PO Box 1127
Rotorua 3040
Ph: + 64 7 921 1883
Fax: + 64 7 921 1020
Email: info@ffr.co.nz
Web: www.ffr.co.nz

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A Review of Cable Logging Literature

Authors:
Hunter Harrill & Rien Visser

Research Provider:
University of Canterbury

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EXECUTIVE SUMMARY

The primary goal of the Future Forests Research (FFR) harvesting research programme is to realise substantial gains in productivity and reduce the cost of harvesting on steep country by introducing improved harvesting technologies that are more productive and cost effective than existing equipment. The secondary goal is to remove workers from the hazardous tasks of manual tree felling, breaking out and unhooking. Part of this programme is to increase the productivity of cable extraction (Programme 2). One of the projects in this area is to evaluate and compare cable rigging configurations used in cable harvesting operations. Through a better understanding of the abilities and limitations of these configurations, forest managers will be able to match them optimally to various site conditions. Selecting a given site's ideal configuration could maximize efficiency by saving time and money, and reduce the risk of injury.

A literature review of cable logging research worldwide that is relevant to New Zealand plantation forests was undertaken to provide information to logging planners and practitioners who work with cable logging systems. The purpose of this report is to provide an overview of the development of these cable logging systems, with a particular focus on developments in New Zealand. Learning and understanding the outcomes of previous research work will enable the New Zealand logging industry to make real gains in cable logging operations as a safe and cost effective harvesting technique.

This comprehensive literature review highlights the fact that many research projects have studied aspects of cable logging operations, and many concepts and ideas of current interest to New Zealand have previously been approached. Recent research world-wide has investigated efficiency of logging machinery and operations, and improvements made through adopting new technologies. However, the literature review showed that despite many manuals and best practice guidelines, there was little information relating to which rigging configurations are more productive or safer under various stand and terrain conditions. New Zealand is in a unique position given current needs, innovation and research capacity, to become world leaders in these efforts to improve the efficiency of cable logging operations.

INTRODUCTION

Cable Logging

Logging is a specialised form of materials handling and transportation, where the materials being handled vary from logs to whole tree stems. Using cables to extract felled stems rather than horse or oxen, known as cable logging, emerged as a common practice around the turn of the 20th century, and became the preferred method of extraction on steep slopes (Studier and Binkley 1974). Cable logging practices date back centuries in Europe, but modern cable yarding practices commenced in the late 19th century with the advent of steam powered engines like the Dolbeer Steam donkey in 1881 in Eureka, California (City of Eureka 2010). The machinery used has improved over the years from the early steam powered winch sets to current yarders with highly-sophisticated diesel-powered engines, air controls, water-cooled brakes and interlocking drums. However, the problem of avoiding ground objects and reducing the friction and thus the force required to transport the material, and the solution to this problem, providing some “lead” or upward lift on the logs to provide partial or full suspension of the logs, has remained the same since these early days of cable logging.

Modern cable logging with integrated tower yarders (referred to as haulers in New Zealand) was introduced into plantation forestry in the 1950s with the development of diesel yarders, and has continued to be the preferred method of extracting timber on slopes limiting conventional ground-based equipment around the world (Kirk and Sullman 2001). There have been numerous developments in the methods of cable logging, and practices differ world-wide. Cable yarding is preferred due to its environmental benefits over ground-based yarding, because the partial or full suspension of logs generated results in minimal soil disturbance (McMahon 1995; Visser 1998). Alternatives, such as modified ground-based equipment and helicopters exist for the extraction of timber on steep slopes. Helicopters are not often preferred due to their high rate of fuel consumption and expensive operating costs. To date, modified ground-based equipment is limited in its application due to the short economic yarding distance and the difficulty of traversing rough terrain. However, new equipment options are being developed to push the limits of ground-based machinery on steep terrain (Evanson and Amishev 2010). But as ground-based machinery becomes increasingly dangerous and less productive to operate on steep terrain (> 45% slope) cable extraction of stems still remains as one of the most viable options for extraction.

Despite its wide use and environmental benefits, cable logging is expensive and is more complex than either tractor or skidder logging. It has a high incidence of accidents to workers and is generally less productive than ground-based methods of harvesting timber (Slappendel *et al.* 1993). Cable logging as it is practiced in New Zealand differs in several respects from how it is practiced elsewhere in the world. The reasons are various, but the nature of *Pinus radiata*, the value of the wood recovered, features of New Zealand’s terrain and climate, and the reliance on plantation forestry, are all factors (Liley 1983).

When using a yarder for cable extraction, the main criterion determining the extraction method to be used is the ground slope or profile of the area to be harvested (Visser 1998). The first decision made is whether the extraction of timber will be uphill or downhill. Then there are a variety of factors including desired lift, tower height of the yarder, number of drums for the yarder, crew size, and availability of carriages and gear, to name a few, which all determine which rigging configurations can be used. There are about ten different basic cable yarder rigging configurations, and literally hundreds of variations when including different carriages and attachments. Therefore, a given stand of timber has no one wrong or right method for extracting the timber.

Rigging Configurations

When defining a cable logging method, practitioners first describe the operation by the system which is being used. A cable logging system is defined by the type, number and the functions of cables or wire ropes (Kendrick 1992; Studier and Binkley 1974). There are four main types of cable logging systems: Highlead, Standing Skyline, Live Skyline and Running Skyline. After defining the cable logging system, practitioners then further define the cable yarding method by what's called a rigging configuration. A rigging configuration refers to the gear/rigging (i.e., blocks, geometric arrangement of ropes and carriage type) being used. Some rigging configurations can be used between systems while others cannot. For instance, motorised carriages can be used in Standing, Live or Running Skyline systems, while Grabinski ("scab skyline") is a rigging configuration exclusive to the Running Skyline System.

Each rigging configuration has its own set of capabilities and limitations, and the job of the forest engineer or harvest planner is to match the appropriate rigging configuration to a given site in order to satisfy the land owner's objectives. However, the natural environment in which these operations are applied is highly variable, making the estimation of potential outcomes, whether they be financial, social or environmental, very difficult during the planning process. Because of these complexities with the natural environment, the topic of cable logging has received a great deal of attention and has been the subject of many scientific research projects within the forest industry. While the latter sections of this literature review describe and list a selection of these scientific reports, a number of cable logging manuals and other documentation has been developed over time. These manuals are a great starting point for investigation of cable logging operations, as they summarise best practices based on the current state of knowledge.

Reference Manuals, Books and Software

Manuals

1. LIRA Cable Logging Handbook (Liley, 1983) – Overview of cable logging in 1983. Includes charts to help calculate payloads for various setting and rigging types.
2. Best Practice Guidelines for Cable Logging (FITEC, 2000) – Published in 2000 and updated in 2005 by NZ Forest Industry Training and Education Council, this combines industry training standards, Approved Code of Practice (ACOP) rules, hazard management and best practice information to provide a reference manual for practitioners.
3. Yarding and Loading Handbook (OR-OSHA, 1993) – Published by Oregon Occupational Safety and Health Division, this is a comprehensive overview of many of the elements and processes within cable logging, including many very good illustrations. (www.cbs.state.or.us/osha/pdf/pubs/1935.pdf)
4. Cable Yarding Systems Handbook (WorkSafeBC, 2006) – Published by WorkSafe British Columbia in 2006 and available online at: http://www.worksafebc.com/publications/health_and_safety/by_topic/assets/pdf/cableyarding.pdf
5. Grapple Yarder and Supersnorkel Handbook (WorkSafeBC, 1992) – Revised in 2011 by WorkSafe British Columbia, this guide is aimed specifically at grapple yarding systems with many familiar charts and references from Cable Yarding Systems Handbook.

6. Harvesting Systems and Equipment British Columbia (MacDonald, 1999) – British Columbia guide for selecting appropriate harvesting equipment and systems, including charts for comparison and dichotomous key for decision making.
7. Guide to Managing Risks in Cable Logging (Safe Work Australia, 2013) http://www.safeworkaustralia.gov.au/

Books

1. Cable Logging Systems (Studier and Binkley, 1974) – One of the original and most complete references to cable logging in North America.
2. Cable Logging Systems (FAO, 1981) – European version of complete cable logging reference.
3. Winch and Cable Systems (Samset, 1985) – Civil engineering handbook on winch and cable systems, with content based on author's 35 years of experience with winch and cable operations as leader of the Norwegian Institute of Forest Operations.
4. Wire Rope Splicing Handbook (Simpson, 1984) – Published by the Logging Industry Research Association as a guide to splicing wire ropes in forest operations.

Software

1. LoggerPC (Jarmer and Sessions, 1992) – Universal Windows-based cable analysis program to analyse ground or map profiles for skyline yarding systems to determine where to place skyline landings, skyline yarding boundaries, and the results of skyline payload capabilities. The latest version (4.2) is freely available and easy to use, making it an excellent tool for teaching and analysis of single skyline corridors.
2. SkylineXL – SkylineXL is a free public domain Microsoft Excel spreadsheet, developed by the USDA Forest Service and Oregon State University. Effectively it is LoggerPC transferred to an Excel spreadsheet to avoid any Windows type problems. It covers four different skyline configurations: standing skyline, multi-span skyline, running skyline and live skyline.
3. PLANS (Twito *et al.* 1987) – Developed by the USDA Forest Service, PLANS has been used for developing timber harvest and road network plans based on large-scale topographic maps. The model provides useful information, such as payload analysis, cost analysis, road layout, and terrain information.
4. RoadEng – Developed by Softtree, it is primarily road and surveying software, but has a Forestry module that includes the opportunity to analyse cable corridors. Especially good if planning road layout with regard to cable logging feasibility.

5. PLANEX (Epstein *et al.* 2001) – PLANEX is able to generate an approximately optimal allocation of equipment and road network based on a heuristic algorithm. System does not have the ability to analyse cableways with their topographic profiles.
6. CYANZ (Cable Yarding Analyses New Zealand) – Developed by Forest Solutions Ltd as an integrated application for optimizing cable logging extraction. (www.cyanz.com/).
7. CHPS (Cable Harvesting Planning Solution) – CHPS is a planning tool developed by Geographic Business Solutions Ltd for analyzing terrain where cable haulers are used to extract logs. It is an extension integrated into Esri® ArcGIS™ for Desktop software. www.cableharvesting.com/

CABLE LOGGING RESEARCH

Research into cable logging operations has been conducted world-wide by numerous individuals and organizations over recent years, some carried out by logging contractors, universities, private companies and public or government agencies. Because cable logging is not as common or popular as ground-based methods, there has been comparatively less research on the topic. However, since its emergence as a practice there have been some great contributions to research. The main regions making early and regular contributions to the field of research have been the forested mountainous regions with existing or mature forest industries where the practices of cable logging originated, mainly in the Pacific Northwest (PNW) region of North America and in central Europe. In more recent years, regions with maturing forest industries where interest in cable logging has increased, such as Japan, New Zealand (NZ), and parts of South America and Eastern Europe, have contributed to this research.

The US Forest Service was particularly active in cable logging research between 1960 and 1990, especially through their collaboration with Oregon State University via their forest engineering graduate program. The US Forest Service faced the challenge of increasing their proportion of annual harvest on steep terrain, which was marginally economic at the beginning of the 1960s, such that they felt compelled to train more than 500 specialists in less than a decade (Carson 1983). Many of the developments during this period aimed to reduce manpower as it became more expensive, but skilled labour also became harder to obtain and worker accidents and fatalities were increasingly a concern (Christensen 1978). A few of the more relevant studies during this period and more recently have been summarized and are discussed in further detail.

The objective of this literature review is to outline the general topics of cable logging research, and highlight the most applicable studies to NZ plantation forests within those topics. The aim is to provide scientific resources to aid in education as well as research and development efforts towards steep terrain harvesting in New Zealand plantation forests. Figure 1 provides an overview of the types of studies that have been carried out, as well as highlighting relevant publications for each category.

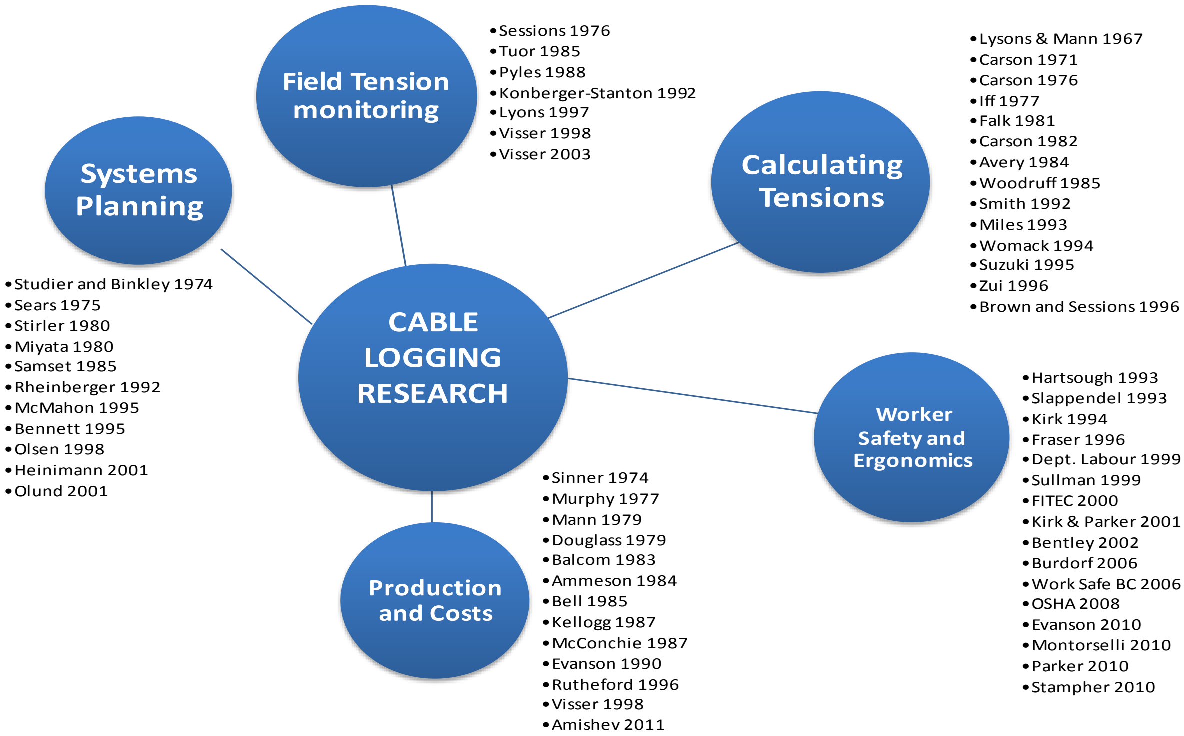

Figure 1: Topics in cable logging research and individual papers associated.

Systems and Planning

Studier and Binkley (1974) established one of the best guides to earlier cable logging, which built on the fundamentals of the skyline tension and deflection handbook from Lysons and Mann (1967). The Logging Industry Research Association (LIRA) later developed its own version of the cable logging handbook for New Zealand (Liley 1983). The Norwegian Ivar Samset published a cable logging textbook "Winch and Cable Systems" that was subsequently translated into English. This is very detailed with formulas, and integrated 40 years of research work in cable logging in Europe and around the world (Samset 1985).

Interest in European systems brought about a project in carriage development for endless line systems used with conventional yarders in thinning operations (Sears 1975). With more machines becoming available, a method of selecting cable harvesting machines in Vermont forests was developed using desktop computers (Stirler 1980). Formulas for calculating equipment ownership and operating costs (i.e., machine rate) became necessary for such an analysis (Miyata 1980). Different types and specification of ropes became more available, warranting a study on selecting wire rope design factors in cable logging (Rheinberger 1992). Soil disturbance resulting from New Zealand cable logging operations became an increasing concern internationally and was investigated (McMahon 1995). Alternative rigging options for the North Bend configuration were studied as it became a common practice and practitioners looked to solve some potential disadvantages (Bennett and McConchie 1995). Statistical methods used in time studies and how to apply them were explained in an attempt to provide a foundation for future production and cost studies (Olsen *et al*. 1998). Perspectives on European cable yarding systems and how they differ from the rest of the world (Heinimann *et a*l. 2001), as well as the future of cable logging operations, were discussed (Olund 2001).

Cable Tensions Research

Most research in cable logging tensions in the past has focused on how to calculate mathematically and model static tensions for various systems and rigging configurations: like the Skyline Tension and Deflection Handbook (Lysons and Mann 1967); running skyline load path (Carson and Mann 1971) later revised and transferred on to programmable desktop calculators (Carson 1976); analysis of slackpulling forces in manual thinning carriages (Iff 1977); analysis of guylines (Carson *et al.* 1982); lateral yarding forces (Falk 1981); tethered balloon logging (Avery 1984); analysis of North Bend, South Bend and Block in the Bight configurations (Woodruff 1984); remote tension monitoring for yarders (Smith 1992); clamped and unclamped carriage tensions including downhill logging (Miles *et al.* 1993); analysis of triangular running skyline system (Suzuki *et al.* 1996); formulas for the vibration method of estimating cable tension (Zui *et al.* 1996). Field measurement of wire rope tensions were conducted for several systems and rigging configurations including: indirect measurement of cable tension and vibration using lasers (Kroneberger-Stanton and Hartsough 1992); a maximum log load solution procedure (Brown and Sessions 1996); skyline and guyline tensions measured at tail spars (Lyons 1997); clamped and unclamped carriages effect on skyline tension (Miles *et al*. 1993); static tensions of guylines at tail spars (Pyles 1988); field measurement of skyline deflection and tension using vibration method (Sessions 1976); static forces in pendulum balloon logging (Tuor 1985); tension monitoring of forestry cable systems (Visser 1998); forces in wire rope slings used to prevent log loss on steep slopes (Visser 2003).

Safe working loads in logging operations typically suggest keeping loads under one third of the rope's tensile strength (safety factor of three) in order to account for both static and dynamic loading (Liley 1983). Many accidents in cable logging happen when there is a failure in the equipment or wire ropes used, and various studies over the years have investigated these potential failures and the benefits that tension monitoring provides (Fraser 1996; Fraser and Bennett 1996; Hartsough 1993; Smith 1992; Visser 1998). Few researchers with the exception of Womack (1994), Pyles *et al*. (1994) and Visser (1998) have investigated the dynamic forces in wire ropes used in cable logging.

Safety and Ergonomics

Many guide books on cable logging safety and best practices have been produced over the years to teach workers to reduce accidents. Notably the Yarding and Loading Handbook by OR-OSHA (1993) and revised (2008), which built on the Cable Yarding Systems Handbook by WorkSafeBC (2006) and subsequent versions. Similar guides exist in New Zealand, like the Approved Code of Practice by the (Department of Labour 1999) and the Best Practice Guidelines by (FITEC 2000). Unfortunately, worker fatalities occur in the same ways as they did 40 years ago (OR-OSHA 2008). Improving our knowledge of forces and tensions involved with complex cable logging systems, as well as a better understanding of control over the extraction process, can help improve safety. (Slappendel *et al.* 1993) investigated factors affecting work-related injury in forest workers in New Zealand. Hartsough (1993) investigated the use of remote tension monitors and the benefits to safety they provide. Physical demands of steep terrain workers were quantified by Kirk and Parker (1994), and later Kirk and Sullman (2001) investigated heart rate and strain of choker setters. Yarder tower collapses became a concern prompting two studies by Fraser (1996) and Fraser and Bennett (1996) on hauler collapses and potential causes. The New Zealand accident reporting scheme was established to combat increasing rates of accidents (Sullman *et al.* 1999). Bentley *et al.* (2002) outlined how the accident reporting scheme data could be used to identify priority areas for research into ergonomics and health and safety. Danish researchers Burdorf *et al.* (2007) investigated effects of mechanized equipment on the physical work load of labourers in road building. Montorselli *et al.* (2010) quantified safety and productivity of motor manual operations in the Italian Alps, while in New Zealand the use of video clips from cameras mounted on forest workers and their effectiveness for training purposes was investigated (Parker 2010).

Productivity Studies

System productivity has been extensively researched in logging operations, as increasing productivity typically results in lower logging costs in \$/tonne or \$/m^3 (Visser 2009). One example of a number of studies that provided insight and understanding into production potential of various logging systems and rigging configurations was known as the Pansy Basin Studies carried out in the Pacific Northwest. Production rates and costs for cable, balloon and helicopter yarding systems in old growth stands where established (Dykstra 1975), with a follow up study on the same systems in thinned and clearcut young growth forests (Dykstra 1976a). A further investigation into system delays was also published by Dykstra (1976b). There were other research projects carried out at the time such as: running skyline production using a mechanical slack pulling carriage (Mann 1979); production of a manual slack pulling carriage in thinned stands (Sinner 1973); comparison of skyline carriages for small wood harvesting (Balcom 1983); production of pendulum balloon logging systems (Ammeson 1984); and production costs and optimal line spacing of running skyline and standing skyline systems using slack pulling carriages (Rutherford 1996).

Amishev (2011) investigated the factors affecting cable yarding crew performance in forest operations in New Zealand. Improved performance through efficient extraction by estimating and optimizing payloads was investigated (Visser *et al.* 1999). Other studies quantified system production rates, and even compared production rates of different systems and equipment side by side over the same terrain and stand conditions. These studies include a comparison of Washington 88 and Madill 009 (Bell 1985); cycle time comparison of Timbermaster and Wilhaul yarders (Douglass 1979); shift level data collection of Ecologger2, Bellis, Lotus, and Thunderbird TMY70 yarders in downhill logging (Evanson 1990a, 1990b); and a case study of a mobile Madill 90S in mature radiata pine (Murphy 1977). These studies and many other yarder trials carried out by LIRA between 1973 and 1991 have been summarized by Harper (1992). Some studies have investigated different rigging systems and their productivities, such as alternative rigging variations for the North Bend configuration to improve productivity by improving control and reducing required line shifts (Bennett and McConchie 1995), and system evaluations of a Madill 071 using North Bend, Shotgun, Slackline and mechanical slack pulling carriage configurations, published as four separate reports (McConchie 1987a, 1987b, 1987c, 1987d).

Very few studies have compared the production rates between various rigging configurations using the same equipment in similar conditions. One exception is Kellogg (1987), who compared three different rigging configurations of the same machine in the same stand of timber. Few studies have investigated fuel consumption in cable logging operations, or have compared fuel use between rigging configurations. Cable yarding machines typically consume 20-40 litres/hour, and up to three times as much fuel per tonne of wood harvested as ground-based systems (Gordon and Foran 1980).

Rigging Configurations Research

There has been considerable interest around rigging configurations and their appropriate uses in the last few years. A recent survey of cable logging practitioners by Harrill and Visser (2011) found that cable logging practices differ in New Zealand from other countries with a strong dependence on three non-carriage configurations, namely North Bend and gravity return (shotgun) standing skylines and Grabinski running skyline. Results also indicated that survey participants had a good understanding of the other configurations as well as their versatility and perceived advantages. However, only 28% had tried any of the other configurations in the last five years. The survey work was expanded the following year to include an expert panel which discussed the true advantages and disadvantages of each rigging configuration (Harrill and Visser 2012). With a strong dependence in NZ on the North Bend configuration, research has attempted to quantify the differences in dynamic tensions between North Bend and other similar fall block configurations using a model yarder (Harrill and Visser 2013). One researcher noted that the most successful loggers have a variety of carriages and configurations at their disposal, they have an excellent understanding of the optimal application of each one, and whenever the opportunity arises to improve costs by changing configurations, they do so (Hemphill 1985).

Cable Logging Research Trends

An insight into international cable logging research from the period from 2000 to 2011 has been summarised in a literature review by the Italian researcher Cavalli in 2012. The majority of works in that review were from conference proceedings and scientific journal articles, and the vast majority were from countries other than the USA and New Zealand. Cavalli found that the last 10 years of research by forest engineers interested in cable logging was directed mainly (45%) towards efficiency (Figure 2).

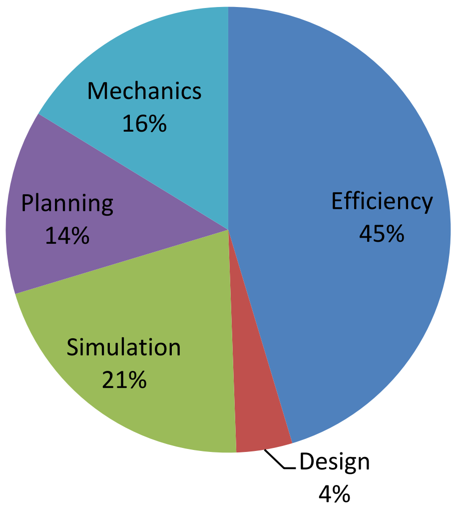

Figure 2: Topics of cable logging research 2000-2011 (Cavalli 2012).

With increases in the cost of labour and fuel, and increasing global market competition, there will be increased focus on operational efficiency (Visser *et al.* 2011). Reduction in energy expenditure (kW) and fuel consumption, as well as automated controls (for improved safety, increased worker satisfaction and a reduction in labour requirement) has increased the interest in modern, mainly European-designed, yarders. Cavalli (2012) predicted that in the near future efficiency will continue to be the topic in cable logging research and that efforts in optimization, including computer automation and control of machinery, will aid this focus on efficiency. It will be interesting to see how a country such as New Zealand transitions into this new cable logging era through research and development efforts.

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