harvest site and is taken the full distance to the mill in The Pas. Two UAV Logger scenarios are used to analyse this case.

- Scenario One: The UAV Logger moves the payload to what would be the end of the 85 kilometre Dickstone Road and the haul is continued by trucks on existing highways. This road build can be eliminated.
- Scenario Two: The UAV Logger moves the payload from the harvest area, the full trip to the mill that adds an additional 95 kilometres.

Road maintenance costs are estimated to be $100,000 per year. To determine an estimated maintenance cost per cubic meter for use in the Model, the estimate cost per year of maintenance is multiplied by the estimated harvest time period of 20 years and divided by the harvest volume. This equals approximately $1.00 per cubic meter.

With the GRP data input into the Model, the cost per cubic meter for the truck alternative is $19.30, as seen in table 9. This includes one $500,000 bridge.

Table 9: Case #1: Truck and Road Build costing

TRUCK		
Harvest size	3,000,000	m^3
Travel Distance to Mill (from logging road)	115	km
Distance over Terrain for build	85	km
Truck speed(avg) - logging road	50	km/hr
Truck speed - hwy	80	km/hr
Road build cost (in block)	$75,000	per km
Bridge	$500,000	
Maintenance costs	$1.00	per m^3
Truck Rental	$110.00	per hr
Load per haul (cycle)	50	m^3
Travel time (round trip)	6.28	hours
Load / Unload	1	hours
Total time per cycle:	7.28	hours
# of hauls (full harvest)	60000	trips
# of hours for total hauls	436500	hours
Cost of Truck rental for full harvest:	**$48,015,000.00**	
Cost of Road Build:	$6,875,000.00	
Cost of Road Maintenance:	$3,000,000.00	
Total Cost for GRP Harvest =	**$57,890,000.00**	
Cost per cubic meter =	**$19.30**	

As described above, there are two different UAV Logger scenarios analysed. The first scenario is seen in table 10 and has the UAV Logger haul the timber the length of the Dickstone Road and a truck completes the haul. The result is $40.44 per cubic meter. Of this total, $31.91 is the contribution of the UAV Logger haul and the balance belongs to the remaining truck haul to the mill.

Table 10: Case #1: UAV Logger costing with road haul

UAV Logger		
Harvest size	3,000,000	m^3
Distance over terrain	85	km
Airship speed	50	km/hr
Airship rental	$88.64	per hr
Load per haul (cycle)	15	m^3
Travel time (round trip)	3.4	hours
Load / Unload	2	hours
Total time per cycle:	5.4	hours
# of hauls (full harvest)	200000	trips
# of hours for total hauls	1080000	hours
Total Cost for GRP Airship Harvest =	$95,734,090.91	
Cost per cubic meter (Airship Harvest) =	$31.91	
To finish the travel from bush road to Mill		
Distance (hwy)	115	km
Truck speed	80	km/hr
Load per trip	50	m^3
Cost per hour (truck)	$110	per hr
Travel time (round trip)	2.88	hours
Load / Unload	1	hours
Total time per cycle:	3.88	hours
# of hauls (full harvest)	60000	trips
# of hours (full harvest)	232500	hours
Cost of truck to finish the haul =	$25,575,000.00	
Cost per cubic meter (truck haul) =	$8.53	
Total Cost for GRP Airship Harvest + Haul =	**$121,309,090.91**	
Cost per cubic meter =	**$40.44**	

The results for the second UAV Logger scenario performing the full haul to the mill with the additional 95 kilometres after the Dickstone Road, can be seen in table 11 below.

Table 11: Case #1: UAV Logger costing direct to mill

UAV LOGGER		
Harvest size	3,000,000	m^3
Distance over terrain (logging road)	85	km
Distance from logging road to mill (direct)	95	km
UAV Logger speed	50	km/hr
UAV Logger rental	$88.64	per hr
Load per haul (cycle)	15	m^3
Travel time (round trip)	7.2	hours
Load / Unload	2	hours
Total time per cycle:	9.2	hours
# of hauls (full harvest)	200000	trips
# of hours for total hauls	1840000	hours
Total Cost for GRP UAV Logger Harvest =	**$163,102,525**	
Cost per cubic meter =	**$54.37**	

The result of $54.37 per cubic meter is a 34 percent increase in cost from the first UAV Logger scenario and more than double the cost of the truck-road build alternative. This increase in cost is due to the high cycle time, which significantly increases the costs. When existing road infrastructure is available, the UAV Logger alternative may not be competitive because of its slower speeds and smaller payload.

With the current 220 day annual operating window, the lowest direct cost alternative for this case study is the truck-road build option. However, the results may change significantly if the externalities were quantified and associated costs included.

With the opportunity to extend the annual operational window to 320 days, table

12 demonstrates that the UAV Logger scenario one has a result of $34.61 cost per cubic meter. This calculation references the cost for the trucks to complete the haul of $8.53 per cubic meter and revised cost from the harvest portion of $26.09. This cost is still 35 percent higher than the truck-road build option, which is $19.30 per cubic meter.

Table 12: Case #1: UAV Logger costing with road haul (320 days)

UAV LOGGER			
Harvest size		3,000,000	m3
Distance over terrain		85	km
Airship speed		50	km/hr
Airship rental		$72.47	per hr
Load per haul (cycle)		15	m3
Travel time (round trip)		3.4	hours
Load / Unload		2	hours
	Total time per cycle:	5.4	hours
# of hauls (full harvest)		200000	trips
# of hours for total hauls		1080000	hours
	Total Cost for GRP Airship Harvest =	$78,262,500.00	
	Cost per cubic meter (harvest) =	$26.09	
	Cost per cubic meter (truck haul) =	$8.53	
	Total Cost for GRP Airship Harvest + Haul =	**$103,837,500.00**	
	Cost per cubic meter =	**$34.61**	

With the increased annual transportation window, the UAV Loggers' cost for hauling the payload the full distance to the mill is $44.45 per cubic meter, as seen in table 13. This cost is more than double the truck-road build option.

Table 13: Case #1: UAV Logger costing direct to mill (320 days)

UAV LOGGER		
Harvest size	3,000,000	m^3
Distance over terrain	85	km
Distance from logging road to mill (direct)	95	km
UAV Logger speed	50	km/hr
UAV Logger rental	$72.47	per hr
Load per haul (cycle)	15	m^3
Travel time (round trip)	7.2	hours
Load / Unload	2	hours
Total time per cycle:	9.2	hours
# of hauls (full harvest)	200000	trips
# of hours for total hauls	1840000	hours
Total Cost for GRP UAV Logger Harvest =	**$133,336,111.11**	
Cost per cubic meter =	**$44.45**	

The cost comparison analysis for this case study concludes that the truck-road build option is the lowest direct cost alternative. This case example demonstrates the inability for the UAV Logger to compete with existing road infrastructure and higher travel speeds. The UAV Logger would be better suited for remote, un-accessed areas.

7.2 Case Study #2: Peninsula Harvest Area with Interprovincial Surface Access

The Western Peninsula (WP) is located in the northwestern portion of Ontario, in the Kenora Forest SFL (Ontario Ministry of Natural Resources, 2012b). It is an area that is not accessible by land without crossing a provincial border. The Weyerhaeuser Kenora mill operates within this SFL and currently harvests on the WP. Weyerhaeuser Company is involved with many facets of the forest product industry and promotes sustainability and ingenuity when it comes to forest product solutions. Their mill is located in Kenora, Ontario and produces engineered lumber products (Weyerhaeuser, 2011).

7.2.1 Operational Costs

There is an estimated 262,000 cubic meters of timber for harvest in the WP operational area; a mix of poplar, spruce and jack pine. The estimated harvest cost is $22.00 per cubic meter that includes mechanical harvest and product transport to roadside for loading. The estimated haul cost is $18.40 per cubic meter of softwood, which includes the cost of the truck and driver, associated fuel costs and the loading of the product (Forester B, 2012). In Ontario, the stumpage fees for timber used to make composite products are $4.60 per cubic meter for softwood and $1.07 per cubic meter for hardwood (Ontario Ministry of Natural Resources, 2012e).

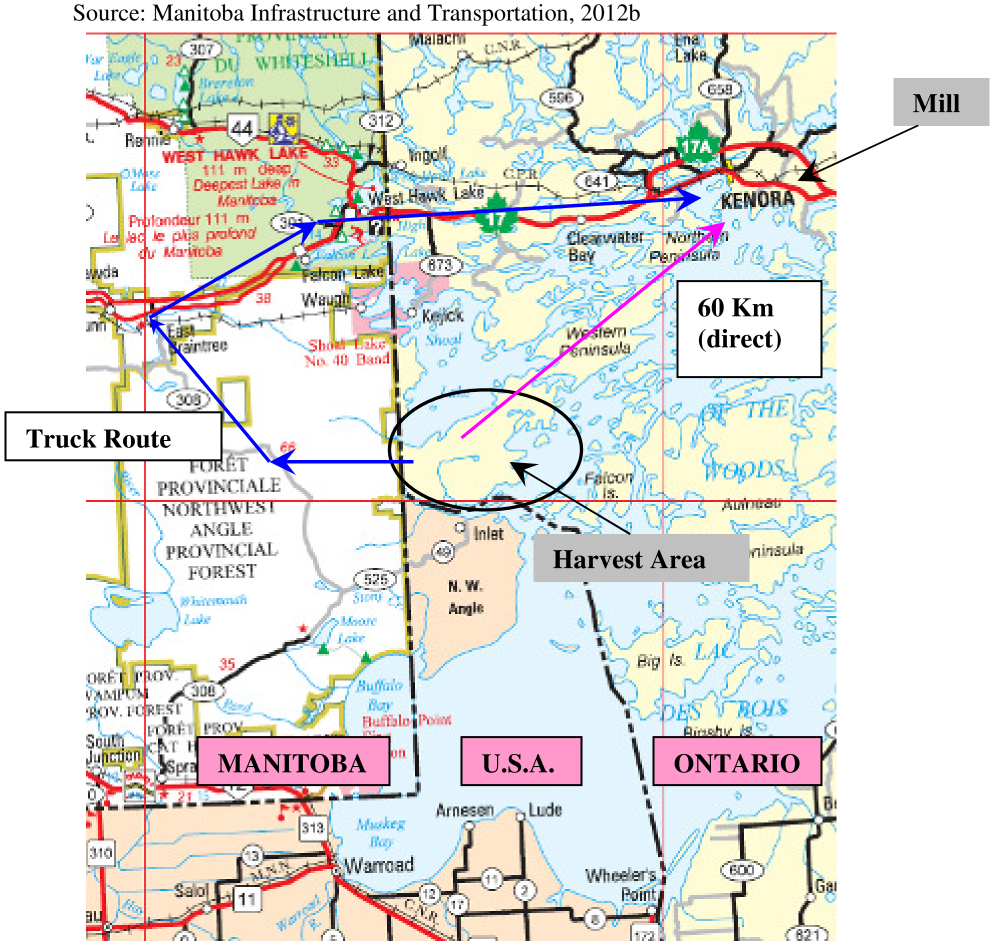
Cost contribution from the in-block road system and any secondary road cost is in addition to the estimated haul rate. The 20 kilometre connecting road between the WP operational area and the Manitoba highway is assumed to be a gravel road built at a cost of $25,000 per kilometre. This operational area has approximately 25 kilometres of secondary roads and eight proposed water crossings (Ontario Ministry of Natural Resources, 2012c). Built at a cost of $7,000 per kilometre, plus $10,000 per water crossing and $2.00

per cubic meter maintenance costs, the secondary roads cost $4.88 per cubic metre. Therefore, approximate cost per cubic meter for haul and road build for the Western Peninsula Operational area is $24.00.

7.2.2 Haul Distance and Operational Information

The WP terrain is comprised largely of swamp land. The surface truck route to the mill requires the travel across the provincial border and follows the existing road infrastructure, as seen in figure 22. The one-way travel distance between the WP operational area and the mill at Kenora is approximately 160 kilometres and 56 percent of the route is within Manitoba. The direct distance between the WP operational area and the mill is approximately 60 kilometres.

Figure 22: Location of Western Peninsula and Case 2 Harvest Block
Source: Manitoba Infrastructure and Transportation, 2012b



7.2.3 Application of the Cost Comparison Model

When the cost comparison model is applied to the WP area, the truck-road build option results in a cost of $21.75 per cubic metre, as seen in table 14.

Table 14: Case #2: Truck and Road Build costing

TRUCK		
Harvest size	262,000	m^3
Travel Distance to Mill	160	km
Distance over Terrain for build (in block)	25	km
Distance from Operational Area to hwy	20	km
Truck speed (average over all roads)	60	km/hr
Road build cost (in block)	$7,000.00	per km
Road build cost (gravel)	$25,000.00	per km
Water crossings	$80,000.00	
Maintenance costs	$2.00	per m^3
Truck Rental	$110.00	per hr
Load per haul (cycle)	50	m^3
Travel time (round trip)	6.17	hours
Load / Unload	1.5	hours
Total time per cycle:	7.67	hours
# of hauls (full harvest)	5240	trips
# of hours for total hauls	40173.33	hours
Cost of Truck rental for full harvest:	**$4,419,066.67**	
Cost of Road Build:	$755,000.00	
Cost of Road Maintenance:	$524,000.00	
Total Cost for Wp Harvest =	**$5,698,066.67**	
Cost per cubic meter =	**$21.75**	

The UAV Logger alternative with the 220 day operational window is presented in table 15. Using the direct unobstructed distance of 60 kilometres to the mill, a complete haul cycle would take 4.4 hours and the cost per cubic meter is $26.00. The truck-road build option is 16 percent lower than that of the UAV Logger.

Table 15: Case #2: UAV Logger costing

UAV LOGGER			
Harvest size		262,000	m^3
Distance over terrain (direct to mill)		60	km
UAV Logger speed		50	km/hr
UAV Logger rental		$88.64	per hr
Load per haul (cycle)		15	m^3
Travel time (round trip)		2.4	hours
Load / Unload		2	hours
	Total time per cycle:	4.4	hours
# of hauls (full harvest)		17467	trips
# of hours for total hauls		76854.8	hours
	Total Cost for UAV Logger Wp Harvest =	**$6,812,615.19**	
	Cost per cubic meter =	**$26.00**	

With the 320 day transportation window, the UAV Logger option has a result of $21.26 per cubic meter, as seen in table 16.

Table 16: Case #2: UAV Logger costing with road haul (320 days)

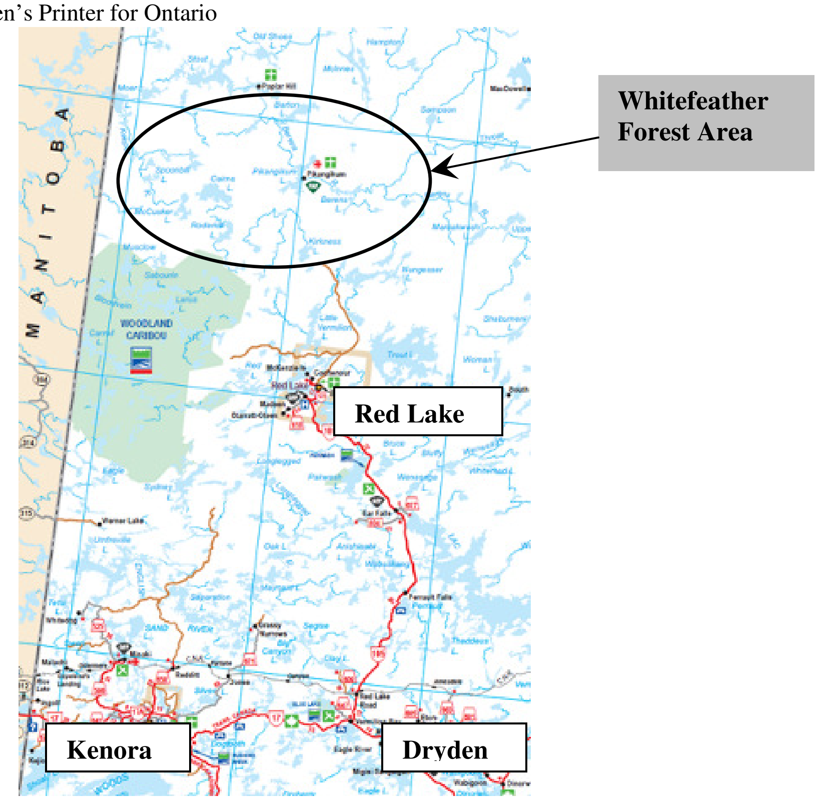
UAV LOGGER			
Harvest size		262,000	m^3
Distance over terrain (direct to mill)		60	km
UAV Logger speed		50	km/hr
UAV Logger rental		$72.47	per hr
Load per haul (cycle)		15	m^3
Travel time (round trip)		2.4	hours
Load / Unload		2	hours
	Total time per cycle:	4.4	hours
# of hauls (full harvest)		$17,466.67	trips
# of hours for total hauls		$76,853.33	hours
	Total Cost for UAV Logger Wp Harvest =	**$5,569,198.15**	
	Cost per cubic meter =	**$21.26**	

Despite the minimal road build in this case, the relatively long road detour and related hourly cost for surface transportation brings the truck-road build cost high enough to warrant the investigation of other potential alternatives. With the 320 day transportation window and the UAV Loggers' ability to cross the body of water directly to the mill, the UAV Logger haul rate is essentially equal to that of the truck-road build option. It would now be a question of what value is put on the externalities.

7.3 Case Study #3: New Forest Land for Forestry Operations

As a new addition to the forestry industry, the Whitefeather Forest (WFF) is a unique case because it is relatively untouched forest land. Found north of Red Lake, Ontario (seen in figure 23), the 1.2 million hectare forest is home to one community, the Pikangikum First Nation.

Figure 23: Location of Whitefeather Forest and Case 3 Harvest Block
Source: Queen's Printer for Ontario



The land is found north of the Ontario landscape currently covered by the Class EA Approval (MNR-71/2)(Ontario Ministry of Natural Resources, 2011a). Modeled on the MNR-71/2, the Declaration Order MNR-74 was granted in April 2009, which is the EA for the Whitefeather Forest and associated forest management activities on their Crown land (Ontario Ministry of Natural Resources, 2011b).

The community-based land strategy "Keeping the Land", approved in 2006, describes the strategic land use direction that incorporates Pikangikum First Nation's "holistic approach to Stewardship and Protection" (Pikangikum, 2006, p.8) as its guiding philosophy. This strategy sets the expectation for remoteness to be maintained, of transparent operations and for timber harvest to follow natural disturbance patterns and boundaries. The primary goals of this initiative is to maintain the cultural values and traditional practices, while reaping such community benefits as economic development and employment through forestry, mining and eco-cultural tourism. The Pikangikum Elders have provided guidance as to which sections of the forest shall be dedicated to forestry practices and which areas are to remain protected. The selected harvest areas and primary road corridors are guided largely by the dynamic caribou habitat schedule (DCHS) (Ontario Ministry of the Environment, 2011b).

This initiative is not only unique because it is a relatively untouched area in regards to the lack of forest management activities, but the full responsibility of the SFL belongs to the Whitefeather Forest Management Corporation (WFMC), owned by Pikangikum First Nation. First Nations influence with each SFL is common and all communities are publically consulted prior to harvest operations, however the majority of the influence and responsibility of SFLs belong to the logging industry.

Area dedications have been provided within this forest that comprises 30 percent for general use, 35 percent as enhanced management areas and 35 percent dedicated protected (Pikangikum, 2006). The enhanced management areas of special interest can still be used for some economic development activity. This category of area promotes enhanced remoteness and therefore dictates the use of temporary roads with a design and construction that facilitates access controls and closure upon harvest completion. Seasonal roads are preferred and additional seasonal restrictions are contemplated to protect natural processes, such as fish conservation (Pikangikum, 2006).

Dedicated protected areas are designated to preserve natural and cultural heritage landscape features. These areas exclude commercial forestry practices and are deemed "incompatible with road building" (Pikangikum, 2006, p.48). However, the development of recreation and eco-cultural tourism, as well as the use of non-timber products, such as blueberries and mushrooms, is guided through policy.

7.3.1 Operational Information

A draft of the Forest Management Plan (FMP) was released in 2012 and covers the first 10 years of activity. Phase 1 of the plan is from April 2012 until March 2017. The FMP defines the area as having 96 percent softwood, mostly jack pine and black spruce. The operational areas are guided by the DCHS and their boundaries are determined by the natural features, such as lakes and forest stand ages. The harvest method of choice is cut-to-length due to the ability to have a more even distribution of branches and tops than the conventional full-tree harvest operations (Palmer, 2011). Natural regeneration is the preferred treatment post-harvest, with the potential to supplement with aerial seeding in order to achieve a higher density.

7.3.2 Operational Costs

The FMP estimates 6.6 million cubic meters of net merchantable timber in an area of 46,580 hectares (Palmer, 2011). In Phase 1 (2012-2017), the planned harvest is 1,074,680 cubic meters of net merchantable product (Palmer, 2011). The estimated cost to bring logs roadside is $25.00 per cubic meter, which includes the cost contribution of the in-block roads. The estimated transportation cost is $20.00 per cubic meter. The stumpage fees are set at $5.00 per cubic meter for conifer species and $1.00 per cubic meter for hardwood species (Palmer, 2011).

Estimating the cost contribution from these new primary roads is difficult because the roads are intended to be maintained for community access year-round.

7.3.3 Road Build and Haul Distance

This forest lacks road infrastructure, with the exception of three portions of all-weather road and a relatively large number of winter road corridors. The main all-weather road is the Nungesser Road that is a 95 kilometre stretch that travels north from Red Lake but does not directly access any community. There is also Taxi Bay Road, which is an emergency all-weather road that travels west from Nungesser Road towards Pikangikum. The current road structures provide access to only two harvest blocks. All other logging roads must be developed (Ontario Ministry of the Environment, 2011b). The alignment of these roads is along the edges of caribou habitat tracts.

Only primary roads are planned for construction within the first 10 years of the FMP. No branch roads are proposed and while the tertiary roads for operational purposes will be constructed, their cost is included in the harvest cost per cubic meter.

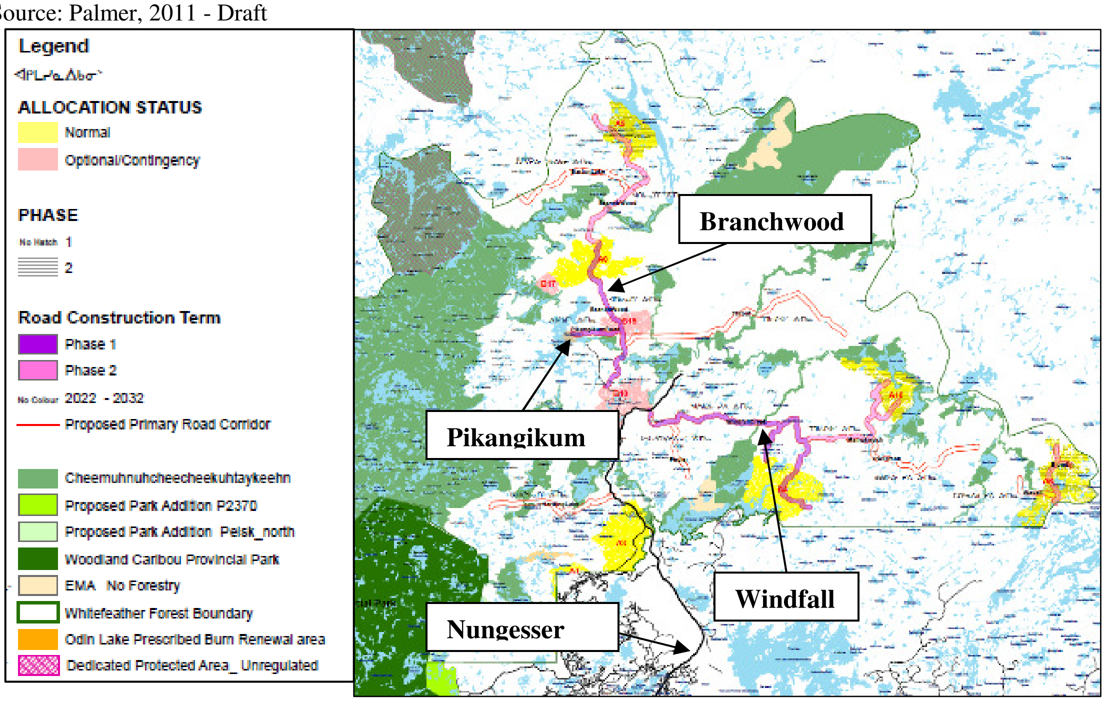
The estimated annual maintenance costs for the roads is $5,000 per kilometre, with the exception for the roads to be used for community access regardless of harvest operations. In this case the cost rises to $20,000 per kilometre per year.

The Pikangikum road is designed as a long-term solution for road access to its community. The cost per kilometre is $45,000 and on-going maintenance will cost $20,000 per kilometre each year. The Branchwood road would be built at a cost of $75,000 per kilometre and the Windfall Creek Road is at a cost of $30,000 per kilometre. Table 17 presents a summary of road costs and figure 24 shows the location of each Phase 1 road in the Whitefeather forest.

Table 17: Phase 1 WFF Planned Road Construction
Source: Palmer, 2011 - Draft

Phase 1	Km	Cost	Total
Pikangikum	10.9	$45,000.00	$490,500.00
Branchwood	38.8	$75,000.00	$2,910,000.00
WindFall	73.3	$30,000.00	$2,199,000.00
		Total	**$5,599,500.00**

Figure 24: Map of the Phase 1 WFF Roads
Source: Palmer, 2011 - Draft



7.3.4 Application of the Cost Comparison Model

Three strategically chosen all-weather roads are built during Phase 1 of the WFF plan. These roads are for harvesting purposes, as well as for basic community access. There are no plans for decommissioning upon harvest completion. In this case, the “logging” road provides the positive externality of improved community access.

The planned road build is 123 kilometres and the estimated annual maintenance cost for harvesting purposes only of $5,000 per kilometre is used to estimate a cost per cubic meter of $2.00.

Two main assumptions for this analysis are that the WFMC operates their own mill in close proximity to the forest (Palmer, 2011) and that the UAV Logger travels an average of 95 kilometres to the mill. For the purpose of truck-road build option during Phase 1, the average haul distance will be equal to the length of the Nungesser Road plus the Branchwood Road. This is a total distance of 133.8 kilometres to the southern edge of the forest.

The result in table 18 is that the cost per cubic meter for the truck-road build alternative is $25.70. Another item to note in this table is that the maintenance costs are essentially equal to the road build costs. For the five years of harvest, there is a 70/30 ratio for road build and road maintenance costs.

Table 18: Case #3: Truck and Road Build costing

TRUCK			
Harvest size - Phase 1	1,074,680	m^3	
Travel Distance to Edge of Forest	133.8	km	Nungesser
Distance over Terrain for build	10.9	km	Pikangikum
(123 kilometres of road)	38.8	km	Branchwood
	73.3	km	Windfalls
Truck speed (avg)	50	km/hr	
Road build cost	$45,000	per km	Pikangikum
	$75,000	per km	Branchwood
	$30,000	per km	WindFall
Maintenance costs	$2.00	per m^3	
Truck Rental	$110.00	per hr	
Load per haul (cycle)	50	m^3	
Travel time (round trip)	6.90	hours	
Load / Unload	1.5	hours	
Total time per cycle:	8.40	hours	
# of hauls (full harvest)	21493.6	trips	
# of hours for total hauls	180632.21	hours	
Cost of Truck rental for full harvest:	**$19,869,544.00**		
Cost of Road Build:	$5,599,500.00		
Cost of Maintenance:	$2,149,360.00		
Total Cost for Harvest =	**$27,618,404**		
Cost per cubic meter =	**$25.70**		

The UAV Logger alternative calculations for the 220 day operating window, seen in table 19, results in $34.28 per cubic meter. The truck-road build option is 25 percent lower than this alternative.

Table 19: Case #3: UAV Logger costing

UAV LOGGER			
Harvest size		1,074,680	m^3
Distance over terrain		95	km
UAV Logger speed		50	km/hr
UAV Logger rental		$88.64	per hr
Load per haul (cycle)		15	m^3
Travel time (round trip)		3.8	hours
Load / Unload		2	hours
	Total time per cycle:	5.8	hours
# of hauls (full harvest)		71646	trips
# of hours for total hauls		415547	hours
	Total Cost for UAV Logger Harvest =	**$36,835,180.67**	
	Cost per cubic meter =	**$34.28**	

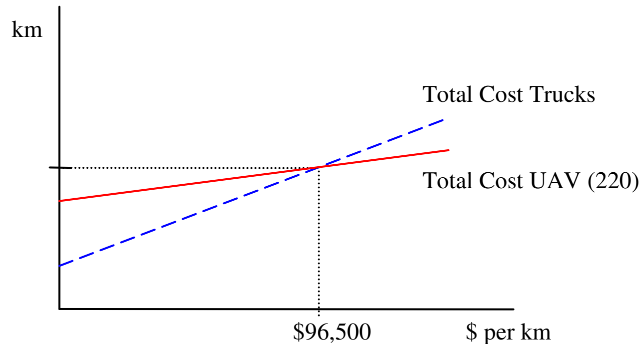
With the extension of the annual operating window to 320 days, table 20 shows the cost drop to $28.02 per cubic metre for the UAV Logger alternative. This result puts the truck-road build option lower by eight percent.

Table 20: Case #3: UAV Logger costing (320 days)

UAV LOGGER			
Harvest size		1,074,680	m^3
Distance over terrain		95	km
UAV Logger speed		50	km/hr
UAV Logger rental		$72.47	per hr
Load per haul (cycle)		15	m^3
Travel time (round trip)		3.8	hours
Load / Unload		2	hours
	Total time per cycle:	5.8	hours
# of hauls (full harvest)		71645.33	trips
# of hours for total hauls		415542.93	hours
	Total Cost for UAV Logger Harvest =	**$30,112,434.09**	
	Cost per cubic meter =	**$28.02**	

With the 220 day operating window for the UAV Logger option to be on par with the truck-road build option, the total cost per kilometre for road build would be $137,932.00. However, with the brief discussion above, noting that the cost to build and cost to maintain these roads throughout the five years has a 70/30 ratio, the average cost per kilometre for build alone can reach $96,500, as seen in figure 25.

Figure 25: Case #3: Break-even: cost ($ per km)



With the extended annual operating window of 320 days, and the 70/30 ratio, the average cost per kilometre could reach $58,000 before the two alternatives are equal.

Given the unique characteristics of this forest area and its fresh canvas, an opportunity exists to employ the best practices from around the world in regards to forest management and harvesting methods. With the extended window, the UAV Logger alternative results in a cost per cubic meter difference of eight percent. With additional efficiencies in the supply chain to help bridge the cost gap, perhaps the new UAV Logger can be incorporated into a section of the forest plan, in order to reap the benefits of a 'green' alternative.

Chapter 8
Discussion of Results

8.1 Case Study Cost Comparison Results

The case study scenarios with the 220 day annual operating window yield results where the truck-road build alternative is the lower cost option. In the WP and WFF cases, the cost difference between the two alternatives is less than 50 percent. In the GRP case, the UAV Logger alternative is more than double the cost of the truck-road build option.

With the three million cubic meter harvest area found north of the GRP, the surface option results in the lower cost. Denser harvests tend to favour the truck-road build option because the cost of the road can be spread out among the higher number of cubic meters of timber. This low haul rate can only be achieved by building the Dickstone Road through the park. Environmentalists resist this road because of potential disturbance to the caribou habitat. The transportation rate increases without this road option and with travel required to be around the park, the harvest area may become uneconomical.

An alternative transportation strategy may be to use the UAV Logger as part of a mixed transportation strategy. The UAV Logger could move the logs over the GRP, to an intermodal transportation point allowing haul trucks to complete the trip to the mill on existing highway infrastructure and at higher travel speeds. With the extended operational window, this mixed strategy results in a cost of $34.61 per cubic meter. This result is approximately 10 percent higher than the highest proposed surface access alternative, which is $31.38 per cubic meter (Tolko Industries Ltd, 2012c). However, the mixed strategy could avoid further build of roads and water crossings in the area.

The results for the Western Peninsula case show that the UAV Logger could be the lower cost alternative with its ability to move the payload directly to the mill over the water. With an extended operational window, the cost per cubic meter for the truck-road build alternative is $21.75 and that of the UAV Logger is $21.26. The UAV Logger cycle time of 4.4 hours is able to compete with the 7.8 hour cycle of the truck-road build alternative. By traveling the direct route from the harvest area unrestricted by surface access, the UAV Logger scenario presents an economically viable alternative to the traditional haul method. Additionally, the lower harvest volume increases the cost per cubic meter of the road build and maintenance. These smaller harvest volumes favour the UAV Logger alternative.

The Whitefeather Forest presents a unique opportunity for the forest industry to expand into new forest land, while able to keep within the Pikangikum First Nation's vision of maintaining their cultural values and practices. The cost comparison analysis shows that the UAV Logger is not a potential alternative when operating 220 days of the year and is 25 percent higher in cost than the truck-road build option. With the extended window, the cost difference is reduced to eight percent and may be further reduced when more data are available for analysis or if other efficiencies are found within the supply chain. The lowest cost per cubic meter may be achieved by creating a mixed plan that would combine the advantages of a limited road network and the use of the UAV Logger to sustainably harvest untouched forest land.

Two significant road costs not incorporated into the analysis are the cost to decommission the road and the full cost for water crossings. Bridges can be costly and the cost of decommissioning a road can equal the price of building it. The full inclusion of these costs could reduce or eliminate the gap between the two alternatives and potentially result in the UAV Logger being economically viable. However, the current demand for wood can be met from established areas, which makes these two costs irrelevant at the present time.

8.2 Price Target for UAV Logger Manufacturers

The case studies show that the UAV Logger units, priced at $4.1 million, are generally not economically viable alternatives in the boreal forest logging industry. If additional efficiencies are found within the harvest process and log hauling supply chain, the difference in cost per cubic meter between the two transportation alternatives analysed may be minimized or eliminated.

By using the current logging industry haul rates, road build and maintenance costs, it may be an advantage for the UAV Logger manufacturers to know what the Canadian boreal forest logging industry may be willing to pay for each UAV Logger unit. The basic methodology for this analysis is to calculate the total available amount of dollars that would be spent on the haul portion of the process, which includes the cost per cubic meter for road build and maintenance. This total available dollar amount could be used to cover the costs of the ground controller, the fuel cost and the UAV Logger units.

To fulfill the logging companies timelines for harvest completion, the number of UAV Logger units required is adjusted accordingly. Appendix E has a full explanation of the methodology and equations. The following two equations are the basis of this price target calculation:

1) Total $/m^3 • Total m^3 harvest = Total $ Available

and

2) Total $ Available = $ Ground Controller + $ Fuel Cost + $ UAV Unit(s)

Using the information from each case study, three possible UAV Logger unit prices are calculated. Detailed calculations for each case study are found in Appendix E.

<u>Case Study #1:</u> The total haul rate for the harvest area north of the GRP is $21 per cubic meter. To harvest the three million cubic meters of timber within the 20 year operational timeline, calculations show that 23 UAV Logger units are required. Each UAV Logger could cost up to $2.13 million.

<u>Case Study #2:</u> The total haul rate for the Western Peninsula case study is $27 per cubic meter. Six UAV Loggers are required to meet the three year harvest completion timeline. Each UAV Logger could cost up to $587,000.

<u>Case Study #3:</u> The total haul rate for the WFF harvest area during Phase 1 is $26 per cubic meter. To meet the goal for the five year timeline, 33 UAV Loggers are required. Each UAV Logger could cost up to $687,500.

The data from these three case studies determines a potential UAV Logger price range of $0.5 million to $2.2 million per 15 ton payload unit, with a near-ground speed of 50 kilometres per hour. Regardless of the price range, there may be a fundamental concern of having up to 33 UAV Loggers operating in one harvest area's air space. UAV Loggers are useful for harvesting in remote areas where access is costly and the timeline for harvest completion is secondary to the ability to reach and harvest the remote timber.

8.3 UAV Logger Concept in Other Industries

Current market conditions for OSB and Kraft Paper make it difficult for the UAV Logger to be an economically competitive transportation alternative. At lower market prices, fewer dollars can be spent on the transportation portion, being a derived demand of the end-product.

Current surface transportation rates for logging are between $15 and $30 per cubic meter. Applying these rates to the 15-ton UAV Logger, the potential earnings per cycle are between $225 and $450. These earnings are unlikely to cover the cost of operations, profit and associated risk.

The UAV Logger concept may be better suited for industries such as hauling mineral concentrates from remote or limited access mine sites and for cargo movement to remote northern communities. Industries that have the ability to charge higher rates for transportation may be more appropriate audiences for this UAV cargo-carrier concept.

For example, the current cargo rates from Winnipeg to Northern Manitoba locations range from approximately $2.00 per kilogram to $8.00 per kilogram depending on the destination and priority level of the cargo (Perimeter Aviation, 2012). At these rates the potential earning per 15-ton UAV Logger cycle could be between $30,000 and $120,000. This is a significant increase in potential earnings compared to the forestry option. With higher value cargo, the opportunity for potential earnings could be increased and more easily justify the use of a UAV for cargo transport.

8.4 The Challenge of Quantifying Externalities

The positive and negative externalities for each haul alternative are identified and discussed but not quantified or included in the cost comparison analysis. The direct cost comparison in this thesis favours the truck-road build option, however the results may change with the inclusion of externalities.

The measurable effect of many externalities is a subjective judgment. For fair compensation there would have to be proof that the externality causes the outcome. For example, the effect of GHG emissions from forestry operations alone and the effect of newly built logging roads on Woodland caribou habitat patterns must be quantified. Quantifying externalities for public environments, such as airspace, forest land, roads and highways is a personnel and financial challenge.

If the effects of having new industrial developments in a forest area, or the social costs of increased predators, traffic and pollution are quantified, the cost per kilometre of the logging road may increase. In contrast, the social benefits of the contribution to the local economy and the enabling for other economic activities, such as mining and eco-tourism, should also be quantified and included. Assuming that the social costs outweigh the social benefits, the result may be a decrease in the maximum distance to economical harvest blocks using the truck-road build option.

This increase in total costs may lead to the re-evaluation of alternatives such as the UAV Logger. It may be logical to assume that the UAV Logger is a greener transportation alternative, but without quantifying its advantages or “greenness” the exact effect will remain unknown.

Chapter 9
Conclusions and Areas of Future Research

9.1 Conclusions

This research suggests that the UAV Logger is uneconomical for timber transportation in the Canadian boreal forest at current product prices and supply availability. At the engineered price estimate of $4.1 million and availability for service at a rate of $88.64 per hour, the UAV Logger is not a competitive alternative. This analysis includes one case when the UAV Logger is a viable alternative at current market prices, if the cost assumptions were satisfied.

Small harvest volumes and high road build costs are conditions that result in the UAV Logger being economically competitive. The advantage of the UAV Logger is greatest when harvest areas are not economically feasible due to the high cost of access. Additional favourable conditions include the extension of the current annual log transportation window and satisfying the concerns of environmental groups. For example, the UAV Logger can avoid construction of water crossings, minimize approval processes and eliminate the habitat disturbance of endangered species, such as the Woodland caribou.

All current harvest methods could take advantage of the UAV Logger, but it is best suited for those using a processor machine. Having the logs processed and piled near the stump allows the UAV Logger to pick up payloads directly from inside the cut block. This reduces the number of machines used during harvest and transportation, minimizes fuel use and emissions and maintains the forest floor biodiversity. The skidding requirement, additional labour and logistics could be minimized, further reducing the cost per cubic meter.

The potential earnings for the 15-ton UAV Logger in the Canadian boreal forest logging industry at current surface transportation rates is between $225 and $450 per cycle. To be a current economic alternative, the manufactured price range for each 15-ton UAV Logger unit is between $0.5 million to $2.2 million.

The UAV Logger concept may be better suited for industries such as hauling mineral concentrates from remote or limited access mine sites and for cargo movement to remote Northern communities. Here, the potential earnings per cycle could increase to upwards of $30,000.

The short to medium trends for the OSB and Kraft paper markets do not display adequate increases to allow for higher haul rates. The United Nations (2004) projects that the world population will be 8.9 billion people by the year 2050. The time could well come when the UAV Logger is a competitive alternative in the forestry industry.

9.2 Limitations of the Study

This study is limited in a number of ways. First, the UAV Logger's economic analysis is dependant upon the engineering cost estimate of $4.1 million. It does not provide for the research and development costs required to bring this technology from a concept to fruition. A comprehensive UAV Logger component list could allow for a more precise engineering cost estimate, along with some fundamental design changes.

Additionally, the cost estimate assumes the full cost of the tethered balloon communication platform on one UAV Logger. In fact, this platform may be used for multiple units and potentially for cell phone communication, therefore the cost could be shared.

The economies of scale for manufacturing larger quantities is briefly discussed, but not quantified, in Chapter Five. This research is limited to identifying the number of UAV Logger units required to satisfy current log harvest timelines of the three case studies. It does not consider the production plan and feasibility of multiple units sharing the same airspace. The optimal and maximum UAV Logger fleet size requires further investigation.

It is acknowledged that further research and development is necessary to make this UAV Logger a success. Outlined below are several areas that require research.

9.3 Areas of Future Research

9.3.1 Auxiliary Equipment and Employee Movement

With minimal or no harvest area road network, there is a need for alternate transportation for the employees, harvest equipment and other auxiliary equipment into the operational area. Under current regulations, the UAV Logger would not be able to transport the employees and other humans into the area because hydrogen is used in the envelope. A helicopter or alternate type of air transportation would be required.

Non-human items that are within the weight limits of the UAV Logger maximum payload capacity could be moved and would not require another type of cargo-lift air vehicle. During harvest operations, auxiliary equipment and miscellaneous items can be moved as full or partial ballast weight, between the "home base" and the forest cut floor.

Air-lifting heavy machinery and indivisible loads into difficult terrain and remote areas has been successful in the recent past. For example, at Powell Lake, British Columbia, helicopters successfully transported a processor up a mountain-side (MacDonald, 2002). Led by Tymatt Contracting, a Canadian Air Crane S-64E Sikorsky helicopter was used to move this piece of logging machinery in seven pieces. It was subsequently re-assembled at the remote harvest site. This cut block used the traditional logging techniques, mixed with heli-logging transportation (MacDonald, 2002).

A second example of moving heavy equipment using air transportation is in the case of the Galore Creek Mine Project. Located in a remote section of northwestern British Columbia, this gold and copper mine is approximately 60 kilometres from the nearest existing road. This required everything to be air-lifted in, from heavy machinery to the living accommodations including the kitchen sink (VanNatta, 2008). The heavy machinery required the use of a Russian-built helicopter, the MI-26 flying crane, where the hook was rated to carry 20 tons. This helicopter had a crew of five and carried a high cost for fuel and operation (All the World's Rotorcraft, n.d.).

9.3.2 Operations Control Centre (OCC)

The requirement and use of the OCC is discussed in Chapter Five. Its main functions are the monitoring, coordinating, dispatching and telecommand activities of the UAV Logger. The OCC may house a virtual cockpit and trained pilots, responsible for the flight paths and emergency piloting. Monitoring weather patterns and adjusting the flight path is vital to the efficient use of a UAV Logger, which would otherwise be adjusted by a pilot on-board.

When this UAV Logger technology is adapted and more widely used, the opportunity could exist for a common OCC. Similar to current airports, control tower operators could assist and manage several aircrafts from one central location. If different industries utilized UAV Logger technology for cargo transport, the trained personnel could assist regardless of the cargo being transported.

9.3.3 Ground-Handling Procedures

Efficient ground-handling procedures are pertinent to the success of the UAV Logger operation. As in many industries and processes, it is important to minimize the required non-value added steps such as product handling and turnaround time. Maximizing the amount of air time is crucial because it is the value-added contribution to the overall process.

9.3.3.1 Docking Process and Ballast Exchange

The docking and ballast exchange processes both require further research. This is a two part process because of requirements in the field and at the landing or mill. A suggestion for the in-block process could borrow some of the current elements from heli-logging. This requires an employee on the forest floor that has the capability to estimate the weight of the logs with respect to the payload lift capacity of the UAV Logger and attach a cable around the log or grouping of logs for transport.

To facilitate the docking procedure and ease the process of ballast exchange, on-site management of this exchange at both points, the main landing and in the cut-block, is suggested. This could be done using a joy-stick type of controller, where the employee safely guides the UAV Logger to the proper position for the load or unload process. At a certain approach distance, the auto-pilot could indicate that it requires a piloted approach for further operations.

9.3.4 Storage and Maintenance

The storage, long term docking and hangar placement for maintenance procedures also needs to be further researched. Ideally, these units should have the ability to be anchored at the harvest site such that they could be protected in adverse weather. For long-term storage and more extensive maintenance requirements, the UAV Logger could be deflated and returned to the designated hangar. Emergency repairs or smaller repairs can be done in the field.

9.3.5 Harvest Operation Efficiencies

Additional efficiencies and cost savings can be found by the potential adjustment to the harvest operation that was not considered in this research. For example, the UAV Logger could perform site pickups at the point where the processor or feller-buncher is operating. This would minimize or eliminate the skidding operation and reduce costs associated with transporting logs to a roadside pickup point.

The employees at each pickup site could potentially use infrared flashlights to signal to the UAV Logger for payload pickup. This type of tracking technology could assist with pin-pointing the load in the forest and assist with minimizing the movement of the timber from the cut site.

9.3.6 Production Plan and Supply Chain Efficiencies

Several UAV Loggers may be required to move the harvest volume within a designated timeframe. For efficient use of the UAV Loggers, the financial investment and all employees, a production plan should be created that optimizes fleet utilization, harvest operation and mill production.

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Acronyms

AIAA:	The American Institute of Aeronautics and Astronautics
AOP:	Annual Operating Plan
CAR:	Canadian Aviation Regulations
CBA:	Cost benefit analysis
CBI:	Canadian Boreal Initiative
CBFA:	Canadian Boreal Forest Agreement
CFSA:	Crown Forest Sustainability Act (Ontario)
CPAWS:	Canadian Parks and Wilderness Society
CTL:	Cut-to-Length
DARPA:	Defence Advanced Research Projects Agency (United States Department of Defense)
DCHS:	Dynamic caribou habitat schedule
DOT:	Department of Transport (Canada)
EA:	Environmental Assessment
EA Act:	Environmental Assessment Act (Ontario)
FAA:	Federal Aviation Association (USA)
FML:	Forest Management Licence
FMP:	Forest Management Plan
FRDP:	Forest Road Development Plan
FRL:	Forest Resource Licence
GHG:	Greenhouse Gas (emissions)
GRP:	Grass River Park
IRMT:	Integrated Resource Management Team
LEMV:	Long Endurance Multi-Intelligence Vehicle
LSL:	Laminated Strand Lumber
LTA:	Lighter-than-Air
MIT:	Manitoba Infrastructure and Transportation
MNR:	Ministry of Natural Resources (Ontario)
MPB:	Marginal private benefits

MPC:	Marginal private costs
MSB:	Marginal social benefits
MSC:	Marginal social costs
NASA:	National Aeronautics and Space Administration
OCC:	Operational Control Centre
OSB:	Oriented-Strand-Board
PVC:	Polyvinyl chloride
SFL:	Sustainable Forest Licence
SFMM:	Strategic Forest Management Model
SFOC:	Special Flight Operation Certificate
TC:	Transport Canada
UAS:	Unmanned Aircraft System
UAV:	Unmanned Aerial Vehicle
UV:	Ultra-violet
VTOL:	Vertical takeoff and landing
WFF:	Whitefeather Forest
WFMC:	Whitefeather Forest Management Corporation
WP:	Western Peninsula

Glossary

All-weather road: An unpaved road constructed of a material (mainly gravel) that does not create mud during rainfall.

Avionics: The electronic systems used on an aircraft. Its systems may include communications and navigation.

Ballast: A heavy substance placed in such a way as to improve stability and control.

Ballonet: A compartment of variable volume within the interior of a balloon, or airship used to control ascent and descent. Commonly filled with ambient air.

Back-haul: The return trip of a vehicle transporting cargo back along the route from its destination to its point of origin.

Boreal forest: The boreal forest is a worldwide band of conifer-dominated forest that stretches across Scandinavia, Russia, Alaska and northern Canada. Within Canada, the boreal forest region covers more than 290 million hectares. Boreal forests are dominated by species of spruce, fir, pine, larch, birch, and aspen. Their forest floors are usually covered with mosses and many species of wildflowers.

'Bring Logs Roadside': Term used in reference to the completion of the harvest operation steps. Normally used for costing purposes and includes the costs for all processing steps from felling the tree to having it ready for transport.

Composite wood: Engineered wood that is made by binding together strands, particles or fibres together to make a composite product. Commonly used in building construction; joists, beams, panels.

CTL: Cut-to-Length. A forest harvest method where the felling and processing steps are performed at the stump. Common machinery used for this method is the processor – forwarder combination.

Cut block: A specified area where the trees will be cut as part of a forestry operation.

Decommission: The formal process to remove something from active status. May include the removal of water crossings and silviculture activities.

Delimbed:	To remove all the limbs and branches from a tree.
Doppler radar:	A specialized radar that makes use of the Doppler effect to produce velocity data about objects at a distance. Commonly used in aviation, meteorology and police speed guns.
Downwash:	In aeronautics, downwash is the air forced down by the aerodynamic action of a wing or helicopter rotor blade in motion as part of the process of producing lift.
Edge dweller:	A being that resides near the edge of a habitat (or forest).
Faller:	A person who fells trees.
Fell (felled):	To cut down a tree.
Feller-buncher:	A forest harvest machine that is used to cut and bunch the trees stems during harvest.
Forest stand ages:	The ages of the standing timber or of a forest area of trees.
Forwarder:	Self-propelled machine, usually self-loading, designed to transport trees or parts of trees by carrying them completely off the ground. Commonly used in combination with a processor.
Harvest block:	see 'cut block'. Can be used interchangeably.
Ice road:	Man-made, seasonal winter roads mainly built over frozen waterways and frozen terrain.
Landing:	An area use for log processing, intermediate storage and as a transfer point for transportation.
Limbed:	see 'delimbed'.
LSL:	Laminated Strand Board. A type of composite wood. See 'OSB'.
OSB:	Oriented Strand Board. A composite wood product that is manufactured by layering strands of wood in specific orientations.
Payload:	The revenue-producing part of cargo, usually expressed in weight.
Primary road:	A permanent, general access road throughout the forest.
Processor:	Can perform the duties of the feller-buncher, delimber and slasher in a single process step. Also called a harvester.

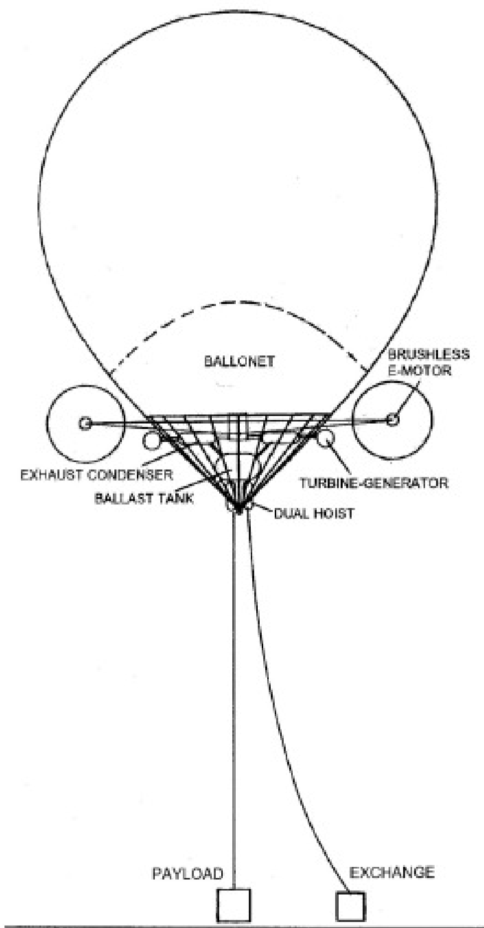
Secondary road:	An access road to and within harvest operating areas. Usually all-weather roads.
Silviculture:	The care and cultivation of forest trees.
Slash:	Refers to the residual woody debris after timber harvesting.
Slashing:	To cut felled trees into pre-determined lengths, with a shear or saw. Normally done after the tree is delimbed.
Stranded asset:	An asset whose market value is less than its book value because it has become obsolete before the completion of its depreciation schedule. For example, an all-weather logging road that is abandoned without decommissioning efforts.
Stumpage fees:	An amount a contractor pays the landowner for standing timber. Also referred to as 'timber dues'.
Telecommand:	A command sent to control a remote system not directly connected. Commonly via wires or satellite communication.
Tertiary road:	An access road to and within harvest blocks. Usually seasonal type roads.
Tier 1 company:	In manufacturing, a Tier 1 contracts and supplies materials and parts direct to the manufacturer. For example, supplying parts and labour for the final assembly of the airship.
Tier 2 company:	A Tier 2 company sells to the Tier 1. For example, supplying parts for a airship sub-assembly.
Top (topped):	To remove the top portion of the tree depending on the minimum diameter for the log.
Virtual cockpit:	A computer simulated environment that can simulate physical presence in the cockpit of an aircraft.
Winch:	A mechanical device used to adjust the tension of a rope.
Yarder:	A winch (or system of winches) powered by an engine and uses cables to pull logs from the stump to a landing.

Appendix A

Logger: Baseline Definition

Source: Juergen Bock
SLTA Engineering – Consulting

The aircraft herein denoted as „LOGGER" is an unmanned self-propelled cargo balloon conceived for operations particularly in Northern Canada at areas not prepared for aviation ground operations. The Logger is therefore designed for externally suspended payloads and stays aloft at the operations site, thus avoiding any direct carrier footprint during payload pick-up/delivery.



To maintain aerostatic equilibrium, the Logger is equipped with two (2) suspension cables, one for the payload and a second one for a compensatory exchange ballast provision.

The concentrated suspended load will be dispersed by means of rigid upside-down conical cage structure which transfers the load into the non-rigid envelope at a moderate membrane stress level. The design provides thus a defined interface of rigid and soft structures of the carrier.

The envelope comprises an essentially spherical balloon with its bottom portion adapted to the a.m. conical cage. The upper volume of the balloon is filled with the lifting gas, while the lower part, the so-called „ballonet", is separated by a gastight fabric diaphragm. The ballonet volume is connected with an external blower (here not shown) which provides a permanently defined pressure differential between the interior of the balloon and the varying exterior atmospheric pressures.

Subsystems

1. Propulsion and Control

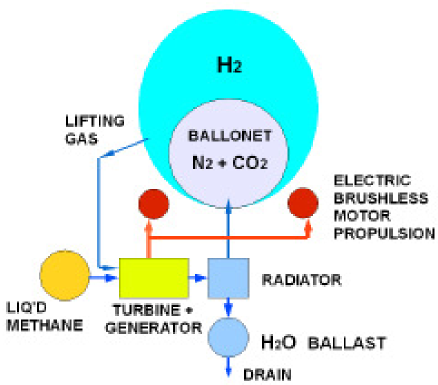
The propulsion system consists of two 6 m diameter propellers, laterally mounted at an transverse outrigger structure and driven by brushless electric motors which are powered by two turbine generators for reasons of redundancy. The combined energy from both generators will be distributed and controlled by a telecommanded avionic blackbox.

Directional flight control will be achieved by differential thrust. Vertical control is foreseen by utilizing the vertical thrust components of both propellers by virtue of a slight upward inclination of the prop disks. For a craft at aerostatic equilibrium, augmented thrust would affect instant climbing, reduced thrust affects descent, respectively. The purpose of this feature is to enable precise landing maneuvers.

2. Fuel, Gas and Trim

The turbines for the electric generators are driven by liquefied methane, being a highly hydrogenerized „clean“ fuel with a high energy content per mass (kWh/kg).

The upper main volume of the balloon is inflated with hydrogen, the gas with the highest lifting power for aerostats. In addition, it is foreseen hydrogen may be urilized as a propellant for the turbines as well, in order to compensate for the weight loss of the liquid methane consumed during flight operations.



The diagram indicates a further option of equilibrium balancing, i.e. collecting water from an exhaust condensor, thus providing the capability of quick water ballast discharge if required.

An additional installation comprises a tubing from the condenser to the ballonet which directs portions of the dried exhaust gases – primarly nitrogen and carbondioxyde - into the ballonet to suppress dangerous oxyhydrogen gas in case of an internal hydrogen leak.

3. Avionics and Telecommand

The avionics and telecommand system is TBD and has to be tailored according to the specific requirements of the various scenarios of Logger operation. Logger-specific equipments are e.g.:

- Doppler radar to determine the crosswind angle at low cruise speed
- Hydrogen gas monitoring and control
- Liquid fuel tankage monitoring and control
- Ballonet/hull cavity oxyhydrogen gas monitoring and flush control
- Video link for ground cockpit virtual flight control
- Pressure, temperature and icing monitors

4. Operation Scenarios

Operation and Mission Scenarios are based on a hierarchical system of ground stations as follows:

- ”Classical” airship base with hangars and all necessary provisions for assembly, full servicing, maintenance and repair
- Operations Control Center for the coordination, monitoring, dispatching and telecommand of the individual missions
- Servicing stations for one or a number of outpost stations with mooring provisions and all facilities required for fuelling and replenishment of lifting gas, being located at strategic points for cargo transfer from a Logger-type carrier to alternative means of transportation.
- Outposts or Field Stations with mooring facilities for pick-up and delivery of payloads at unprepared field locations.

4. Data

4.1 Configuration

Lateral diameter:	30 m
Overall height:	38 m
Gross volume:	14,100 m3 sea level
Hydrogen volume:	13,600 m3 sea level
Free aerostatic lift:	6900 kg equivalent

4.2 Propulsion

2 generators à	1000 kW
2 lateral propellers	6,00 m diameter

4.3 Performance

Max airspeed:	72 km/h sea level
Propulsion efficiency:	77 per cent
Overall efficiency:	23 per cent
Liq'd methane fuel:	13,9 kWh/kg
Average head wind:	15 knots

Notice:

This Baseline Definition Document represents the essential engineering concept of the Logger system as the outcome of a careful system requirements analysis w.r.t. the design and operational conditions dictated by the environmental and economic boundary conditions. However, this does not exclude modifications of the overall appearance and/or technical details as results of a continuative development plan.-

Appendix B

Logger: Operational Modes

Source: Juergen Bock
SLTA Engineering – Consulting

This document describes a spectrum of guidelines for the derivation of realistic data for the purpose of economic evaluation. It is based on data provided by the Baseline Definition Document in addition of the environmental and operational boundary conditions given for each individual case (e.g. prevailing wind, operational sequence etc.).

In view of the North Canadian scenario, the flight altitude is in general assumed to be in the order of 1600 ft or 500 m, respectively. For the standard two-way case, one leg may be assigned for payload transfer while the other one will be assigned for ballasted flight (e.g. lumber hauling on the return leg).

1. Mission Profiles

Each mission starts at a servicing station where a Logger is temporarly moored by means of ground anchor located at the lower tip of the upside down conus structure. Here it will be serviced, i.e. maintained, replenished with hydrogen gas and refuelled with liquefied methane and – last not least – provided with the payload or compensatory ballast, respectively.

1.1 Shuttle Timelines

Shuttle timelines (e.g. w.r.t. lumber hauling) may be subdivided into the following phases:

- Approximately 1 to 2 hours preparation time prior to take-off, including ballast attachment to the respective suspension line and equilibrium trimming. During this time, fuel will be consumed at a lower level, typically 20 per cent of maximum power
- Take-off and forward flight time at an individually set power level
- Hovering at the mission field site, pick-up of payload (logs) and disposal of ballast. The time required for these actions may be calculated to last one hour, again at a low level of fuel consumption
- Return flight at an individually set power level
- Touch-down and landing at the servicing station, reballasting and delivery of the payload and preparation for another cycle

1.2 Airspeed and Power Settings

For the determination of the most economical and ecological flight strategy, the following parameters have to be taken into account:

- Given range – e.g. 50 km
- Still air operation or
- Headwind blowing on both ways or
- Headwind on the forward, tailwind on the return flight or vice versa
- Chosen airspeed : 72 km/h or 55 km/h
- Power installed for 72 km/h or 55 km/h

Example #1:

(a) Still air – airspeed 72 km/h

Time req'd for one shuttle cycle:

2 + 50/72 +1 + 50/72 = 4.39 hours

(b) Fuel required:

2000 /13,9 (3 x 0.20 + 2x50/72) = 286 kg

to be deducted from gross lift to determine payload: 6900 – 286 = 6614 kg

(c) Fuel efficiency factor:

6614/286 = 23.1 payload/fuel

6614/1000 x 50 / 286 = 1.156 ton km/kg

(d) Transport efficiency:

6614/1000 x 72 = 476 ton km/h

An interesting comparison will be given, when the airspeed will be reduced to 55 km/h; in this case the power required will be reduced according to the cube law, hence only 892 kW will be applied with following results:

Example #2:

(a) Still air – airspeed 55 km/h

Time for one shuttle cycle: 4.82 hours

(b) Fuel required: 155 kg

deduction from gross lift:

6745 kg payload carrying capability

Example #2 (cont'd):

(c) Fuel efficiency factor:
43.5 payload/fuel
2.174 ton km/kg
(d) Transport efficiency:
371 ton km/h

These two examples highlight the difference between the ecologic aspect (payload/fuel as well as ton km/kg fuel) and the economic figure (ton km/h), whereas the ecologic point of view assumes the more prominent position w.r.t. the environmental impacts.

1.3 Wind Conditions

Since the foregoing chapter indicates a distinct preference of lower operational airspeed, one has to emphasize the impact of headwinds on the speed-over-ground where the carrier with the higher airspeed has an obvious advantage in comparison with a slower craft. The calculated headwind in either case is 15 knots = 7.7 m/s (28 km/h) with the pessimistic assumption that headwind will be effective on both forward and return flights.

Example #3: headwind 15 knots on all flights
(1) airspeed 72 km/h; ground speed 44 km/h
shuttle cycle 5.27 hours
airspeed 55 km/h; ground speed 27 km/h
shuttle cycle 6.70 hours
(2) airspeed 72 km/h;
fuel required: 413 kg; payload: 6487 kg
fuel efficiency: 15.69 payload/fuel
transport efficiency: 285 ton km/h
(3) airspeed 55 km/h;
fuel required: 276 kg; payload: 6624 kg
fuel efficiency: 24.00 payload/fuel
transport efficiency: 179 ton km/h

This comparison indicates also the superior ecologic performance of the lower power setting.

2. Design Aspects

2.1 Powerplant Installation

Emphasis on ecology as well as production cost may favor an installed powerplant for a maximum airspeed of 55 km/h. The weight savings w.r.t.the engines, generators and associated structures from 2000 kW to about 900 kW will result in an increase of gross lifting capability from 6900 kg up to 9800 kg; a rather attractive aspect!

Whether such a design decision should be realized depends on following critical considerations:

(1) Do the weather statistics of Northern Canada permit economic operation of an inherently slower Logger – or will down-times exceed a tolerable level?
(2) For the evasion of foul weather fronts it is advisable to escape potential hazards at a temporary highest speed level. This requires extra power installed for the sake of system safety!
(3) Also, it is conceivable that a number of individual missions may – due to urgency - depend upon maximum transportation speed rather than optimum ecology.

Résumé:
The final decision concerning the necessary power to be installed depends, at this time of the project, on the anxiety factors w.r.t. the uncertainties of weather, detail design and aerodynamics.-

2.2 Upscaling

Upscaling of carrier systems to improve both ecology and economy is a commonly accepted procedure. On the other hand, it is a well-known fact that increases in size bear new problem parameters that may be contra-productive w.r.t. the overall system concept and deserve careful attention.

Upscaling to 35 m Diameter:
Volume: 22,450 m3
Available lift: 11,850 kg equivalent
Max airspeed: 72 km/h
Power req'd: 2866 kW
at 50 km range shuttle:
Payload: 11,449 kg
Payload/fuel: 27.90
Ton km/fuel: 1.395 t km/kg
Ton km/h: 824
at 50 km range shuttle and 55 km/h:
Power required: 1278 kW
Payload: 11,628 kg
Payload/fuel: 52.32
Ton km/fuel: 2.616 t km/kg
Ton km/h: 640

Upscaling to 40 m Diameter:
Volume: 33,510 m3
Available lift: 18,500 kg equivalent
Max airspeed: 72 km/h
Power req'd: 3950 kW
at 50 km range shuttle:
Payload: 17,900 kg
Payload/fuel: 31.73
Ton km/fuel: 1.587 t km/kg
Ton km/h: 1,291
At 50 km range shuttle and 55 km/h:
Payload: 18,190 kg
Payload/fuel: 59.40
Ton km/fuel: 2.970 t km/kg
Ton km/h: 1,001

This data indicate the definite advantages of scale; however, there are several issues that deserve not only attention but inevitable further analyses, e.g.:

- Development and production costs
- Integration and assembly facilities
- Configuration of propulsion system
- Compliance with existing needs
- Utilization factor over lifetime

Subsequent section 3 will indicate approaches how to determine realistic solutions.

3. Marketing and Operations Research

Based on the assumption of a theoretical large carrier for – say – 80 tons payload over a distance of 100 to 300 km or more with favorable flight economics properties may be a show-stopper at first sight; in a realistic scenario, however, it may be oversized for a wide spectrum of transportation tasks in a country with a multitude of scattered destination sites. Consequently, such a carrier will scarcely utilize its full capacity or will have to wait for orders that demand full payload carrying cabability. The economic utilization factor over lifetime may thus be rather unsatisfactory, especially w.r.t. the high development and productions costs for singular units.

3.1 Fleet Concept and Consequences

An analogy with a truck company may serve as an example: For long distances and well-established mass deliveries, very large („Super")-Trucks are being recommended as an economical and ecological favorable solution. In the case of local deliveries, , of a broad variety of goods, however, a fleet of maneuverable delivery vans represents the better choice. Moreover, transportation of large quantities of apportionable goods can be conveniently distributed over a number of vans, while flexibility of efficient distribution can be achieved by a clever dispatching policy, in other words – software!

In consideration of the logging scenarios in the Northern Canadian forests, one may , due to the working conditions in the field, expect air transportation of single logs and/or smaller bundles of logs rather than a huge heavy pile of lumber that would require heavy machinery and securing devices. This would also apply to minerals and other apportionable materials.

In case of large quantities of lumber, fleet operation could provide a transportation chain, whereas the sequence Logger schedules has to be controlled such that no mutual interferences will occur at any phase of the mission (e.g. waiting for a landing permit while a predecessor Logger still stays on the touch-down site).

3.2 Estimates on Carrier and Fleet Sizes

Estimates on carrier and fleet sizes are subject to a continous requirements research and analysis. The gradual progress in data acquisition may induce a corresponding buildup of a fleet and the associated control organizations. There is, however, no doubt about the advantage in price in case of a serial production.

Predominant problem remains the decisions w.r.t. the selection of the optimum size of a Logger type as the best compromise, especially w.r.t. the conflict between best economy and realistic demands, i.e. production costs, maneuverability, flexibility of operation etc.-

Appendix C

Logger: Lumber Hauling

Source: Juergen Bock
SLTA Engineering – Consulting

1. Introduction

This paper is an attempt to establish cost models of lumber hauling scenarios using Lighter-Than-Air UAV transportation systems. The objective is to economically optimize the use of LTA carriers by matching the daily harvest of an off-road lumber crew with the capabilities of said carriers.

2. Harvesting Modes

For modeling the harvesting modes, the following assumptions are being made:

- The cutting crew works off-road about 50 km away from a so-called servicing station being located at solid road or navigable waterway
- Said servicing station comprise anchoring and servicing provisions for LTA carriers, as well as interfaces with tele-piloting and tele-command centers
- Said servicing stations comprise also facilities for intermediate storage of lumber for further expedition via road or waterway
- The off-road harvesting and hauling in more detail is based on the following assumptions
  - The daily area being covered is in the order of hectares
  - Clear cutting and planting of seedlings and/or selective cutting
  - The daily harvest amounts to TBD tons (tentatively 20 tons)
  - Due to the extension of the daily working area, the logs will be piled up for pick-up in conveniently distributed stacks rather than being compiled in a single stack
  - Members of the cutting crew will be available to hook up the stacks to the cargo suspension line and release the ballast necessary to keep he aerostatic equilibrium when flying without payload

3. Sizing of LTA Carrier Systems

The rule-of-thumb would lead to a carrier type that would carry the daily yield in one single haul, based on the rule that the carrier with the highest load capacity provides also the highest economy of transportation. Although true in theory, this assumption is false in reality because:

- The daily yield varies and may exceed the inherent load capacity, thus resulting in uneconomical multiple flights
- The daily yield varies and does not at all require the inherent load capacity, thus resulting in carrying non-paying ballast
- Assuming a full shuttle cycle of five hours, the craft would lie idle for the rest of the day, thus resulting in a low overall utilization factor
- In the case of multiple scattered stacks, complex payload pick-up procedures would be necessary, resulting in extra work loads on the ground crew

To warrant a flexible adaption of mission operations to a wide spectrum of uses, subsequent sections will attempt to define a compromise LTA craft that will satisfy a variable spectrum of requirements, preferably within the scope of a fleet operation.

3.1 Data of Candidates

Table 1 indicates the key data of various sizes of Loggers:

Common features: 60 km/h max airspeed near ground; 80 per cent propulsion efficiency. The prototype development, manufacturing and certification price is assumed to be 2000 $/m3

Table 1

Type #	diameter m	volume m3	max load kg	max power kW	prototype million $$
1	20	4.190	2.034	523	8,4
2	25	8.180	4.823	788	16,4
3	30	14.140	9.258	1.115	28,3
4	35	22.450	15.403	1.501	44,9
5	40	33.510	23.765	1.957	67,0

Subsequent Tables 2 to 6 summarize the performance data for shuttle ranges up to 100 km, assuming liquefied methane or natural gas as a fuel with an energy content of 13.9 kWh/kg. Operating time assumed is 12 hours/day; downtime between shuttle cycles is 2 hours for cargo loading/unloading and replenishment. The average speed over ground is 50 km/h.

Table 2 – Type #1

range km	cycle h duration	fuel kg methane	lift less fuel kg payload	payload/fuel factor kg/kg	efficiency ton km / kg	efficiency ton km/h
25	3	53	1981	37,6	0,940	39,6
50	4	90	1944	21,5	1,076	38,9
75	5	128	1906	14,9	1,117	38,1
100	6	166	1868	11,3	1,129	37,4

Table 3 – Type #2

range km	cycle h duration	fuel kg methane	lift less fuel kg payload	payload/fuel factor kg/kg	efficiency ton km / kg	efficiency ton km/h
25	3	79	4744	59,8	1,494	94,9
50	4	136	4687	34,4	1,722	93,7
75	5	193	4630	24,0	1,802	92,6
100	6	249	4574	18,3	1,834	91,5

Table 4 – Type #3

range km	cycle h duration	fuel kg methane	lift less fuel kg payload	payload/fuel factor kg/kg	efficiency ton km / kg	efficiency ton km/h
25	3	112	9146	81,4	2,0	182,9
50	4	193	9065	47,1	2,4	181,3
75	5	273	8985	32,9	2,5	179,7
100	6	353	8905	25,2	2,5	178,1

Table 5 – Type #4

range km	cycle h duration	fuel kg methane	lift less fuel kg payload	payload/fuel factor kg/kg	efficiency ton km / kg	efficiency ton km/h
25	3	151	15252	100,9	2,5	305,0
50	4	259	15144	58,4	2,9	302,9
75	5	367	15036	41,0	3,1	300,7
100	6	475	14928	31,4	3,1	298,6

Table 6 – Type #5

range km	cycle h duration	fuel kg methane	lift less fuel kg payload	payload/fuel factor kg/kg	efficiency ton km / kg	efficiency ton km/h
25	3	197	23568	119,6	3,0	471,4
50	4	338	23427	69,3	3,5	468,5
75	5	479	23286	48,6	3,6	465,7
100	6	619	23146	37,4	3,7	462,9

3.2 Fleet Performance Data

To decide whether single heavy lifters or a fleet of smaller sized LTA carriers should used for lumber hauling, the following tables are generally based on the assumption of three shuttle cycles per day over a distance of 50 km at normal moderate climatic conditions. These tables show the maximum transported payloads per diem and also the amount of fuel required, thus providing data for further analyses.

Table 7 – Fleet Performance: tons per diem

TYPE				FLEET SIZE				
	1	2	3	4	5	6	7	8
#1	5,8	11,7	17,5	23,3	29,2	35,0	40,8	46,6
#2	14,1	28,1	42,2	56,2	70,3	84,4	98,4	112,5
#3	27,2	54,4	81,6	108,8	136,0	163,2	190,4	217,6
#4	46,4	92,8	139,2	185,6	232,0	278,4	324,8	371,2
#5	72,9	145,9	218,8	291,7	364,6	437,6	510,5	583,4

TYPE			FUEL REQUIRED kg					
	1	2	3	4	5	6	7	8
#1	90,3	180,6	270,9	361,2	451,5	541,8	632,1	722,4
#2	136,1	272,1	408,2	544,2	680,3	816,3	952,4	1088,5
#3	192,5	385,0	577,6	770,1	962,6	1155,1	1347,6	1540,1
#4	259,2	518,3	777,5	1036,7	1295,8	1555,0	1814,2	2073,3
#5	337,9	675,8	1013,7	1351,6	1689,5	2027,4	2365,3	2703,2

Comments: The color code indicates the types and fleet size for the required daily haul, e.g.:

- *Yellow for 20 tons per diem, whereas 4 units are required for Type #1, 2 units for Type #2 and 1 unit for Type #3. Note that Type #4 and #5 are already over-dimensioned*
- *Blue for 40 tons per diem, whereas 7 units are required for Type #1, 3 units for Type #2, 2 units for Type #3 and 1 unit for Type #4. Type #5 is, again, over-dimensioned*

4. Investment Requirements

The estimated investment requirements for the various fleet sizes take advantage of the serial production learning effect. Subsequent figure shows the diagram of such learning curves:

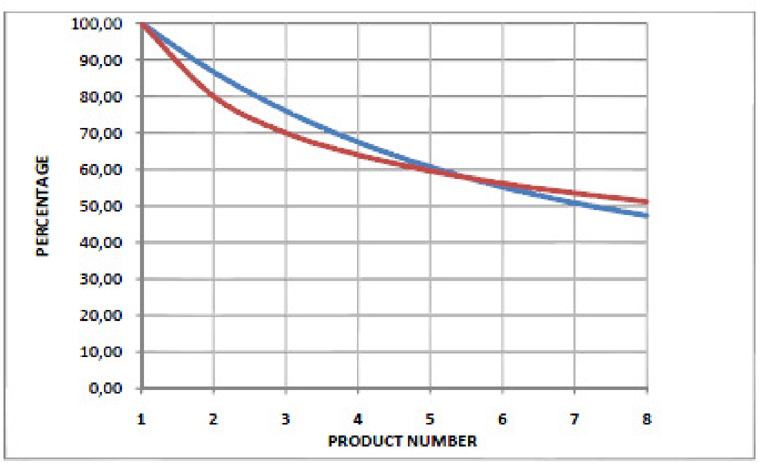


Table 8 presents the estimated costs of the various fleet sizes, accordingly:

Type	1	2	3	4 **million $$**	5	6	7	8
#1	8,4	16,2	23,5	30,5	37,0	43,2	49,2	54,9
#2	16,4	31,6	46,0	59,5	72,2	84,4	96,0	107,1
#3	28,3	54,7	79,4	102,8	124,9	145,9	166,0	185,2
#4	44,9	86,8	126,1	163,2	198,3	231,6	263,5	294,0
#5	67,0	129,6	188,3	243,6	295,9	345,8	393,3	438,9

Comment: Following the color code as per Table 7 (i.e. yellow for 20 tons daily or blue for 40 tons, respectively), one may observe that, for apportionable goods, fleet operation may have obvious merits. Comparing the ecological impact (Table 7 lower table), there is an obvious advantage of large single types, as generally experienced in transportation economy. Fortunately, negative ecological impact of using methane and hydrogen as propellant is definitely minor than in the case of jet fuel, diesel and/or gasoline, the costs of fuel are of predominant interest.

Table 9 presents the estimated fuel costs for the various fleet size, assuming a price tag of 0.05 $/kg for fuel.

TYPE	1	2	3	4 **$$**	5	6	7	8
#1	4,52	9,03	13,55	18,06	22,58	27,09	31,61	36,12
#2	6,80	13,61	20,41	27,21	34,01	40,82	47,62	54,42
#3	9,63	19,25	28,88	38,50	48,13	57,76	67,38	77,01
#4	12,96	25,92	38,87	51,83	64,79	77,75	90,71	103,67
#5	16,89	33,79	50,68	67,58	84,47	101,37	118,26	135,16

Note: These figures do not include any taxes (if applicable), but indicate that they are, indeed, of minor impact as compared with the incurring capital cost.

5. Résumé

This investigation shows that a fleet of four to seven (Type #1) or two to three (Type #2 and #3) LTA-UAVs are capable of daily hauling up to about 50 tons of apportionable goods (i.e. lumber) over a distance of 50 km. Operational flexibility w.r.t. varying mission tasks and the capability to pick up smaller stacks of lumber scattered over a larger area during tree cutting operations represents a definite advantage of fleet operation in comparison with heavy-lifter carriers (Types #4 and #5) being dedicated for indivisible heavy payloads.

Personnel costs have not been considered as yet due to omission of piloted operation.

Appendix D

Visuals and Descriptions of Common Forestry Machinery

Feller – Buncher:
Used to cut and bunch tree stems during harvest.

Delimber:
Used to remove all limbs from the stem of the tree and to cut the tree top.

Grapple Skidder:
Drags the trees to a landing or roadside. The skidder shown here has a grapple head attachment.

Slasher:
Cuts felled trees to pre-determined lengths using a shear or saw.

Loader:
Loads the processed trees onto a truck for haul.

Processor:
Can perform the duties of the feller-buncher, delimber and slasher in a single process step. Also called a *harvester*.

Forwarder:
Loads logs into its 'basket' and hauls them from the forest floor to a landing or roadside. Commonly used in combination with a processor.

Appendix E

Methodology and Calculations for UAV Manufacturer Price Targets based on Current Logging Industry Haul and Road Build Rates

Calculations for the "work backwards" methodology that estimates the current available dollar contribution for the UAV Logger.

Basic Methodology:

A) The total \$ per m^3 for the truck-road option includes the cost contribution from the haul rate, the road build and the road maintenance. Therefore:

$$\textbf{Total \$ per m}^3 \cdot \textbf{Total m}^3 \textbf{ harvest} = \textbf{Total \$ Available}$$

B) To harvest the specified harvest area within the time limits of the logging company, the number of UAV Logger Units required can be calculated by dividing the daily harvest volume by the amount of payload per haul. In this case, it is 15 m^3.

Daily Haul = Total m^3 harvest / Total number of days to complete harvest

UAV loads per day = Daily haul / 15 m^3

# of UAV Units = UAV Loads per day / Cycles per day per UAV

C) The amount in (A) that would have been put towards the Surface Truck Haul option could be used to fund the Airship option. Therefore:

Total \$ Available = \$ Ground Controller + \$ Fuel Cost + \$ UAV Unit(s)

The Ground Controller cost can be calculated by using its contribution to the hourly rental rate of \$25 per hour (table 5, Chapter Five). This position can be monitoring multiple units simultaneously, therefore the number of hours is

\$ Ground Controller = Total # of hours for full Airship harvest / # of UAV Units

The Fuel Cost can be calculated based on Juergen Bocks performance data for the Type 4 Unit. The cost per hour is $11.88 (table 5, Chapter Five)

$$\text{\$ Fuel Cost} = \text{\$11.88 per hour} \cdot \text{Total \# of hours for full Airship harvest}$$

After subtracting all known variables, the balance is equal to the dollar amount for UAV Unit(s).

$ UAV Unit(s) = Total $ Available - $ Ground Controller - $ Fuel Cost

D) The available dollars per Unit required can be calculated.

$ per UAV Unit = $ UAV Unit(s) / # of UAV Unit(s)

<u>Result:</u> At the specified Total Haul Rate, the $ per UAV Unit is the total dollar amount that can be put towards one UAV Logger (rented or purchased).

Case Study #1:

Harvest volume = 3,000,000 m^3 Haul Rate = \$20/ m^3 Includes road build Maintenance = \$1/ m^3 Total = \$21 / m^3 Timeframe to complete harvest = 20 years Operational days per year = 220 days Total days = 20 • 220 = 4,400 days	UAV Data: Payload = 15 m^3 Cycle time = 5.4 hours. (table 10) Each UAV can haul 2 loads per day Fuel cost = \$11.88 per hour Total number of hours to complete harvest by Airship = 1,080,000 hours (table 10)

A) Total \$ Available = \$21/m^3 • 3,000,000 m^3 = **\$63,000,000.00**

B) Volume to move per day = 3,000,000 m^3 / 4,400 days = 682 m^3/day
UAV loads per day = 682 m^3 per day / 15 m^3 per load = 45.5 = 46 loads

\# of UAV Units = 46 loads / 2 per UAV **= 23 UAVs required.**

C) **Total \$ Available = \$ Ground Controller + \$ Fuel Cost + \$ UAV Unit(s)**

Fuel Cost = \$11.88 / hr • 1,080,000 hours = <u>\$12,830,400.00</u>

With 23 UAV's required for haul at one time, the number of hours for the ground controller = 1,080,000 hours / 23 = 46,957 hours
The cost of the Ground Controller = \$25/hr • 46,957 hrs = <u>\$1,173,925.00</u>

\$ UAV Unit(s) = \$63,000,000 - \$1,173,925 - \$12,830,400
= \$48,995,675.00

D) To equal the budget for the truck – road option, each Unit could cost up to

= \$48,995,675.00 / 23 Units = \$2,130,246.74

<u>Result:</u> To satisfy the harvest timeframe for Case Study #1, each UAV Logger, lifting 15 tons of payload and traveling at 50 kilometres per hour can cost approximately <u>\$2.13 million each</u>.

<u>Case Study #2:</u>

Harvest volume = 176,000 m^3 Haul Rate = $20/ m^3 Road Build = $5/ m^3 Maintenance = $2/ m^3 Total = $27 / m^3 Timeframe to complete harvest = 3 years Operational days per year = 220 days Total days = 3 • 220 = 660 days	UAV Data: Payload = 15 m^3 Cycle time = 4.4 hours. (table 15) Each UAV can haul 3 loads per day Fuel cost = $11.88 per hour Total number of hours to complete harvest by Airship = 76,855 hours (table 15)

A) Total $ Available = $27/ m^3 • 176,000 m^3 = **$4,752,000.00**

B) Volume to move per day = 176,000 m^3 / 660 days = 267 m^3/day
UAV loads per day = 267 m^3per day / 15 m^3 per load = 17.8 = 18 loads

\# of UAV Units = 18 loads / 3 per UAV **= 6 UAVs required.**

C) **Total $ Available = $ Ground Controller + $ Fuel Cost + $ UAV Unit(s)**

Fuel Cost = $11.88 / hr • 76,855 hours = <u>$913,037.40</u>

With 6 UAV's required for haul at one time, the number of hours for the ground controller = 76,855 hours / 6 = 12,810 hours
Therefore, the cost of the Ground Controller = $25/hr • 12,810 hours = <u>$320,250</u>

$ UAV Unit(s) = $4,752,000 - $320,250 - $913,037.40
= $3,518,712.60

D) To equal the budget for the truck-road option, each Unit could cost up to

= $3,518,712.60 / 6 Units = $586,452.10

<u>Result:</u> To satisfy the harvest timeframe for Case Study #2, each UAV Logger, lifting 15 tons of payload and traveling at 50 kilometres per hour can cost approximately <u>$587,000 each</u>.

Case Study #3:

Harvest volume = 1,074,680 m^3 (Phase 1) Haul Rate = \$19/ m^3 Road Build = \$5/ m^3 (estimate from table 18) Maintenance = \$2/ m^3 Total = \$26 / m^3 Timeframe to complete harvest = 5 years Operational days per year = 220 days Total days = 5 • 220 = 1,100 days	UAV Data: Payload = 15 m^3 Cycle time = 5.8 hours. (table 19) Each UAV can haul 2 loads per day Fuel cost = \$11.88 per hour Total number of hours to complete harvest by Airship = 415,547 hours (table 19)

A) Total \$ Available = \$26/ m^3 • 1,074,680 m^3 = **\$27,941,680.00.**

B) Volume to move per day = 1,074,680 m^3 / 1,100 days = 977 m^3/day
UAV loads per day = 977 m^3 per day / 15 m^3 per load = 65.1 = 66 loads

\# of UAV Units = 66 loads / 2 per UAV **= 33 UAVs required.**

C) **Total \$ Available = \$ Ground Controller + \$ Fuel Cost + \$ UAV Unit(s)**

Fuel Cost = \$11.88 / hr • 415,547 hours = <u>\$4,936,698.36</u>

With 33 UAV's required for haul at one time, the number of hours for the ground controller = 415,547 hours / 33 = 12,593 hours
The cost of the Ground Controller = \$25/hr • 12,593 hrs = <u>\$314,825.00</u>

\$ UAV Unit(s) = \$27,941,680.00 - \$314,825.00 - \$4,936,698.36
= \$22,690,156.64

D) To equal the budget for the truck – road option, each Unit could cost up to

= \$22,690,156.64 / 33 Units = \$687,580.50

<u>Result:</u> To satisfy the harvest timeframe for Case Study #3, each UAV Logger, lifting 15 tons of payload and traveling at 50 kilometres per hour can cost approximately <u>\$687,500 each</u>.