Assessment of the Opportunity of Modern Cable Yarders for Application in New Zealand

A thesis submitted in partial fulfilment of the Master of Forestry Science

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Abstract

This study examined the opportunity of implementing modern yarder machinery to increase the productivity and worker safety of cable logging operations within New Zealand. Cable yarding equipment used in New Zealand is generally based on designs from pre-1980 with the majority of the machines built around that time in the Pacific Northwest, USA. New yarder designs have a number of features that may give them an advantage, including being; smaller, quieter, more fuel efficient, safer and more ergonomic to operate. These benefits can be of even greater value as the forest industry transitions from predominantly larger scale commercial plantations, to a significant proportion of woodlot scale operations.

Field studies ranging from three to five day of duration were carried out on three new machines believed to have potential in New Zealand; the Active 70 at two locations in the central North Island region of New Zealand, the Koller 602h in the Gisborne region of New Zealand and for comparison the Koller 507 in Austria. The studies focussed on assessing productivity and ergonomic advantages. Productivity was measured with a time and motion study and the potential ergonomic advantages were assessed using choker-setter heart rates and machine noise emissions.

The time and motion study found a productivity level for the Active 70 of 23.5m^3/SMH with a utilisation rate of 65% at site one and 24.5m^3/SMH at a utilisation rate of 76% for site two. The productivity for the Koller 602h was 21.0m^3/SMH at an utilisation rate of 55% and 7.9m^3/SMH for the Koller 507 at an utilisation rate of 55%. Productivity was deemed to be negatively impacted by poor site conditions for the Active 70 and Koller 507, and utilisation was low for the Koller 602h which was mainly attributed to the lack of crew experience with the new machine. Choker-setter heart rate results showed choker-setters to be working at the level of ‘hard continuous work’ (‘relative heart rate at work’ over 30%, but less than 40%). In this study the motorised carriage used at the first Active 70 study site offered no ergonomic advantages over the traditional North Bend system at the second site. Decibel analysis found that the modern equipment was significantly quieter, resulting in smaller zones in which hearing protection is required. In particular, the Koller K602hrecorded 70dB at 5 meters during operation, well below the 85dB level that is common recognised as the decibel threshold for hearing damage.

During these case studies the machines all operated below the average New Zealand productivity rate of 26.3m^3/SMH and no clear ergonomic advantage was established for the choker-setters. As such these machines are not likely to out-compete existing machinery choices in either productivity or choker-setter work rate. However, cost-benefit analyses were not possible because of limited information about operating cost and the absence of truly comparable settings. Advantages such as the advanced control systems and lower noise levels, while still achieving respectable productivity figures, indicate that they are viable alternatives for New Zealand cable yarding if applied correctly.

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1. Introduction

Commercial plantation forestry currently covers 6% of New Zealand's land area, equating to 1.7 million hectares. Of this area, 44 thousand hectares is harvested annually, resulting in a recovered harvest volume of almost 30 million cubic meters. At a value of 4.5 billion New Zealand dollars it is the country's third largest export earner. Although forestry is a large industry, it is a relatively lower value land use and as such often occupies steep, remote and erosion prone land (New Zealand Forest Owners Association Inc, 2013).

Harvest generally occurs at 28 years of age and is based on a clear fell system. There are two main harvesting systems; ground based and cable yarder based. The method selected is based on the terrain, with steep gradients and rough terrain often making cable yarding a necessity.

In New Zealand the average cost of harvest in 2014 using cable based machinery is $35.90 per tonne while ground based harvesting costs $26.90 per tonne (Visser 2015). Cable harvesting increased from 15% in 1976 of the total volume harvested in New Zealand (Fraser, Murphy, & Lersesk 1976) to 40% in 2014 (Visser 2015), indicating a higher proportion of harvested areas are now in steep and rough terrain where ground based methods are not viable. Some forested areas are currently non-viable to harvest due to prohibitive harvest costs. Areas that are cost prohibitive to harvest are typically small, steep and remote necessitating cable harvesting (New Zealand Forest Owners Association Inc, 2013). The seriousness of this situation is highlighted in the Whanganui region, in which under the 2012 pricing conditions 5 to 10% of the area of forest blocks under 1000 hectares were not viable to harvest (Park, Manley, Morgenroth, & Visser, 2012).

It has been identified that as operating costs such as labour, fuel and global market competition increase, there will be added focus on operational efficiency to remain nationally and internationally competitive in the forestry market (Visser, Spinelli, & Stampfer, 2011). These issues are portrayed in the New Zealand industry with cable harvest costs from 2009-2014 rising $0.88/tonne per annum on average and productivity of cable based operations also increasing 0.8t/SMH per annum (Visser, 2015).

A key focus of primary industries in New Zealand is worker safety. Forestry is one of the nation's most dangerous industries, in the 2011 to April 2016 period there were 27 deaths and 750 serious harm incidences reported (Work Safe New Zealand, 2016). In 2013 the forestry industry was reported as the most dangerous sector per capita in New Zealand, with an average per capita injury rate twice that of other sectors and a fatality rate 15 times the average rate. The cost of injuries in 2013 was over $9.5 million and contributed to over 50,000 days in lost time (Ministry of Business Innovation and Employment, 2014).

Within the New Zealand forest industry cable yarding extraction is a common cause of injury and death, and contributed 14% of all forestry related deaths from 1988 to 2005, only second to felling at 42%. Of these deaths almost 50% of deaths were caused by being hit by a stem during inhaul or a rope during line shifts. Cable yarding was also reported as being the third highest cause of 'serious injury and accidents resulting in harm', behind felling and skid operations (Department of Labour, 2011).

This highlights why personnel safety is a key consideration concerning cable logging equipment. One of the areas that can influence risk levels is the ergonomics of equipment, with more ergonomic equipment likely to result in comparatively lower workloads for the workers, resulting in lower levels of fatigue. This is important as previous research shows that fatigue is felt by all workers on site, including machine operators (Inoue, 1996; Kirk & Sullman, 2001) and is recognised as being one of the largest safety issues within the forestry industry (Lilley, Feyer, Kirk, & Gander, 2002).

Workers that reported high levels of fatigue also reported higher rates of near miss incidents over the previous 12 month period (Lilley et al., 2002). High fatigue levels are linked with high workloads and long hours, both of which are present in the New Zealand forestry industry indicating cause for concern. Kirk and Sullman (2001) found choker-setting was a more demanding job than steel working or cane cutting, both highly demanding occupations. A Department of Labour workplace report found that over 50% of forestry workers worked more than 40 hours a week, with over 9% of forestry workers reporting to work more than 60 hours a week, compared to an overall New Zealand average of 6.9% (Department of Labour, 2011), indicating long and above average working hours.

Improving ergonomics is also likely to have productivity benefits, with a forest study focused on planting finding that although the heart rate levels remained constant, productivity levels increased significantly over rougher terrain when ergonomics were improved (Sullman & Byers, 2000). This indicates in a more ergonomically friendly work environment, workers can be more productive for similar work inputs.

These factors are largely why there has been considerable research into cable yarding internationally with the focus generally concerning productivity and worker safety. Harrill and Visser (2014a) provide a thorough review of the available literature. They proposed that one of the solutions to efficiency and safety issues is the utilisation of modern yarder machinery. This is a logical conclusion with the benefits of modern yarders including worker safety, satisfaction and a reduction of labour input, modern yarders present a viable solution to safety and ergonomic concerns.

While yarder manufacturing and development stagnated in the Pacific North-West (PNW) due to a severe decline in harvest volumes (USDA Forest Service, 2000), central Europe has continued to develop and modernise yarders. Examples of companies that manufacture ten plus modern yarders per year include; Koller, Myer-Melnhof and Konrad ForstTechnik in Austria, and Valentini and Greifenberg in Italy. However, other countries also develop and manufacture yarders: including the Brightwater and Active machines in New Zealand, the Madill range in Canada (also licenced to New Zealand), the T-Mar range from Canada and the Alpine yarders from South Africa. Ergonomic cabs, clear lines of sight, tension monitors and simplified controls are advertised as modern features and advantages by builders of modern cable yarders internationally (Brightwater Forest Equipment, 2014; T-Mar Industries LTD, 2015).

Although the benefits of modern yarders are well recognised internationally, common machinery currently used in New Zealand is considerably older, larger and more powerful than the European counterparts that exist internationally (Heinimann, Stampfer, Loschek, & Caminada, 2001; Liley, 1983). A survey of yarders currently used showed they are almost entirely North American designed or built (Visser, 2013) and are generally based on designs from pre-1980. The most common yarder is the TMY 70 which was released in 1975, weighs 50 to 60 tonnes and is generally fitted with a 220 kW engine. Although there has been extensive research and development on older North American systems to make them more efficient and safer, the base machinery is still less advanced than recently released counterparts. Visser, Spinelli and Stampfer (2011) provide an analysis of differences in European systems versus machines based on North American designs.

The literature examined indicates that cable yarding in New Zealand is dangerous and increasingly expensive and that the industry would benefit from the application of modern yarders. Although there have been a number of studies of modern cable yarding techniques, there has only been one short study performed on a modern yarder operating in the New Zealand setting (Evanson & Hill, 2015). This study will assess modern yarder options that are likely to have potential in New Zealand.

For the purpose of this study, only machines currently working in NZ were considered. The two most modern systems identified were the Active 70 (for description see Section 1.1.1), of which no previous studies had been conducted and the Koller 602h (see Section 1.1.3), of which one brief study had occurred. An opportunity also presented itself to study the Koller 507 (see Section 1.1.2) in Austria; this was included to provide a case study comparison of a machine similar to the Koller 602h operating in the environment that it was initially designed for. These machines were judged to be of interest since they were significantly different to the existing machines in New Zealand and utilize a number of features not typically found in older yarders.

1.1.Machine descriptions

1.1.1. Active 70

This is a track mounted tower yarder (Figure 1.1.1) developed by Active Equipment, Rotorua, New Zealand. It was first released in 2014. It weighs 58 tonnes, has a 70ft (21.3 m) inclined tower and is powered by a 384 kW turbo diesel engine. It is a three drum yarder equipped with a 28mm swaged skyline, 22mm mainline and a 22mm haulback line. While the Active 70 is very similar in size and power levels to existing yarders within the New Zealand industry, it differs by being fitted with a range of new technology that may give it efficiency, safety and ergonomic advantages. Differentiating features include: inbuilt tension monitoring of the skyline and mainline, an integrated computer system with GPS tracking of choker-setters, an improved cab with simplified controls and better sight lines, and a motorised drop-line carriage with radio control. Some of these features are increasingly being retrofitted to older yarders.

Figure 1.1.1: Active 70 with Boman carriage at site one.

Tension monitor

Tension monitors are widely regarded as a useful production and safety tool and have been for many years. Usage allows accurate moderation of cycle volumes which results in less overload occurrences, resulting in less rope failures and extended rope life. Tension monitoring allows cycle volumes to be modified to suit the lift capacities of a site. These factors are positive for long term efficiency and safety (Evanson, 2009; Hartsough, 1993).

The Active 70 is fitted with a real time tension monitor and uses a colour indicator change to warn the operator when the load is above the safe working load. The use of tension monitors within the New Zealand industry is increasing but is still relatively uncommon (Evanson, 2009).

GPS tracking

A live time tracking system is used to track individual choker-setters. The choker-setters wear speciality GPS units which are synced each morning with the yarder. The system creates a corridor between the tail-hold and the yarder around which a safety corridor is set. The corridor width can be changed as required, but generally is set at the safe retreat distance. The yarder operator can track the location of the choker-setters on a screen at all times without needing a clear line of sight. As a secondary warning system when the choker-setters are inside the pre-set corridor, a flashing warning is present on the operators ACDAT (Active data) screen. This means that any miscommunication regarding location of choker-setters is avoided and accidents are less likely to occur.

There are no existing studies or data on the effectiveness of the GPS tracking system. However multiple yarder producers market cabs with improved visibility characteristics (Brightwater Forest Equipment, 2014; T-Mar Industries LTD, 2015) with advantages likely to be linked to being able to see choker-setters.

ACDAT system

The Active 70 is fitted with the ACDAT system. This system is a one screen, multiple application computer that can be retroactively fitted to any machine. Four key functions of the computer were identified; GPS tracking of choker-setters, live time tension monitoring, modelling of the terrain and operational data recording. Most operators rely on experience or simple indicators to do the same job.

The ACDAT captures a range of information from the machine over the course of the day. This information is stored by day and over a month of data is retained on the computer. Downloading is simple via USB and data is already in the Microsoft excel format. Information categories include; skyline tension, mainline length, skyline length and engine voltage. The yarder operator can manually enter haul statistics. The collection interval is typically set at 20 seconds, however the frequency of data collection can be increased.

The value of this system is that it allows a retrospective examination of logging operations and areas where problems may arise, along with the utilisation of the machine. No data could be found on the value of these systems, however other companies that produce modern yarders advertise similar systems (T-Mar Industries LTD, 2015).

Ergonomics

Yarder operator

The yarder is fitted with a number of features designed to optimise operator comfort and reduce fatigue. They include an ergonomically designed cab and seat; electronic controls that are simplified to two joy-sticks with control buttons and cab windows are designed for maximum sight lines of both the terrain and rope drums. The cab is air conditioned and soundproofed and all windows are tinted. Traditionally yarder are very loud machines, the modern engine fitted to this machine is quieter than a typical New Zealand yarder. These cab features are typical with what is being applied to modern yarders internationally (Brightwater Forest Equipment, 2014; T-Mar Industries LTD, 2015).

Choker-setters

Yarders can be configured to operate a number of different rigging configurations. The contractor operating the Active 70 had and used a Boman motorised drop-line carriage. Motorised carriages are recognised in New Zealand as being useful in settings with long haul distances, rough terrain and where full suspension is necessary. They are considered to be faster in operation than the typical carriage systems in New Zealand (Raymond, 2012). The choker-setter work rate advantage of a motorised dropline carriage was a 12% decrease in heart rate versus a non-line feeding carriage (Sripraram & Tasaka, 1999). In New Zealand only 4% of loggers use mechanical slack pulling carriages regularly and only 28% have used them in the previous five year period (Harrill & Visser, 2014).

1.1.2. Koller 507

The Koller 507 (Figure 1.1.2, see technical specification details in Appendix F) is an Austrian designed truck mounted cable yarder weighing 18 tonnes produced by Koller Forsttechnik, Austria. It is fitted with a 10 meter telescopic tower and uses a 350 kW turbo diesel engine to power both the truck and the hydraulic winches used for the yarder. It typically runs a 20mm swaged skyline (1000m), and two 11mm swaged operating lines (haulback and main lines).

This combination is typical of Austrian cable yarding equipment, with the small size and high manoeuvrability of the system lending itself to yarding from roads and small skid sites.

Figure 1.1.2: Koller 507 during set up.

1.1.3. Koller 602h

The Koller 602h (note: check through report, but be consistent in using either a lower or upper case 'h') (Figure 1.1.3, Appendix E) is an Austrian (Koller Forsttechnik, Austria) trailer mounted tower yarder weighing 15 tonnes. It is fitted with a 10-11.5 meter telescopic tower and is powered by a 147 kW turbo diesel engine. It is fitted with three drums with a 22mm swaged skyline (720m), a 22 mm swaged mainline (730m), a 12mm swaged haulback (1350m) and a synthetic 6mm strawline (1700m).

This Koller yarder is the first one operating in New Zealand with the configuration typical of what would be used in Europe. A brief study on this machine was carried out in the Gisborne region where the machine was demonstrated for the New Zealand forest industry (Evanson & Hill, 2015).

Figure 1.1.3: Koller 602h with crew on site.

Because the Koller 507 and 602h are similar in characteristics and have similar advantages and limitations within the New Zealand setting, machine systems and characteristics are jointly discussed below.

Lift capacity

The European forestry conditions these machines are typically used in has smaller average tree sizes than New Zealand forestry (Liley, 1983). The Koller has a reported maximum lift capacity of 4.3 tonnes (Ellegrad, 2015) which is the rating of the pull power of the mainline winch at mid-drum as that line is used to lift the load through the mechanical slack-pulling carriage typically used. It is typical for European yarders to be rated by their mainline pullng power, whereby the PNW yarders are typically mainly rated by their tower height..

It is expected that the Koller 602h will have a different optimum piece size than the typical larger yarders currently used in New Zealand (Huyler & LeDoux, 1997). To optimise performance of these machines they may require need to work in forests with smaller piece sizes than the national average of 2.2 tonnes (Visser 2015).

Motorised slack pulling carriage

Similar to the Active 70 at study site one, both Koller systems are typically fitted with slack pulling carriages. These are expected to provide similar advantages as the Boman carriage that was explained earlier, indicating that the MSK 3 carriage fitted to the Kollers may offer significant physiological advantages.

Remote control system

The remote yarder controls are operated by both choker-setter and yarder operators, allowing accurate carriage placement and cable feed reducing workloads (Koller Forsttechnik, 2010). Dual control reduces issues with communications that can create dangerous situations and create inefficiencies. The remote system is portable and simple enough that the operator can drive another machine while the carriage is running out and picking up logs, increasing site efficiency. The yarder controls have automated components that are typically the out-haul and in-haul phases of the extraction cycle, where the carriage moves automatically from the tower to the site where the choker-setter is working and back once the payload is brought up to the carriage.

Transport advantage

Due to its low weight the Koller has a distinct advantage over traditional machines regarding transport between sites and is highly likely to reduce the considerable cost associated with moving equipment (Väätäinen, Asikainen, Sikanen, Ala-Fossi, & Sikanen, 2006). The faster and cheaper nature of transporting the Koller means it can be easily and effectively transported and used across a wide region. The effort and cost to move a typical New Zealand cable yarder which weighs 50 to 70 tonnes is significant compared with the Koller which at 18 tonnes (heaviest configuration) is small enough to be transported on public roads without special allowances or permits needed for on road vehicle loads over 44 tonnes (New Zealand Transport Agency, 2014).

Efficient transportation is important with findings showing that for blocks under 5 hectares the relative cost of movement is very high, transport cost proportions diminish in blocks over 10 hectares (Park et al., 2012). The reduced cost of moving is expected to give the 602h and 507 a significant advantage when operating in small blocks.

Fuel cost

With the cost of fuel being a significant contributor to the overall harvest cost (Dash & Marshall, 2011), the Koller yarders have an advantage with smaller more modern engines reducing fuel consumption compared to yarders currently employed in New Zealand.

Synthetic strawlines

Both of the Koller yarders are fitted with synthetic straw lines that are lighter and easier to move than steel equivalents (Garland, 2012). One study found that when using heavier strawlines the workers percent of heart rate reserve showed a 4% increase, which in an already highly demanding job is a significant proportion (Stampfer, Leitner, & Visser, 2010).

Decibel emissions

The Koller is reported to have an operating volume of 60 decibels and is described as being quiet (Ellegrad, 2015). This is considerably lower than traditional machinery and there are expected to be safety benefits. The exact levels of noise from typical machinery is not published, but is identified as being loud and above a safe volume as measured using the speech test[1] (Accident Compensation Corporation, 2013).

Hearing damage caused by working in or around a cable yarder is expected to be minimal due to the hearing protection equipment that is now legally required under the Health and Safety at Work Act 2015. The benefit is in the extra alertness that may be available due to the quieter landing area and a generally more pleasant work environment that may reduce fatigue (Inoue, 1996).

Existing research on machines similar to the Koller 507 and 602h

One New Zealand based study has been conducted on the Koller 602h, which observed it working across both single and multi-span settings (Evanson & Hill, 2015). The study was operating at a site that had a retrieved piece size of 0.68m^3 and 0.72m^3 respectively, which is considered small in the New Zealand setting, and with a stocking of 829 stems per hectare for both settings. Correspondingly the average cycle weight was 2.7 tonnes and 1.5 tonnes and overall delay free productivity rates were 15.25t/PMH and 13.85t/PMH. At these production rates it was calculated that with a combination processor/loader and four to five personnel, harvest costs would vary between $34-$41/t and $41-$48/t for respective operations (2015). The average New Zealand cable logging rate at $35.90 for 2014 (Visser 2015) was within the range of values predicted for the single span operation, however using the multi-span configuration is above the average harvest rate. The study concluded that a four man Koller system with a low number of supporting machines could be competitive in New Zealand settings, but that piece sizes over 1.6 tonnes are likely to be a limiting factor and that research in larger piece sized forests to assess this effect is advised.

[1] If a conversation cannot be had without raised voices the site ear protection is considered necessary.

A comparative production study (Hochrein & Kellogg, 1988) examined a small Koller 300h yarder (Appendix D) and a Madill 071 yarder. This study is deemed relevant because the 300h is more similar to the Koller yarders utilized in this study than other New Zealand machines, being a small, trailer mounted machine, and the Madill 071 is common in New Zealand with 26 Madill 071 yarders (of 153 yarders total) currently operating (Visser, 2013). Hochrein & Kellogg (1988) found that in a general thinning operation, the small yarder was more expensive due to an increased number of landings and roading distance associated with the shorter haul distances required. However in settings with smaller trees than experienced in the general thinning operation (trees with a DBH of 30 centimetres), with steep slopes and with a yarding distance of less than 300 meters, the extraction cost for the Madill 071 was 11 to 12% more than that of the 300h. This shows that under a specific range of conditions the 300h could be more efficient than its larger counterpart. Although a thinning operation and generally not typical of New Zealand operations, it is relevant to see how a smaller machine can be competitive under specific conditions.

Productivity studies (Ghaffariyan, Stampfer, & Sessions, 2009) were conducted on two truck mounted yarders of European design that had towers in the 10 meter range. The power of both machines was 270kW and both machines used the truck engine for power. The lift capacities with the trialled systems were 1.5 and 3 tonnes which is less than the Koller system trialled (5 tonnes). The forests harvested in the study had an average cycle volume of $0.78m^3$ and an average cycle distance of 101 meters. The overall productivity rate was $9.30m^3$/SMH at a cost of US\$25.48/m^3. As of May 2016 this equates to NZ\$38.05/m^3. As systems and forest characteristics differ these costs cannot be used in direct comparison. The larger piece size found in New Zealand would result in a higher productivity for this system in New Zealand and potentially reduce the cost to similar levels. Conversely the low maximum lift capacity (1.5 to 3 tonnes) of the machines in this study would limit production in larger fully grown New Zealand forests. It is highly unlikely that typical New Zealand yarders could operate competitively in the European forest industry given the smaller piece and harvest area sizes.

The studies presented in Section 1.1 suggest smaller cable yarders are effective in forests with comparatively small piece sizes over small settings. Although multiple studies suggest that machines in this size class could compete with the typical New Zealand machine class (Evanson & Hill, 2015; Hochrein & Kellogg, 1988), they have not proved enough to facilitate the use of this machinery in New Zealand (Visser, 2013). This is believed to be because New Zealand conditions differ or are perceived to differ significantly from international conditions (Liley, 1983). Indications are that for the New Zealand forest industry to have confidence in smaller European machinery, New Zealand based trials will have to occur.

2. Aims and objectives

With the growing proportion of harvest being performed by cable yarding and the increasing cost and dangerous nature of cable yarding, the use of machines that mitigate these issues would positively influence the New Zealand industry. To be deemed suitable they should be able to compete with the more traditional machinery in terms of efficiency and ergonomics, which are important to harvest cost and worker safety.

Aim

Assess the opportunity of implementing smaller and more modern cable yarders to increase system productivity and worker safety of cable yarding operations within New Zealand.

Objectives

Assess, through a series of case studies, the Active 70, Koller 507 and 602h for suitability and advantages for the New Zealand industry by assessing;

- Productivity levels with a time and motion study.
- Choker-setter work rates with a heart rate study.
- Noise levels by measuring decibel emissions.

3. Methods

Three machines were studied at four sites. Details of the Active 70, Koller 602h and 507 are presented in Sections 1.1.1, 1.1.2 and 1.1.3 respectively. The study scope is limited to the selected focus areas of productivity, choker-setter work rates and decibel emissions. As such for the Koller studies the advantages of; synthetic guy lines, transportability, fuel efficiency, and motorised carriage effectiveness are not specifically addressed. Similarly, for the Active 70; the modern cab, simplified controls, motorised carriage effectiveness and GPS tracking of choker-setters will not be specifically addressed.

All four sites had different operational techniques and to complete the study safely, efficiently and accurately, assessment techniques had to differ between sites. However analytical techniques were consistent across the study.

3.1. Site descriptions

3.1.1. Active 70 site one

Study site one was in the Tahorakuri Forest managed by PF Olsen Ltd, located 10 kilometres north of Taupo, New Zealand. The study area was part of a larger harvest area of 20.2 hectares. The forest consisted of a radiata pine monoculture planted in 1987/88 with a stocking of 307 stems per hectare and a mean tree size of 2.2 m^3, equating to 675 m^3/ha. The trial took place over five consecutive days from the 15th to the 19th of June, 2015.

The yarder employed a standing skyline system using a Boman Z7850 motorised carriage equipped with three electronic chokers, operated in the shotgun rigging configuration. In New Zealand 4% of loggers use motorised slack pulling carriages regularly and 28% have used them in the previous five year period (Harrill & Visser, 2014), making them relatively rare.

The yarder was located on the same landing (Figure 3.1.1) over this period, with one yarder shift and five line shifts recorded. The operation relied on logs being unhooked in the chute, until it was impractical to unload anymore, then an excavator fitted with a grapple would stack the logs to one side for the processor.

Chokers were connected to stems by two choker-setters. All line shifts were performed using A 30 tonne excavator as a mobile tail hold. The crew was experienced and comfortable with this type of operation.

Figure 3.1.1: Active 70 yarder at study site one, Tahorakuri Forest.

3.1.2. Active 70 site two

Study site two was located in Ryan's Forest managed by PF Olsen Ltd, 10 kilometres North-east of Te Aroha, Waikato, New Zealand. The forest was planted in 1978 and had a stocking of 219 stems per hectare and a mean tree size of 2.5 m^3, equating to 547 m^3/ha. The trial took place over three consecutive days from the 30th of November to the 2nd of December, 2015.

At site two the yarder employed a standing skyline system using a rider block operated in the North Bend rigging configuration. This is the most commonly used configuration in New Zealand, the benefits of this system is its use over a variety of distances, simplicity, versatility and ability to bridle (Harrill, 2014; Harrill & Visser, 2011). The butt rigging was equipped with three electronic chokers.

The yarder was located on the same landing over this period, with four line shifts recorded; the yarder was not moved over this period. The operation was based on two staging with a D6 dozer to a larger landing 50 meters behind the yarder as shown in Figure 3.1.2. There was a 'dead zone' from 0 to 200 meters from the yarder due to a previous logging operation; no stems were available to be taken from within 200 meters of the yarder. Chokers were connected to stems by two choker-setters. All line shifts were performed manually by the choker-setters to tree stumps. The crew was also experienced and comfortable with this type of configuration.

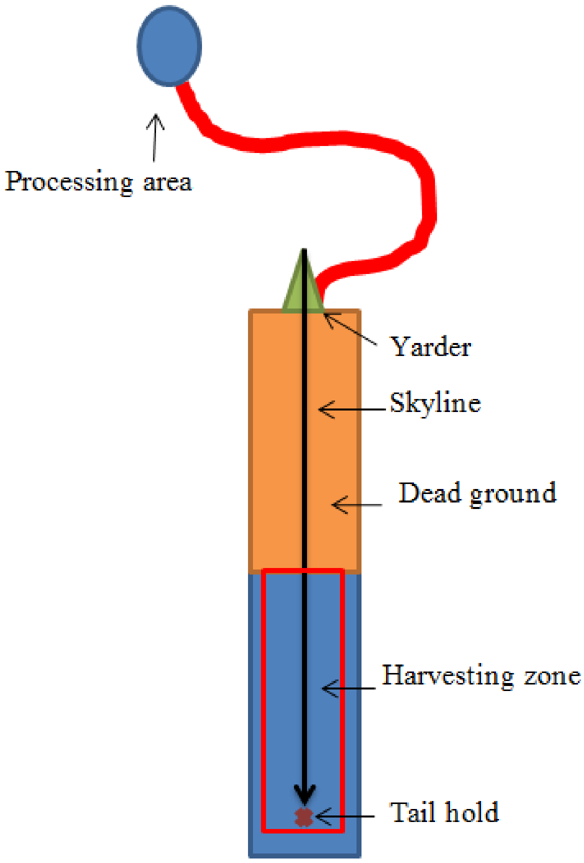

Figure 3.1.2: Active 70 site two diagram.

3.1.3. Koller 507

The yarder employed a standing skyline system and a motorised carriage, using the shot-gun method to send the carriage out.

The trial took place over the 2nd and 3rd of October, in Bad Gestein, Austria. It captured 45 carriage cycles and time data for the rigging of one intermediate and one tail tree support. Figure 3.1.3 displays the site. The machine was operating in a clear felled corridor 400 meters long and 20 meters wide, stems were extracted whole. This is typical of Austrian operations. The forest was predominantly Fir with irregular Larch. The harvest was focused on Fir with Larch left standing. The operating style was very different to the New Zealand standard with no pre-felling occurring; instead the trees being felled for each cycle.

In this study the yarder was running a MSK 3 motorised slack pulling carriage fitted with 3 electronic chokers (Appendix G), which is a typical machine pairing. The MSK 3 carriage weighs 690 kilograms and is powered by a 5.6 kW engine and has a three tonne lift capacity. The machine was fully remote controlled, with both the landing operator and a choker-setter having control systems.

The yarder was parked across a moderately sloping road (estimated at 6%), with three guy lines attached to dead-man anchors. A Caterpillar M318D excavator fitted with a Woody 50 processing head was the only other machine on site. Stems were dragged the 40 meters from the yarder to the main skid were they were de-limbed, processed and stacked. Due to a previous clear fell logging operation, there were no trees extracted from within 155 meters of the yarder. No pre-felling had occurred; felling took place at the same time and vicinity as choker-setting. The crew was experienced and comfortable with this type of configuration.

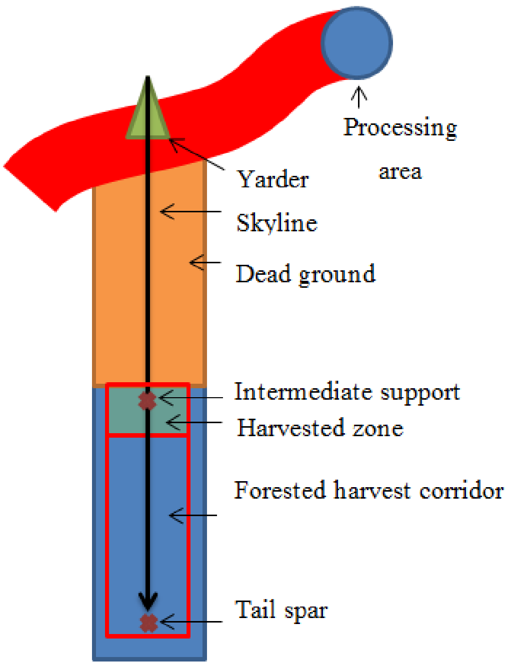

Figure 3.1.3: Koller 507 site diagram

3.1.4. Koller 602h

The Koller 602h study was located on Waikura station, 20 km inland from Hicks Bay, East Cape, New Zealand. The study area was part of a larger harvest area. The forest was planted in 1978 and there was no other crop data available. All trees were pre-felled. The trial took place over five consecutive days from the 27th of February to the 2nd of March, 2016.

In this study the yarder was running a MSK 3 motorised slack pulling carriage (Appendix G) fitted with 2 electronic chokers, which is a typical machine pairing. The MSK carriage weighs 690 kilograms and is powered by a 5.6 kW engine and has a three tonne lift limit. The machine is fully remote controlled, with both the landing operator and a choker-setter having control systems.

The yarder (Figure 3.1.4) operated a single corridor over this period. The corridor had been set on the day before the study started and had not been worked. The initial multi span set up ran from the tower at 10 meters to a 12 meter intermediate support 55 meters away at -9 degrees and then 140 meters at -22 degrees to a 14 meter high tail spar.

On the second day of operations the tower was lifted two meters to prevent logs snagging in the chute. This was followed by lifting the intermediate support one meter on the third day of the study to get a better approach angle to the jack. The approach angle was too steep on the previous day and required additional time to get the carriage over it.

The chute was cleared and logs processed with a John Deere 909 fitted with a HTH625C Waratah processing head. Logs were stacked and sorted with a 30 tonne excavator fitted with a grapple.

Figure 3.1.4: Koller 602hat the study site.

3.2.Production assessment methods

3.2.1. Elemental based time study assessment

Measuring the time taken for cycle elements can identify patterns occurring within systems and where possible advantages, disadvantages or future opportunities exist. As is commonly used this study divided the cycle into four elements (Acuna et al., 2012) (Table 3.2.1), allowing identification and analysis of factors that could influence productivity levels and if so what was influenced. Analysis of elements were limited in this study, results are included to assist further research.

Table 3.2.1 : Time study elements.

Action	Description
Un-hook time	When carriage stops at landing until it starts to leave the landing.
Out-haul time	From leaving landing to stopping for hook up.
Hook-up time	From stopping on out haul to moving on inhaul.
In-haul time	Time from stopped at hook up to stopped on landing.

Complete cycle times were recorded at all sites using a stop watch and pre-prepared time study record sheets. Methods to gather cycle elements were site dependant. For the Active 70 site two and both Koller sites the elements times were recorded by stopwatch. For the Active 70 at site one, cycle analysis data was obtained from tracking the carriage with a GPS unit.

For stopwatch measurement, the start and end time was recorded in 24 hour time and the differences provided the element time interval. Delays were recorded and removed at the cycle elements level to provide delay-free cycle times.

For the Active 70 at site one time elements were calculated post-fieldwork by assessing the carriage movement patterns as tracked by a GPS unit, a previous study found this method effective (Gallo, Visser, & Mazzetto, 2014). Typically cycle element analysis is done using onsite observations, however due to poor sight lines from the designated safe zone only complete cycle times could be assessed safely and accurately.

To track and record for the carriage movements a Garmin GPS unit (Garmin, 1200 E. 151st Street, Olathe, KS 66062-3426, USA) in an electrical box with an aerial for increased accuracy was attached to the carriage using zip ties threaded through ventilation holes. The unit was set to record its location, altitude and time data over the working period. Each data point was then converted into a horizontal distance from the yarder. When the GPS data is graphed it shows clear patterns that can be linked to cycle elements.

A two second record interval was used for the Active 70 on site one where cycle elements were gathered from the data, while at the Koller 602h site a 20 second record interval was considered sufficient accuracy as it was only used for extraction distance measurements.

Figure 3.2.1 displays two complete and two partial cycle periods over an 18 minute period. Movement is represented as an angled line and no movement is represented by a horizontal line. Using both the GPS and observational data time stamps it was possible to match the calculated elements with the recorded cycles and delays.

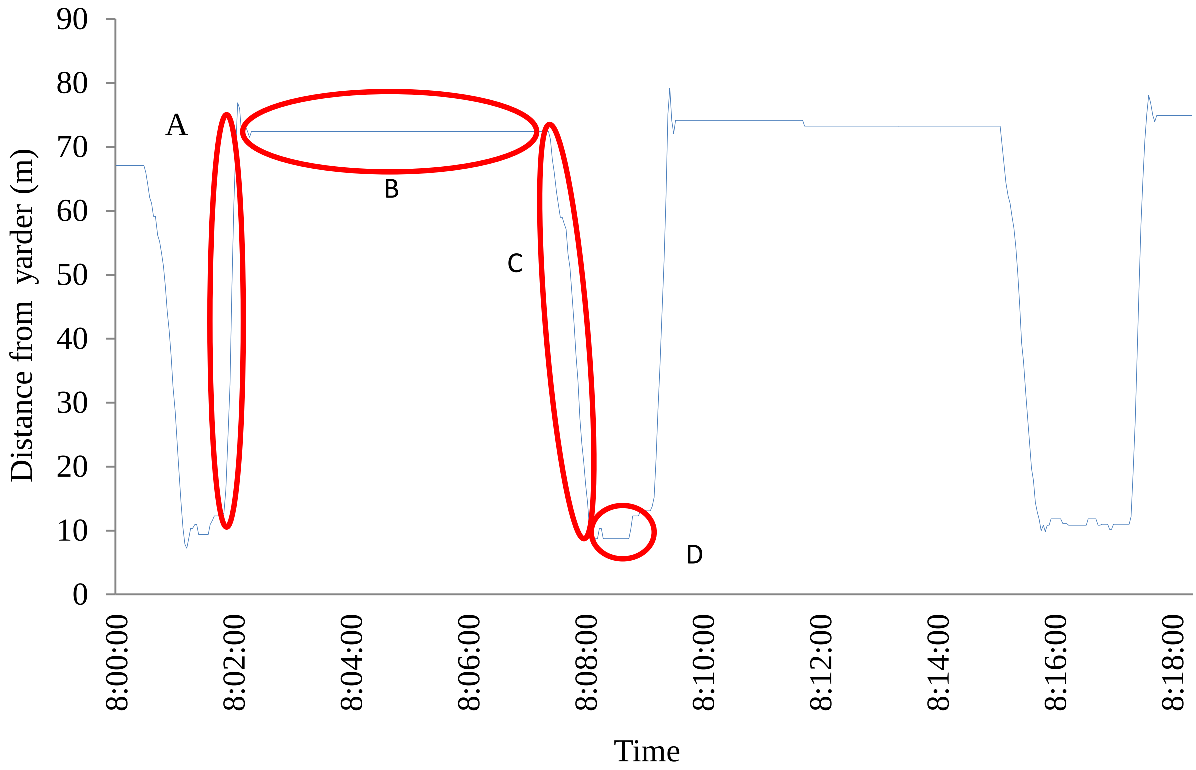

Figure 3.2.1: GPS cycle element data at Active 70 site one.

The technique used to assess cycle elements times relied on patterns in the mainline distance. Outhaul time (A) started when the distance value started increasing and ended when it stopped moving, represented by the distance plateauing. Hook time (B) started when the carriage reached its final outhaul distance, until the carriage started moving inwards. Inhaul time (C) started at this point and continued until it stopped moving at the landing. Unhook (D) is considered the time when the inhaul stops to when outhaul movement started again.

Due to data storage limitations within the GPS, the device had to be accessed once during the work day and the data saved and cleared. This was generally done during the workers lunch break when it had minimal impact on productivity and could be approached safely.

3.2.2. Utilisation rates

The utilisation rate (Equation 3.2.1) assesses how much the machine is being used by calculating the productive hours (PMH) divided by the scheduled machine hours (SMH). Utilisation rate provides insight into the efficiency of the system and were possible productivity issues exist.

Equation 3.2.1: Utilisation rate.

$$\text{Utilization rate (\%)} = \frac{\text{Productive machine hours}}{\text{Scheduled machine hours}} * 100$$

Productive hours are the amount of time the machine is working; this was calculated by adding all the individually recorded delay-free cycle times together. Doing this removes all delays that occurred over the work period.

Scheduled hours was when the crew was meant to be on site, until the majority of the crews left at the end of the working day. In some cases some members of the crew would remain to complete tasks not completed during the work day, which was not included as scheduled hours. It was not viable to use standard work hours for the estimate as work hours varied by day and by site.

Productive machine hour data allows the calculation of volume (m^3) per productive machine hour (m^3/PMH) rather than just at the volume per scheduled machine hour (m^3/SMH) rate. Productive machine hours provide a better comparison of productivity levels between machines, as delay times are highly variable between operations and non-typical delays that may be captured during the study period (or typical delays that do not happen) can skew data sets, potentially resulting in erroneous conclusions.

3.2.3. Description of delays

Delays were classified as any time when the focus machine is not operating, providing the difference between the scheduled and productive machine hours. System delays were separated into four categories (Table 3.2.2). Delays contribute to a significant proportion of the scheduled machine hours and can have significant impacts on production. Some of these delays are necessary and part of operations; however some are not and can result in systems being far less efficient than they should be.

Table 3.2.2: Description of delay types.

Delay type	Description
Operation	Delays caused by operation of the system, example; line shifts
Mechanical	Failure of a piece of equipment resulting in delay.
Personal	Personal delay including communication with the research team
Environmental	Delays caused by weather conditions

3.2.4. Cycle volume assessment

The volume of each stem in a cycle was collected for every cycle. Two methods were used; site specific regression equations for the Active 70 on site one, two and Koller 602hstudy and operator estimation for the Koller 507 study. Both methods also recorded the number of stems per turn.

Regression model technique

Researchers on landings during active logging operations create a safety concern and can reduce productivity. As such taking log measurements for each cycle was not practical.

To estimate cycle volume, each piece had the length and large end diameter estimated when it was pulled to the landing. To ensure accurate estimates the assessor would calibrate by estimating the diameter and length of sample logs and comparing these values with measured values. Using this technique the assessor quickly became more accurate at estimating large end diameters and lengths.

Piece volume was then estimated using a regression model of butt diameter and stem length. This regression model was made by measuring large end diameter, length, and diameter at 3 meter intervals (to provide a taper function) for a minimum of 40 stems at each site. This data was used to create a site specific regression model that predicted volume based on the large end diameter and total length of the extracted stem.

Log callipers were used to measure diameter and pacing was used to measure length. The volume of these pieces was added together to provide an accurate overall estimate of cycle volume (Acuna et al., 2012).

Operator estimation technique

The volume of each stem in the cycle was estimated by the operator of the processor when the chute was cleared. The sum of these was used for the overall cycle volume. Due to operational requirements seven loads (from 45) did not have volumes estimated. For these loads the volume was estimated using a number and size class of the logs recorded during the inhaul and operator predicted volumes of logs of the same size class. Size classification of the logs was divided into large, medium and small to match logs with observed volumes to allow volume prediction of missed loads. Size classes were estimated as; small: $<0.3m^3$, medium: $0.3\text{-}0.6m^3$, large: $>0.6m^3$.

3.2.5. Production process variables

To gain an accurate representation of the work done it is important to assess any features of the site that may have had an effect on production and costs. The following categories capture the key variables that were likely to have a non-random predictable effect on productivity (Acuna et al., 2012; Kirk & Parker, 1994; Kirk & Parker, 1996; Kirk & Sullman, 2001; Samset, 1990).

Outhaul distance

Three different methods were used to assess cycle distance; GPS tracking (Active 70 at site one and the Koller 602h), visual estimation of a fixed point (Koller 507) and analysis of the recorded ACDAT data (Active 70 site two)

GPS tracking method (Active 70 site one and Koller 602h)

GPS tracking data was processed to provide cycle distances. As explained in Section 3.2.1 the plateaus in the data represents the hook periods, the distance from the yarder at this period was considered to be the cycle distance. Cross referencing the plateau with the cycle time data allowed the matching of the cycle with the correlating distance.

Analysis of the recorded ACDAT data (Active 70 site two)

The butt rigging configuration used in this study meant that there was no viable way to attach the GPS system. Analysis from site one indicated that the ACDAT computer system used in the Active 70 recorded the mainline out distance and this in conjunction with the time study could be used to provide cycle distances. This data had a very similar pattern the GPS tracking data as such it was interpreted with the same methodology.

Visual estimation off a fixed point (Koller 507)

The distance from the yarder to the intermediate support was provided by the yarder operator, estimates from the distance of the carriage to the intermediate support were added to provide an estimation of distance. All the cycles were within 50 meters of the intermediate support, reducing the estimation distance by using the intermediate support as a reference point increased accuracy. For this study the lateral cycle distance was also recorded. Lateral haul distance was estimated by the average distance of the logs attached per cycle from the location of the carriage on the skyline.

Deflection

Deflection was calculated using Equation 3.2.2. The chord distance either calculated by the taking GPS points at the yarder and tail hold and calculating distance or shooting the distance with a range finder. Both methods were considered accurate, however the range finder method was more difficult to use when the span length was over 450 meters, subsequently over this the GPS method was used. The chord height at mid-span was estimated by shooting the loaded carriage at mid-span and recording the distance and angle. Using trigonometry this angle and mid-span and carriage distance was used in conjunction with the chord slope was used to provide the difference between the mid-span chord slope altitude and the carriage altitude.

Deflection values below 6% are considered low (poor), and above 15% are considered high (good). The normal range is between 5% and 15% (Harrill & Visser, 2012) .

Equation 3.2.2: Skyline Deflection.

$$\text{Deflection (\%)}=\frac{\text{Chord height at mid-span-Carriage height at mid-span}}{\text{Chord distance}}*100$$

Terrain roughness

Topographic patterns and features of the terrain at each site differ, and influence human and machinery operation differently. The terrain at each site was assessed using the size and frequency of the obstacles on the slope, and if they are permanent or not. Obstacles included; rocks, waterways, mounds, hollows, stumps and logs (Terlesk, 1983). Table 3.2.3 and Table 3.2.4 show the assessment criteria. It was not practical in any of these trials to walk the corridors, so a visible assessment was conducted from the safe zone. The assessment classes and criteria are shown in Table 3.2.3and Table 3.2.4; these are based on a modified terrain assessment method from Terlesk's (1983) report.

Table 3.2.3: Terrain assessment classes (Terlesk, 1983).

Ground Roughness Classes					
Class Rating	Class 1 Even	Class 2 Slightly uneven	Class 3 Uneven	Class 4 Rough	Class 5 Very Rough
Obstacle height/depth	Frequency				
Up to 60 cm	None	Isolated	Infrequent	Moderate	Frequent
Over 60 cm	None	None	Isolated	Isolated	Frequent

Table 3.2.4: Definitions of obstacle frequencies

Definition of Frequency		
Class	Spacing	Obstacles/ha
Frequent	<1.6m	>4000
Moderately frequent	1.6-5.0m	400-4000
Infrequent	5.0-16m	40-400
Isolated	>16m	<40

3.2.6. Tension monitoring

The tension of the skyline during inhaul is often a limiting factor in the cycle volume, therefore having a direct effect on productivity. If the machine can operate just under or at the safe working load the machine is likely to balance productivity and safety (Hartsough, 1993), this is easier to do if the operator has a real time tension display.

This study focused on the tension value and if it was a limiting factor of cycle volume. Skyline tension was assessed for the Active 70 at the second study site and for the Koller 602h.

Tension values were compared with the safe working load (SWL) of the skyline, which is calculated at 33% of the breaking capacity (Ministry of Business Innovation and Employment, 2012). Comparing cycle tensions to the safe working load indicated whether larger or smaller cycle volumes were necessary. The Active 70 fitted with a 28 mm swaged skyline had a SWL of 23.7 tonnes and the Koller 602h with a 22mm swaged skyline had a SWL of 14.4 tonnes (Shaw's Wire Ropes, 2016). Although the safe working load may be exceeded it is important that this does not necessarily indicate dangerous working practice, none of which were identified in this study.

Active 70 skyline tension assessment

The Active 70 was fitted with the ACDAT computer which as one of the options captured the maximum tension of the skyline in tonnes and recorded this value over 20 second intervals.

Figure 3.2.2 shows the tension data plotted and the time of the peaks was matched to the cycle's inhaul periods. The maximum tonnage reached over each cycle period was recorded as the cycle maximum tension.

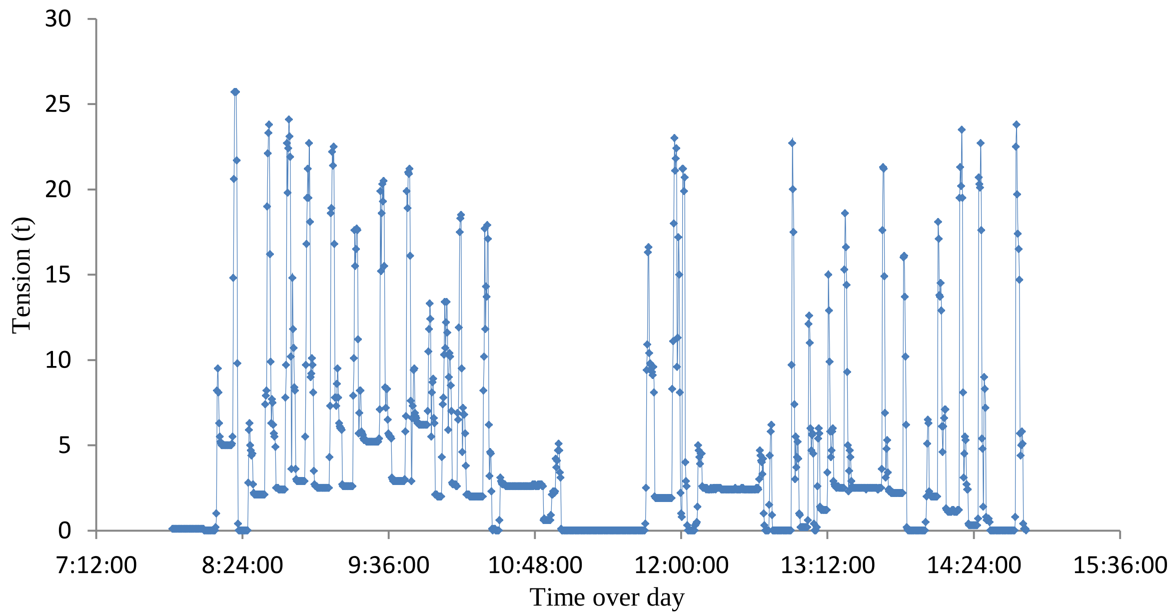

Figure 3.2.2: Active 70 ACDAT tension monitoring data example.

Koller 602h skyline tension assessment

The Koller 602h has the ability to measure skyline tension when it is initially raised / pre-tensioned. However, when the brake is applied to hold the skyline during operation it does not have the ability to monitor the skyline tension. As part of the assessment of the 602h, a tension monitor produced by Actronic New Zealand limited, Auckland, New Zealand (Smith, 1992) was clamped to the skyline two meters above the skyline drum.

The tension monitor was calibrated (Figure 3.2.3) with the rope size (22mm) by recording both the tension registered on the 602h on-board computer and the tension read out supplied by the portable monitor.

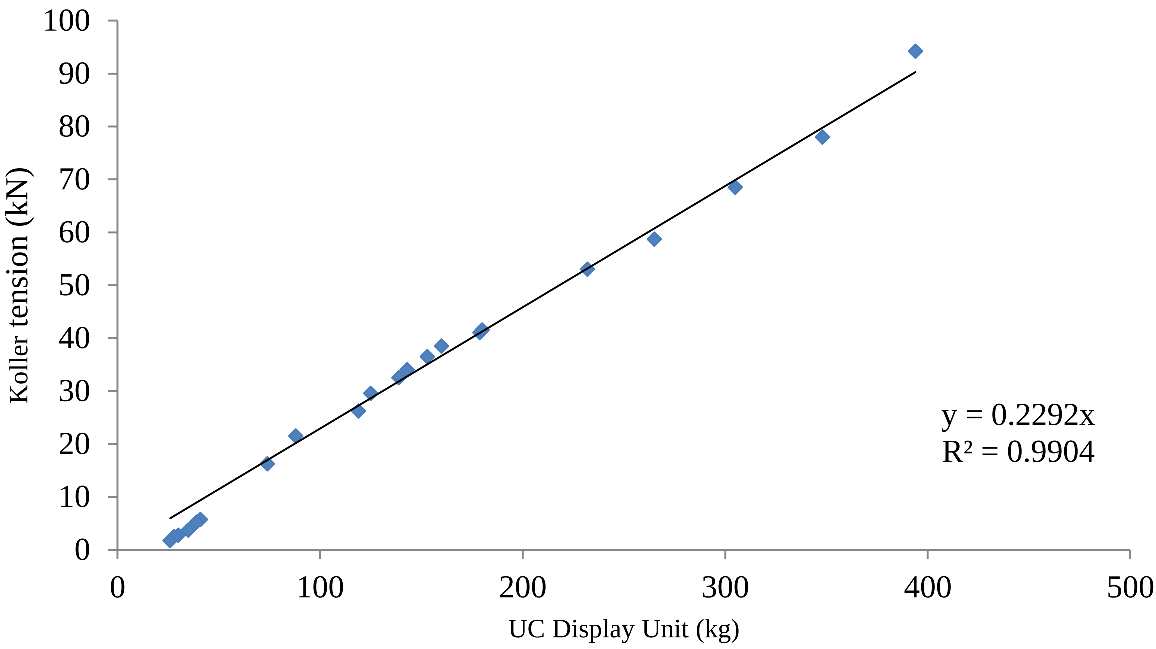

Figure 3.2.3: Koller 602h tension calibration graph.

As expected, there is a very linear relationship between the 602h and the Actronic tension monitor that allowed the accurate extrapolation of the UC data set using the 0.2292 conversion factor from tension monitor (kg) to skyline (kN). Figure 2.1.4 displays and tension patterns common for each cycle.

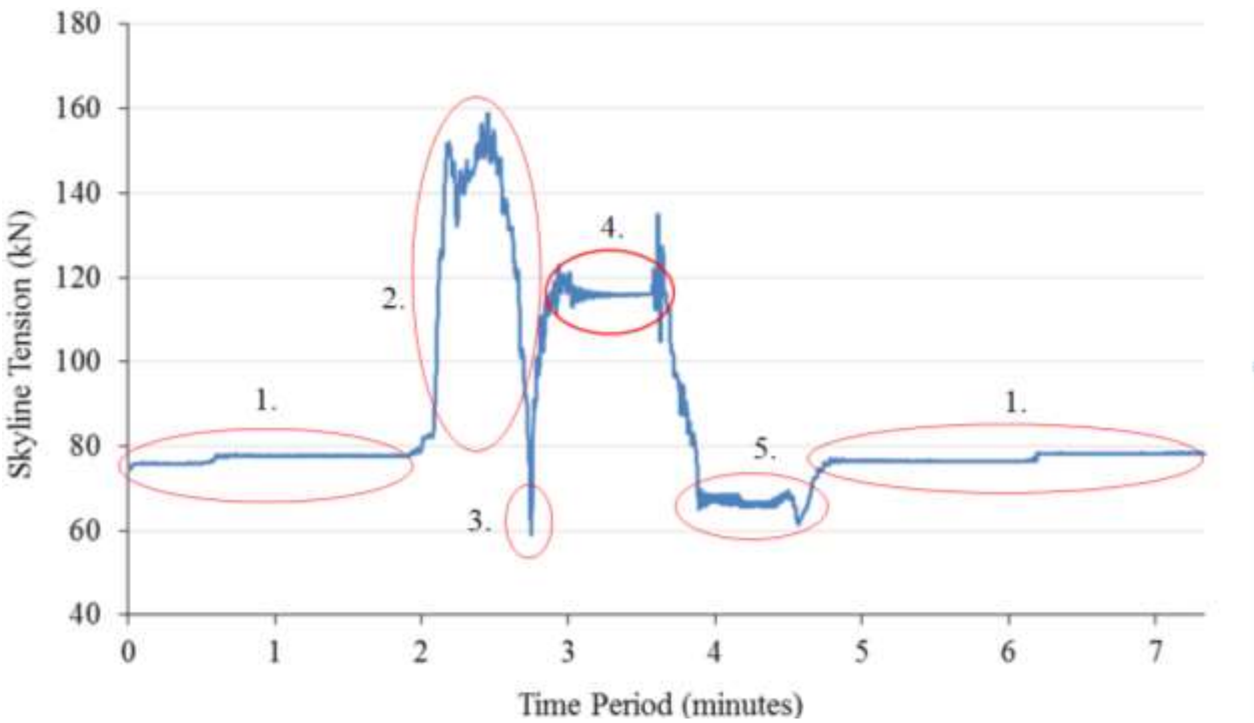

Figure 3.2.4: Koller 602h single cycle tension data.

Figure 3.2.4 above displays commonly found patterns in the 602h skyline tension data, explanation of the patterns is as follows:

1) Represents the outhaul and choker setting periods. The tension is low due to no additional load being on the skyline.
2) This period shows the inhaul starting, with the tension increasing as the load becomes partially supported by the skyline. The tension during this stage is the largest recorded due to the carriage loading. The observable spikes in tension here are likely to be the load catching on the ground due to the partial suspension method used, with this interaction effecting the cable tension.
3) Shows the load passing intermediate support, which transfers the majority of the weight off the skyline and onto the intermediate support, resulting in the skyline holding less of the carriage and load weight.
4) This period is the time the carriage spends at the remote point by the landing before the skid operator takes over control; it is normally not this pronounced.
5) As the load is unhooked the tension decreases, it increases slightly as the outhaul commences and the carriage moves down the first span and decreases slightly when passing the intermediate support.

By plotting all the recorded data in a format similar to above, the peak tension of each cycle was recorded and matched with the load of the cycle. This provided insight into skyline tensions under load for this yarder.

3.2.7. Production and time modelling methods

Linear regression was used to assess which factors had significant effects on cycle times or the delay-free productivity rate per cycle. Better understanding of the factors that influence these measures creates a better understanding of the entire system, allowing future comparisons of data with other studies.

Normalization of data

To build the model, factors that are relevant to the task were assessed using the Shapiro-Wilks test (alpha = 0.05) for normality of distribution and efforts were made to normalise un-normal distributed data sets. However it was found that the majority of factors did not have normal distributions nor could be transformed to meet the normal distribution.

It is likely that the limited span of the study may have resulted in the data sets being unnaturally skewed, and in a longer study more normal distributions are likely to emerge. It is also likely that the naturally limited range of some data sets does not allow normal distribution formation.

Selecting model factors

Relevant factors were modelled and step wise regression was applied. An alpha level of 0.1 was used, any factors that scored a p value of great than 0.1 were removed from the model one at a time, starting with the least significant until only significant factors remained.

An alpha level of 0.1 was used although it is not as limiting as an alpha level of 0.05 the high levels of variance in the data resulted in an excessive number of variables being excluded and overall the 0.1 level was considered a moderate combination of accuracy and significance.

Factors that had a naturally limited range of data not allowing them to form a normal distribution were tested as factors values.

3.3. Ergonomic assessment

3.3.1. Heart rate analysis

Because heart rate is considered an accurate representation of labour input in physical roles and labour input is accepted as being positively correlated to fatigue levels, heart rate data was used to assess physical work levels. This method is common in the forest industry (Kirk & Parker, 1994; Kirk & Parker, 1996; Kirk & Sullman, 2001; Stampfer et al., 2010; Sullman & Byers, 2000). Typically, the focus of these studies is on roles with very high physical workloads such as choker-setters. Subsequently heart rates were used as the primary measure of the work rate required for choker-setting in these studies.

As is consistent with numerous studies, heart rates were measured using a strap mounted pericardial heartbeat transmitter. This connected wirelessly to a wrist watch sized (and mounted) storage unit. In this study a Polar RCX5 heart rate monitor (Polar Electro Oy, Professorintie 5, FI-90440 Kempele, Finland) was used. These were set to record the wearer's heart rate every 5 seconds over the day. This method is considered accurate and had minimal interference on the ability of workers to do their job effectively (Kirk & Parker, 1996; Kirk & Sullman, 2001; Stampfer et al., 2010).

Although the average heart rate data is a useful number and may indicate individuals work levels effectively, it is of little use for comparison between individuals. Heart rates vary naturally between individuals, with one study recording resting and working heart rates that varied between individuals by almost 10% (Kirk & Sullman, 2001); which is linked to a large number of factors including; body type, age, fitness and diet. To standardise physiological strain between workers, three indices were applied to the heart rate data. Values used in these indices are in Table 3.3.1.

Three of the most common and simple indices of heart rate data were used to understand the trends; "relative heart rate at work" (Vitalis, 1987), the "50% of heart rate reserve" (Lammert, 1972) and the "ratio of working heart rate to resting" (Diament, Goldsmith, Hale, & Kelman, 1968). These indices have been demonstrated as effective techniques for assessing the physiological strain of forest workers (Kirk & Sullman, 2001). These measurements are used across a number of studies that examine work rate during choker-setting with cable yarders, allowing simple data comparison (Kirk & Sullman, 2001). Common terms used in these indices are shown in Table 4.2.1.

Table 3.3.1 : Terms used for heart rate indices.

Term	Definition
HRw (Working heart rate)	Average heart beats per minute over the day (bpm)
HRmax (Maximum heart rate)	220 – choker-setter age
HRr (Resting heart rate)	The lower of either the average heart rate value in a sitting position for a 10 minute period in the morning while not; eating, drinking or smoking, or the minimum heart over the whole working day.

Equation 3.3.1: Relative heart rate at work.

$$\%HRR = ((HRw - HRr) / (HRmax - HRr)) * 100$$

For Equation 3.3.1, prolonged physical work scores between 30 and 40% (Astrand & Rodahl, 1986). Choker-setting in one New Zealand study scored 36.3% ± 3.1% (Kirk & Sullman, 2001) .

Equation 3.3.2: 50% of heart rate reserve.

$$HRr + (HRmax - HRr) / 2$$

Lammert (1972) suggested the heart-rate reserve (Equation 3.3.2) is a good technique for assessing worker strain. If the result is scored at or over "1" it could be classified as hard continuous work. A study that utilized this method found that choker-setting had a score of 0.85 ± 0.04 and was therefore not classified as hard continuous work. This may be influenced by very short breaks as loads are hauled to the landing (Kirk & Sullman, 2001).

Equation 3.3.3: Ratio of working heart rate to resting.

$$Ratio\ of\ working\ heart\ rate\ to\ resting = HRw/HRr$$

Equation 3.3.3 is used across a large number of industries and can be easily calculated from published previously published data for comparison purposes. Steel workers and cane cutters, two roles which are believed to be very physical roles scored 1.28 (Vitalis et al., 1994) and 1.38 (Vitalis, 1981) respectively.

Site specific heart rate study details

At Active 70 study site one the two choker-setters wore heart rate monitors for the full five days of the study.

At Active 70 site two the heart rate monitor was fitted to the head choker-setter for the full three days of the study. Although in the previous study both choker-setters wore monitors, in this study one of the monitors was defective and would not connect to the recording unit; resulting in only one choker-setter being assessed.

At the Koller 602h site, the heart rate monitor was fitted to the head choker-setter of each day. The number of choker-setters varied and the head choker-setter varied between two people over the study period, this was recorded and results were assessed with this considered.

Ergonomic process variables

There are multiple factors that contribute to work levels and productivity other than just the machinery used (Kirk & Parker, 1994; Sullman & Byers, 2000). If these variables are not accounted for it is likely to result in inaccurate data comparisons. These factors include; slope, roughness of terrain/obstacle and climatic conditions (Kirk & Parker, 1994; Kirk & Parker, 1996; Kirk & Sullman, 2001).

Climatic conditions

Climatic conditions that are most likely to affect the results are rainfall and temperature. Rain was assessed by intensity and duration of the working day. Intensity was grouped into light, moderate and heavy categories. Duration was calculated as a percentage of the work day spent in rain. Temperature was based on general categories, 0-10, 10-20, 20-30 degrees Celsius.

Hindrance

This was similar to terrain roughness but was focused on obstructions facing the choker-setters that are likely to change work rates. It included both undergrowth and fallen tree obstructions. This was scored based on the subjective rating outline in Kirk and Parker (1996) with a scoring system ranging from 1-4 as shown in Table 3.3.2 below (Kirk & Parker, 1996).

Table 3.3.2 : Assessment criteria for choker-setter hindrance scores.

Rating	Assessment criteria
1	Low to no hindrance apart from felled trees.
2	Moderate undergrowth, small obstacles, slightly more difficult to navigate.
3	Heavy undergrowth, moderate obstacles, moderately difficult to navigate.
4	Extreme hindrance, heavy brush, large obstacles, difficult to navigate.

3.3.2. Decibel monitoring

Hearing damage caused by working in or around a cable yarder is expected to be minimal due to the hearing protection equipment that is now legally required under the Health and Safety at Work Act (2015).

The benefit is in the extra alertness that may be available due to the quieter landing area and a generally more pleasant work environment that is likely to reduce fatigue (Inoue, 1996).

Measurement and standardisation

Noise monitoring was conducted using a Lutron SL – 4033sd decibel meter at a recorded distance from the machine. This was done as the equations surrounding noise dissipation following the inverse square law, which is well understood and can be used to standardise data accurately (Equation 3.3.4). As such the device was located where it was convenient and was exposed to minimal back ground noise created by other landing operations. No data on noise emissions from traditional machinery could be found so a traditional type machine (A Thunderbird TSY255) was tested as part of the study.

Equation 3.3.4: Inverse square sound distance relationship.

$$Decibels\ at\ distance\ =\ source\ strength/\ 4\ *\ Pi\ *\ distance^2$$

As damage to hearing occurs due to exposure to certain levels of decibels over a time period, the noise measurement was set to capture the maximum volume at one second intervals. The length of recording varied depending on the ability to get a clear representative noise sample. As familiarity was gained with the equipment, the time needed to gain these samples was more clearly understood and sample periods decreased as a result.

Volumes above 85 decibels are considered excessive and actions must be taken to reduce exposure (McBride, Firth, & Herbison, 2003) , as such volumes over 85 decibels are described as being a significant risk to hearing if personnel are in this area without hearing protection. Volumes over 80 decibels were classed as moderate risk and volumes below this were classed as minimal risk. It is still recommended that hearing protection is worn anywhere a conversation cannot easily be heard (Accident Compensation Corporation, 2013) regardless of study results.

Decibel monitoring study details

For the Active 70, four, two hour periods recorded at a distance of 21 meters were taken. The monitor was located on the back side of the machine opposite the exhaust. Some interference from chainsaws is likely to have occurred.

For the Koller 602h, two, one hour periods recorded at a distance of 18 meters were taken. The monitor was located on the back side of the machine opposite the exhaust. There is a high chance of interference from the processor working 30 meters from the monitor. To mitigate processor interference the time periods of recording were when there was a low chance of back ground noise affecting the findings. These interference sections of the recording were used for the final estimates.

For the Thunderbird yarder that was used as the typical industry benchmark, three 20 minute periods recorded at a distance of 21 meters were taken. The monitor was located on the back side of the machine opposite the exhaust. There was little to no interference from other machines at this site.

3.4. Methods overview

A summary of data collected and methods used are shown in Table 3.4.1 and Table 3.4.2.

Table 3.4.1: Methods by site used for data collection.

Site/measurement	Active 70 Site One	Active 70 Site two	Koller 507	Koller 602h
Cycle time	Stop watch	Stop watch	Stop watch	Stop watch
Cycle element time	GPS carriage tracking	Stop watch	Stop watch	Stop watch
Haul distance	GPS carriage tracking	ACDAT system data	Point estimation	GPS carriage tracking
Cycle volume	Modelled estimates	Modelled estimates	Operator estimate	Modelled estimates
Tension study	-	ACDAT system	-	Actronic monitor

Table 3.4.2: Summary of data gathered at each study site.

Site/measurement	Active 70 Site One	Active 70 Site two	Koller 507	Koller 602h
Volume	Yes	Yes	Yes	Yes
Cycle time(s)	Yes	Yes	Yes	Yes
Decibels	Yes	No	No	Yes
Heart rates	Yes	Yes	No	Yes
Tension	No	Yes	No	Yes

4. Results and discussion

4.1. Productivity findings

4.1.1. Active 70 site one productivity analysis

Over the five corridors assessed during five days (41.7 SMH), a total of 640m^3 was extracted. Because there was variation in production levels and corridor conditions, data was divided and presented by corridor.

During the study weather conditions were mainly clear, with intermittent light showers and wind on three days; these variations were not considered significant. Temperature was in the 0-10 degrees Celsius category over the time period. The same two choker-setters were present each day, due to the mobile tail-hold choker-setters were not required to help with line shifts. The terrain category scores and descriptions are shown in Table 4.1.1, felled trees and moderate undergrowth provided obstructions for choker-setters and ground roughness was rated as uneven. There were intermittent stumps in the inhaul route from harvesting operations; these had notable effects on inhaul rates and as a result on the third day one stump was removed from the inhaul corridor to reduce hang ups during inhaul. The ground slope that the choker-setters worked on varied between 23 degrees and 37 degrees, with an average of 31 degrees.

Table 4.1.1: Active 70 site one site description scores.

Category	Score	Description
Ground roughness	3	Uneven
Obstacles over 60cm	Moderate	Spacing 1.6-5.0m
Obstacles up to 60cm	Moderate	Spacing 1.6-5.0m
Hindrance class	2.5	Moderately difficult to navigate

Cycle statistics

Cycle measurements are shown in Table 4.1.2. The number of cycles per corridor varied, with an average of 35 cycles being comprised of two corridors of 17 and 20 cycles (corridors two and four) and three corridors of 42-50 cycles (corridors one, three and five). The low cycle count in corridors two and four were due to the difficult terrain limiting access to stems and the use of a mobile tail-hold that allowed fast line shifts, resulting in a low line shift delay ratio per cycle. The average cycle time was 9.33 minutes, with a SD of 2.68 minutes. The average cycle volume was 3.6 m^3, with a SD of 2.1m^3. Overall corridor volume varied depending largely on cycle count and ranged from 57m^3 to 219m^3 with an average of 128m^3.

Due to some error in the GPS cycle element assessment method there are some discrepancies between delay-free cycle times and the element delay-free times. Error was caused by difficulty in identifying individual time points in the graphed data. For this method to be time effective this was unavoidable and should be noted as a weakness.

Table 4.1.2: Active 70 site one cycle statistics.

Corridor/result	1	2	3	4	5	Average
Cycles per corridor	50	17	42	20	48	35
Average delay-free cycle time (minutes)	9.77	11.61	8.91	8.83	8.64	9.33
Standard deviation of delay-free cycle	3.11	2.95	2.58	1.85	1.95	2.68
Corridor volume (m^3)	184	66	112	57	219	128
Average cycle volume (m^3)	3.7	3.9	2.7	2.9	4.6	3.6
SD cycle volume (m^3)	2.4	1.6	1.6	2.0	1.9	2.1

Cycle time element analysis

Cycle elements are shown in Table 4.1.3. The observed average cycle time was 9.33 minutes of this the hook period was the largest contributor to the overall time comprising of 6.01 minutes, followed by inhaul at 1.89 minutes, outhaul at 1.26 minutes and unhook at 0.27 minutes. All elements displayed high SD values of 55% to 120% of the average.

Table 4.1.3: Active 70 site one cycle element times (decimal minutes).

Time element	1	2	3	4	5	Average	SD
Average of outhaul	1.47	1.24	1.11	1.34	1.12	1.26	0.67
Average of hook	6.12	8.27	5.54	6.01	5.44	6.01	2.56
Average of inhaul	2.13	2.13	1.9	1.33	1.81	1.89	1.04
Average of unhook	0.34	0.3	0.23	0.15	0.27	0.27	0.33

Multiple factors influence the variability between the corridor average time elements, these contribute to the overall SD value; factors that typically influence the time period of these elements are displayed in Table 4.1.7.

Random variance affected a number of the cycle elements; generally it was due to factors that were not viable to measure. Inhaul was often influenced by short delays as loads caught on obstructions and poor lines of sight from the safe zone did not allow accurate assessment of these. During the hook period ground steepness and roughness heavily affected walk in and out times, and as this varied by cycle it was not feasible to assess as a terrain factor. The unhook period was influenced by the number of stems on the landings. Observations noted when stem numbers on the landing were high unhooking had to be performed carefully and sometimes with grapple assistance, increasing unhook time and variance. Although these are operational delays the difficulty of estimating stem dimensions before they got mixed with other stems on the landing (which was of higher importance), at the same time meant it was difficult to accurately assess and was often not recorded.

Utilisation over study

Table 4.1.4 displays time consumption and utilisation rates. The overall utilisation rate for the week was 65%. Common utilisation rates for cable yarding systems are around 65-70% (Harper, 1992) indicating that this machine was operating within standard levels for the course of this study.

Table 4.1.5 shows delay type proportions, of which operational delays contributed 62% of delays with multiple contributing events being; a safety briefing, a surge pile in the chute that needed to be processed, a crew breakfast, line shifts and a yarder shift. A carriage breakdown caused 6% of all delays and 60% of mechanical delays. Personal delays at 29% of all delays were all due to lunch breaks.

Table 4.1.4: Active 70 site one time consumption and utilisation rates.

Corridor/Time (decimal hours)	1	2	3	4	5	Sum
Productive machine hours	7.7	3.5	6.2	2.9	6.9	27.2
Delay time	6.2	0.6	1.2	4.1	2.4	14.5
Scheduled machine hours	13.9	4.1	7.4	7	9.3	41.7
Utilisation rate	55%	84%	84%	42%	74%	65%

Table 4.1.5: Active 70 site one delay time by category.

Delay type	Operation	Mechanical	Personal	Environmental
Proportion	62%	10%	29%	0%

Productivity analysis

Table 4.1.6 displays productivity rates by corridor. The site averaged 23.5m^3/PMH with a SD of 17.7m^3/PMH and a scheduled rate of 15.3m^3/SMH, below the New Zealand average of 26.2m^3/SMH for cable logging operations (Visser 2015).

Table 4.1.6: Active 70 site one productivity by skyline corridor.

Corridor/Measure	1	2	3	4	5	Average	SD
m^3/PMH	24	18.9	18	19.4	31.6	23.5	17.7
m^3/SMH	13.3	16.0	15.1	8.1	23.4	15.3	

Influential factors

The variation in cycle times and load sizes both within and between corridors indicate there are likely to be multiple site factors that influence productivity,

Table 4.1.7 shows factors that were assessed during the study.

The average piece size was 1.1m^3 and was between 1.0m^3 and 1.1m^3 for four corridors, with corridor two being above average at 1.4m^3. The average piece count per cycle was 3.5 pieces with a maximum average of 4.6 pieces and a minimum of 2.7 pieces. Average piece size and count contributed to the average cycle volume of 3.6m^3 and variation from 2.7m^3 to 4.6m^3 per corridor.

Variation in average cycle volumes were likely associated with skyline tension issues caused by low deflection experienced over two of the corridors. Two settings were found to have low deflection scores at 2% and three settings had normal deflection values at 7-8% (Harrill & Visser, 2012). The yarder was moved forward on the landing for the fourth corridor to mitigate tension issues encountered due to low deflection in corridor two and three, this resulted in the normal deflection levels of corridors four and five.

The average cycle distance per corridor ranged from 107 meters to 181 meters and averaged 140 meters. The variation present in the inhaul and outhaul times (Table 4.1.3) is related to the cycle distance variation present within and between corridors. The average distance of 140 meters and the inhaul time period of 1.89 minutes gives an average inhaul velocity of 1.23m/s^{-1}.

Table 4.1.7: Active 70 site one potentially influential factors of productivity.

Corridor/result	1	2	3	4	5	Average
Average piece size (m^3)	1.1	1.4	1.0	1.0	1.1	1.1
Average pieces per cycle	3.4	2.8	2.6	3	4.2	3.3
Average cycle volume (m^3)	3.7	3.9	2.7	2.9	4.6	3.6
Average extraction distance (m)	107	142	146	122	181	140
Deflection	7%	2%	2%	8%	7%	5%

Active 70 site one regression modelling

Delay free cycle time model

Equation 4.1.1 predicted a delay-free cycle time of 9.19 minutes, with a residual standard error of 2.42 minutes; the observed average was 9.33 minutes. Extraction distance was the sole significant factor explaining 1% of the variation in cycle times; this with the high residual standard error indicates this model has poor accuracy. The poor accuracy is the result of random error in the dataset; key causes of random error are explained in the 'Cycle time element analysis' section. The distribution of residuals was considered sufficiently normal not to need transformation (Appendix H).

Table 4.1.8: Active 70 site one factors and coefficients for delay-free cycle time modelling.

Factors	p value	Coefficients
Intercept	> 0.001	8.49
Cycle distance (m)	0.1	0.005
R squared value	1%	

Equation 4.1.1: Active 70 site one delay-free cycle time model.

$$Delay\ free\ cycle\ time\ (minutes)\ =\ 8.49\ +\ (0.005\ *\ cycle\ distance)$$

Productivity

Equation 4.1.2 predicted a delay-free production rate of 23.4m^3/PMH, compared with the observed average of 23.5m^3/PMH. The residual standard error of 10.07m^3/PMH indicates this model has poor accuracy. The distribution of residuals was considered sufficiently normal not to need transformation (Appendix I). Piece count, piece size and cycle distance were significant (Table 4.1.9) and explained 68% of the delay-free productivity rate.

Table 4.1.9: Active 70 site one factors and coefficients for productivity modelling (m3/PMH).

Factors	p value	Coefficients
Intercept	>0.001	-25.36
Piece count	>0.001	9.06
Piece size (m^3)	>0.001	20.58
Cycle distance (m)	0.09	-0.02
R squared value	68%	

Equation 4.1.2: Active 70 site one delay-free productivity model.

$$\frac{m^3}{PMH} = -25.36\ +\ (9.06\ *\ piece\ count) + (\ 20.58 *\ piece\ size)$$

$$+ (-0.02\ *\ haul\ distance)$$

Active 70 site one productivity discussion

The overall utilisation rate of 65% was within the standard levels for New Zealand cable yarding operations of 65 to 70% (Harper, 1992). The majority of delays were operational and personal. One significant mechanical delay occurred which was caused by the choker-setters pulling the drop-line off the drum of the carriage, which took 53 minutes to reattach. Approximately 10% of the delay time was non-typical in nature and a higher average utilisation rate is expected.

The 65% utilisation rate contributed to a scheduled productivity rate of 15.3m^3/SMH; which is below the industry average of 26.2m^3/SMH (Visser 2015). The delay-free production rate at 23.5m^3/PMH showed that delay periods were not the sole cause of low production. The site was considered poor having a small average piece size, deflection limited cycle volume and difficult terrain, all features which restricted production.

The delay-free cycle time model found an average cycle time of 9.19 minutes versus the observed average at 9.33 minutes. Haul distance was the sole significant factor and the low R^2 of 1% and comparatively high residual standard error indicates that this model is of low accuracy. The modelled rate of production at 23.4m^3/PMH was similar to the observed rate at 23.5m^3/PMH. The residual standard error for the model is 10.07m^3/PMH indicating low accuracy. Significant predictive factors for the model were; piece size, log count and haul distance, with a combined R^2 value of 68%. The low strength of these models is strongly related to random variation in the data set, observed sources included loads catching on obstructions during inhaul and large variations in walk in and out times between cycles. It was not possible to accurately assess either of these factors and both contributed to reduced factor and model strength.

Higher productivity is expected during operation at better sites with a larger piece size and higher deflection values. On better sites it is expected the Active 70 would reach the national average, and as this level of production would allow it to supply the processing systems currently paired with traditional yarders at the required rate, it is a suitable direct replacement of older cable yarders in New Zealand.

4.1.2. Active 70 site two productivity analysis

During the study weather conditions were windy every day, with light showers on the second and third day. Wind and rain may have had a slight negative effect on productivity of the choker-setters. Temperature was in the 0-10 degree category over the time period. Two choker-setters were working each day and due to the manual tail hold shifts two more workers were required to help with line shifts. Terrain category scores and descriptions are in Table 4.1.10, felled trees, stumps and heavy undergrowth obstructed workers and the ground roughness was uneven. There were stumps in the inhaul route from previous harvesting operations, however suspension of butts meant there was little effect of these on inhaul rates. The ground slope that the choker-setters worked on varied between 27 degrees and 35 degrees, with an overall study average of 31 degrees.

Table 4.1.10: Active 70 site two site description scores.

Category	Score	description
Ground roughness	3	Uneven
Obstacles over 60cm	Moderate	Spacing 1.6-5.0m
Obstacles up to 60cm	Moderate	Spacing 1.6-5.0m
Hindrance class	2.5	Moderately difficult to navigate

Over the three days, four corridors were operated with a total of 424m^3 pulled over 22.70 SMH. Variation in production levels and site conditions justified dividing the data set into corridors.

Cycle statistics

Cycle measurements are shown in Table 4.1.11. The number of cycles per corridor varied with a range of 16 to 39. Corridor one and four were incomplete due work outside of the assessment period, this was not considered an issue as the two incomplete corridors effectively averaged the bias of the other. The overall average cycle time was 10.70 minutes with SD of 2.74 minutes; this variation was caused by multiple influential factors. The average cycle volume was 4.4m^3 per haul, with a SD of 1.9m^3, there was an average extracted volume of 106m^3 per corridor.

Table 4.1.11: Active 70 site two cycle statistics.

Corridor/result	1	2	3	4	Average
Cycles per corridor	16	31	39	11	24
Average delay-free cycle time (minutes)	10.72	11.01	11.82	10.02	10.70
SD of delay-free cycle time (minutes)	1.95	2.39	3.33	2.17	2.74
Corridor volume (m^3)	56	149	168	52	101
Average cycle volume (m^3)	3.5	4.8	4.3	4.7	4.4
SD of cycle volume (m^3)	1.5	1.7	2.2	1.5	1.9

Cycle time element analysis

Cycle time by element is shown in Table 4.1.12. Of the average cycle time of 10.70 minutes, hook period was the largest contributor comprising of 6.73 minutes, followed by inhaul (2.30 minutes), outhaul (1.14 minutes) and unhook (0.74 minutes). All elements displayed high SD values (35% to 60% of the average), which do not take into account differences within cycles and corridors.

Table 4.1.12: Active 70 site two cycle element times (decimal minutes).

Corridor/ Measurement	1	2	3	4	Average	SD
Average of outhaul	0.98	1.21	1.14	1.20	1.14	0.68
Average of hook	6.49	6.63	7.27	5.49	6.73	2.28
Average of inhaul	2.24	2.19	2.54	1.88	2.30	1.25
Average of unhook	0.80	0.78	0.62	0.96	0.74	0.37

Multiple factors influence the variability between the corridor average time elements, contributing to the overall SD. Assessed factors that typically influence the time period of these elements are displayed and discussed in Table 4.1.16.

Variance in outhaul times were observed as the carriage often had to repositioned due poor sight lines resulting in the carriage initially stopping too far away from stems for the choker-setters to attach them. Blind carriage handling was particularly severe for hauls around the 270m – 290m distance where a ridge blocked sight of the stems. The resulting delay was difficult to observe and was not accurately recorded. Inhaul was not generally influenced by delays, as such minimal random variance was introduced.

Ground steepness and roughness heavily effected walk in and out times, which contributed a significant amount of the total hook time and are likely to be linked to the hook time variation between each cycle location. Although corridor terrain assessments were conducted, cycle level assessments were infeasible, and the unmeasured effect is largely random. The rate choker-setters attach stems is also variable depending on stem placement, this was also not assessed and may influence variance.

The unhook period was influenced by the number of stems on the landings, with the two staging system causing landing clearance issues. Delays due to repositioning were often not recorded, due to getting accurate estimations of stem size being more important, it was difficult to accurately identify stems from the cycle once stems were landed. This was important as observations noted that when stem numbers on the landing were high, unhooking delays were most likely to occur.

Utilisation over study

Table 4.1.13 displays time consumption and utilisation rates. This study captured the machine at 76%; above the normal range of 65-70% (Harper, 1992). Key contributors to this high level were the only delays recorded being lunch breaks and line shifts. The high utilisation rate of corridor one was a result of a line shift associated with corridor two occurring before the morning rest break, hence the morning rest break delay was associated with corridor two. The forth corridor had a limited observation time and captured the line shift, resulting in an utilisation rate below the average rate.

Table 4.1.13: Active 70 site two time consumption and utilisation rate.

Corridor/Time (decimal hours)	1	2	3	4	Sum
Productive machine hours	2.85	5.51	7.09	1.84	17.3
Delay time	0.00	1.73	2.83	0.85	5.41
Scheduled machine hours	2.85	7.24	9.92	2.69	22.70
Utilisation rate	100%	76%	71%	68%	76%

Delay types (Table 4.1.14) were all operational and personal. Operational delays were due to the four manual line shifts performed and the brief morning safety meetings. The personal delays were due to lunch breaks for the crew.

Table 4.1.14: Active 70 site two delay time by category.

Delay type	Operation	Mechanical	Personal	Environmental
Proportion	64%	0%	36%	0%

Productivity

Productivity measures are shown in Table 4.1.15. The average delay-free productivity rate was 24.5 m^3/PMH, at the utilisation rate of 76% this equated to a rate of 18.6m^3/SMH. The SD was high at 12.1m^3/PMH; variation is at the cycle level and is the result of variance in multiple site factors over multiple corridors and random error. This production rate was below the New Zealand average of 26.2 m^3/SMH for cable logging operations (Visser 2015).

Table 4.1.15: Active 70 site two productivity by skyline corridor.

Corridor/Measure	1	2	3	4	Average	SD
Average m^3/PMH	20.6	25.1	22.0	28.2	24.5	12.1
Average m^3/SMH	20.6	19.1	15.8	19.3	18.7	

Factors that may influence

The variation in cycle times and load sizes both within and between corridors indicate that there are likely to be multiple influential factors, these are shown in Table 4.1.16.

The average piece size ($1.5m^3$) was similar across corridors two to four. Corridor one had a smaller average piece size at $1.1m^3$. The number of pieces per cycle averaging 3.0 was very consistent across the study and the study had an overall average cycle volume of $4.4m^3$. As a result of the smaller piece size in corridor one, the average cycle volume in corridor one was lower than the average at $3.5m^3$ per cycle.

The deflection varied by only 2% across the corridors and no overloading related delays occurred. The range of 10% to 12% are considered to be a good deflection values (Harrill & Visser, 2012).

The average extraction distance was 351m and ranged from 249m to 399m. A no cycle zone existed from the yarder to 200m out along all corridors assessed. Large changes in extraction distance contributed to the variance noted in the inhaul and outhaul periods. The average distance of 351 meters and the inhaul time period of 2.30 minutes gives an average inhaul velocity of $2.54m/s^{-1}$.

Table 4.1.16: Active 70 site two potentially influential factors of productivity.

Corridor/measurement	1	2	3	4	Average
Average piece size (m^3)	1.1	1.7	1.5	1.6	1.5
Average pieces per cycle	3.1	3.0	2.9	2.9	3.0
Average cycle volume (m^3)	3.5	5.0	4.4	4.7	4.4
Deflection	10%	11%	11%	12%	11%
Average extraction distance (m)	399	362	333	249	351

Tension monitoring study Active 70 site two

The Active was fitted with a swaged 28mm skyline with a breaking strain of 71.2 tonnes, equating to a safe working load of 23.7 tonnes. From the ACDAT data 87 cycles were individually identified.

Over the assessment period the machine operated beneath the SWL, with the tension monitoring finding the average maximum tension at 19.0 tonnes and the overall maximum at 25.7 tonnes, 22% of all cycles were over the SWL. The distribution of these cycles is shown in Figure 4.1.1. Although there were 22 cycles in the sub 16 tonne tension class, cycle volumes were limited by tension over the study which limited overall production.

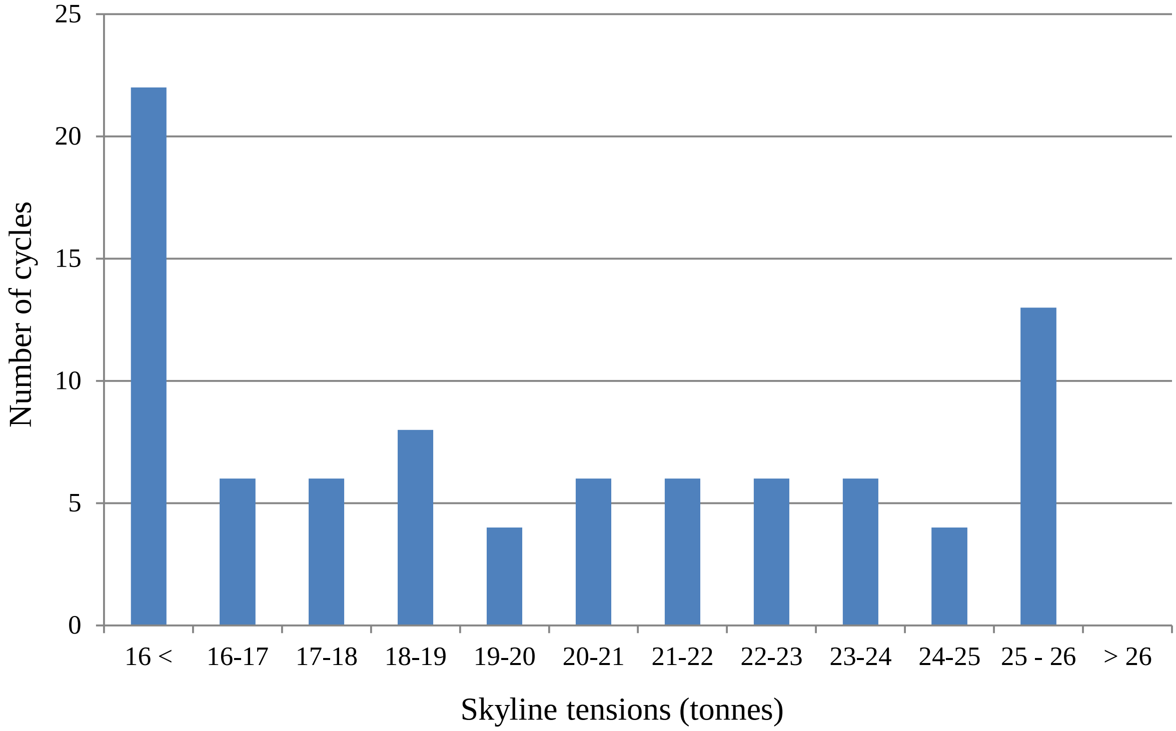

Figure 4.1.1: Active 70 site two distribution of maximum skyline tension per cycle.

The use of the tension monitor to moderate cycle volumes was observed on multiple occasions at both Active 70 study sites. Radio dialogue between the choker-setters and the yarder operator concerning load size and tension measurements was observed at multiple occasions. The communication was to try maintaining skyline tensions just below the safe working load while achieving the maximum load capacity, which would optimise productivity and safety. Without a tension monitor this is highly difficult to achieve and is likely to be inaccurate, resulting in a lower optimisation of productivity and safety(Smith, 1992). This application of the tension monitor is typical of the intended use of real time tension data (Hartsough, 1993).

Active 70 site two regression modelling

Delay free cycle time modelling

No factors were found to be significant predictors of complete cycle time. A number of factors were identified that resulted in variation in outhaul, hook and inhaul times and are addressed in Cycle time element analysis (page 42).

Production modelling

Using average site data, Equation 3.1.3 predicted a delay-free production rate of 23.0m^3/PMH, compared with the observed average of 24.5m^3/PMH. The residual standard error of 6.49m^3/PMH indicates this model has poor accuracy. The distribution of residuals was sufficiently normal not to require transformation (Appendix J).

No factors were found to be significant for complete cycle time as such it was not unexpected that delay-free productivity only had the cycle volume as a significant factor, which explained 71% of the variation present in the model.

Table 4.1.17: Active 70 site two factors and coefficients for productivity modelling (m^3/PMH).

Factor	p value	Coefficients
Intercept	0.750	0.55
Cycle volume (m^3)	>0.001	5.52
R squared value	71%	

Equation.4.1.3: Active 70 site two delay-free productivity model.

$$\frac{m^3}{PMH} = 0.55 + (5.52 * cycle\ volume)$$

Active 70 site two productivity discussions

The average utilisation rate at 76% was above the standard levels for New Zealand cable yarding operations (65-70% (Harper, 1992). Delays were operational (64%) and personal (36%), with no mechanical or environmental delays recorded.

The utilisation rate at 76% contributed to the productivity level of 18.6m^3/SMH, which was below the New Zealand average of 26.2t/SMH (Visser 2015). The scheduled machine rate was expected to be closer to the average rate than was found. Utilisation was above average and the delay-free production rate of 24.5m^3/PMH is still below 26.2t/SMH indicating that delays were not a key cause of the below average productivity rate. The cause instead was due to the site being above average in difficulty; with the key factor being that no cycles completed within 200 meters, reducing the number of high productivity cycles. With shorter haul distances cycle inhaul and outhaul times are shorter, reducing total cycle time and increasing productivity levels.

The low productivity rate was not a result of low cycle volumes, with tension studies finding that the machine was below the safe working load for 78% of assessed loads, and the average at 19.0 tonnes was skewed low by 22 cycles below 16 tonnes. It is considered that although tensions on average were below the safe working load and the deflection was good at an average of 11%, skyline tension did limit load size and productivity. There was communication between the choker-setters and the yarder operator about load sizes, with the tension monitor used to ensure tensions in each cycle were close to the safe working load. Communication regarding tension data to maximise production and maintain safety has been identified as a benefit of tension monitors previously (Evanson, 2009).

No factors were found to be significant predictors of complete cycle time, with multiple sources of random error being identified. Similar to the Active 70 on site one, large variations in walk in and out times of choker-setters due to terrain differences contributed to reduced significance of both models. Productivity modelling found a theoretical rate of 23.0m^3/PMH which is close to the observed rate of 24.5m$^{3/}$PMH. The residual standard error of 6.49m^3/PMH indicates that the model is of low accuracy and should be used with caution. Volume was the sole significant prediction factor; the resulting model produced an R^2 value of 71%.

Higher productivity is expected during operation at sites similar but with shorter average cycle distances and it is expected that this machine in this configuration is likely reach the national average if assessed at such a site. Similar to the Active 70 operating with the Boman carriage, the Active 70 in the North Bend configuration is a suitable replacement for cable yarders in New Zealand.

4.1.3. Active 70 combined sites productivity discussion

The Active 70 on site one captured a utilisation rate at the lower end of the normal range of 65-70% (Harper, 1992) at 65%, the second site was above the expected value at 76%. 10% of all delay time at site one was considered non-typical and the normal rate for both configurations is likely to be between 65% and 75%. A carriage related mechanical delay at site one contributed 10% of the delay rate, indicating that the more complex piece of machinery may be more susceptible to mechanical issues and delays than the simpler North Bend configuration used at site two, which experienced no mechanical delays.

There was very little difference ($23.5m^3$/PMH versus $24.5m^3$/PMH) in the delay-free productivity of the machine running either the Boman motorised carriage or the North Bend system. As there were multiple confounding site factors insufficient data was recorded to conclude any significant differences in production between the systems. Consequently, these data sets should not be directly compared. Environmental conditions differed significantly between sites, key factors were differences in; average cycle distance (140 m versus 340m), average piece size ($1.1m^3$ versus $1.5m^3$) and cycle volume ($3.6m^3$ versus $4.4m^3$). All of which are commonly identified as effecting productivity levels.

Delay-free cycle time modelling was only possible at site one, as such, comparisons cannot be made. It was found that the North Bend configuration used at site two had a higher inhaul velocity at $2.54m/s^{-1}$ than the shotgun system at site one at $1.23m/s^{-1}$. Poor load clearance of site one negatively influenced inhaul times and average inhaul velocities with the Boman motorised dropline carriage are expected to be higher.

To compare system productivity levels without site introduced bias the delay-free productivity models from each site were used to calculate productivity levels with modified significant site factors (Appendix B). The modelled delay-free productivity was $23.0m^3$/PMH for both sites, indicating that over these two settings both systems were equally productive, supporting the observed productive machine rate findings. The models have accuracy limitations as shown by high standard error values for each model, but provide an indication of productivity of the systems under similar conditions.

Tension data was only analysed for site two and it was found that 38% of loads were within 2 tonnes (plus and minus) of the SWL and that the average maximum cycle tension was below the SWL. Similar usage of the tension monitor by the crew was observed at both sites. Specifically to ensure tension in each cycle were close to the SWL. When tensions were not close to the SWL the yarder operator would radio the choker-setters with load instructions. At both sites the crew utilised tension data to maximise production and maintain safety as recommended by previous studies (Evanson, 2009).

Higher productivity is expected during operation at better sites for both rigging and carriage configurations assessed. It is expected that the Active 70 in either configuration would reach the national average at better sites. This machine in either configuration is a suitable direct replacement for traditional cable yarders in New Zealand.

4.1.4. Koller 507 productivity analysis

During the study weather conditions were clear with no wind or rain and temperature was split evenly between 0-10 degrees Celsius and 10 to 20 degrees Celsius. Three men operated the entire system for the production periods of the study. During guy line attachment and tensioning, a forth worker briefly assisted. In the production phase one worker operated the processor, one worked full time as a choker-setter and one divided his time between felling and choker-setting (estimated at 60% to 40% respectively). Category scores and descriptions are in Table 4.1.18. There was little to no obstructions on the ground for workers. Ground roughness was between slightly uneven and uneven. There were intermittent small stumps in the inhaul route from previous harvesting operations, due to suspension of butts at all times these had no notable effect on inhaul rates. The ground slope that the choker-setters worked on was relatively gentle, averaging 24 degrees over the period of the study.

Table 4.1.18: Koller 507 site description scores.

Category	Score	Description
Ground roughness	2.5	Slightly uneven -uneven
Obstacles over 60cm	Isolated	Spacing >16m
Obstacles up to 60cm	Moderate	Spacing 1.6-5.0m
Hindrance class	1	Slightly difficult to navigate

Cycle statistics

Cycle measurements are shown in Table 4.1.19. One corridor was worked over two study days during which a total of 45 cycles were completed and a total of 58m^3 was retrieved. The average cycle time was 9.70 minutes, with a SD of 2.35 minutes. The cause of this variation was likely due to; cycle distance, load size, choker-setter count and other non-assessable factors. The average cycle volume was 1.3m^3, with a SD of 0.4m^3.

Table 4.1.19: Koller 507 cycle statistics.

Measurement	Average
Cycle count	45
Delay-free cycle time (minutes)	9.7
Standard deviation of delay-free cycle (minutes)	2.35
Cycle volume (m^3)	1.3
SD of cycle volume (m^3)	0.4
Total corridor volume (m^3)	57.4

Cycle element statistics

Cycle times by element are shown in Table 4.1.20. Of the total average delay free cycle time of 9.71 minutes, hook was the largest contributor to the overall time at 5.05 minutes, followed by outhaul at 1.75 minutes, inhaul at 2.08 minutes and unhook at 0.83 minutes. The unhook period included moving the carriage from the upper remote point to the landing 20 meters away. This was done to allow an accurate assessment of inhaul velocity. A large amount of variation was observed in both the total cycle time and the cycle elements. Assessed factors that were likely to introduce variance are shown in Table 4.1.24.

Table 4.1.20: Koller 507 cycle element times (decimal minutes).

Component/statistic	Average	SD
Outhaul	1.75	0.73
Hook	5.05	2.16
Inhaul	2.08	0.84
Unhook	0.83	0.78
Total cycle time	9.71	2.35

Outhaul time (1.75 minutes) had a SD of 0.73 minutes; this variation is partially due to the variation in the time required for the choker-setter to remotely guide the carriage from the lower remote point to the final extraction point. The speed this occurred at was observed to vary and no influential factors were observed, introducing random variance.

Hook time (5.05 minutes) had a SD of 2.16 minutes. For some cycles trees were pre-felled, while in other cycles some of the trees for the cycle load were felled while the carriage was in the hook position increasing hook time. It is estimated that the second choker-setter spent 60% of his time on felling tasks and his involvement in helping the main choker-setter attach logs during the hook period varied cycle to cycle. It was not plausible to measure either of these factors and they will have resulted in random variance in the length of the hook period.

Inhaul (2.08 minutes) showed significant variation (0.84 minutes), the speed of passing the intermediate support was identified as the largest source of random variation. Speed varied depending on log length and angle, which had to be in a certain configuration to easily pass the support, these factors were not assessed and the effect was largely random.

Unhook (0.83 minutes) had a high variability (0.78 minutes), the carriage often required careful placement to land the logs in the right place, the speed at which this could be done depended on the size and amount of stems in the cycle and stems already at the landing. This was not recorded as an operational delay as it was not possible to estimate the proportion of the unhook period that was an operational delay.

Machine hours and utilisation rate

Table 4.1.21 shows time consumption and utilisation rates. The overall utilisation rate was 55%, below the average New Zealand utilisation rates for cable yarding systems at 65-70% (Harper, 1992). This was largely due to the study capturing the corridor set up period and with less than 20% of the corridor harvested, delay time was disproportionally high. It is expected that if the study had been longer the utilisation rate would have been similar to the New Zealand average.

Delay type analysis (Table 4.1.22) found the 81% of delay time was operational which was due to due to the corridor set up period. The personal delay time (19%) was due to lunch breaks over the two days.

Table 4.1.21: Koller 507 time consumption and utilisation rate.

Measurement	Sum (decimal hours)
Productive machine hours	7.28
Delay time	5.84
Scheduled machine hours	13.12
Utilisation rate	55%

Table 4.1.22: Koller 507 delay time by category.

Delay type	Operational	Mechanical	Personal	Environmental
Proportion	81%	0%	19%	0%

Productivity rates

The average delay-free productivity rate (Table 4.1.23) was 7.9m^3/PMH with a SD of 3.5m^3/PMH. The utilisation rate was 55% and productivity was 4.4m^3/SMH. As previously mentioned the utilisation rate is disproportionally low and the scheduled productivity rate is of low indicative value of normal operation.

Table 4.1.23: Koller 507 productivity assessment.

Average	Average	SD
m^3/PMH	7.9	3.5
m^3/SMH	4.4	

Site variables

Factors with potential to influence productivity are shown in Table 4.1.24 and indicate that although only one corridor was assessed there were multiple measurable factors that contributed to variance in cycle times and productivity levels.

The average piece size was $0.45m^3$, with a SD of $0.18m^3$. The largest stem pulled in this study had a total volume of $1.00m^3$. The number of pieces per cycle varied, with an average of 3 pieces and a range from 2 to 5 pieces, with a SD of 0.9 pieces.

The cycle distance averaged 164m, with a minimum of 155m and the maximum at 185m. The high minimum value is a result of previously harvested section creating a no cycle zone. The limited range of extraction distances assessed reduced the value of distance as a prediction variable. The average distance of 164 meters and the inhaul time period (Table 4.1.20) of 2.08 minutes gives an average inhaul velocity of $1.31m/s^{-1}$. Lateral yarding distance averaged 8 meters with a maximum of 30 meters.

Due to only one corridor being assessed there was no variability in deflection. Deflection assessed to be 5% which is considered to be in the low range (Harrill & Visser, 2012).

Table 4.1.24: Koller 507 potentially influential factors of productivity.

Corridor/measurement	Average	Max	Minimum	SD
Piece size (m^3)	0.45	1.00	0.14	0.18
Pieces per cycle	3.0	5.0	2.0	0.9
Extraction distance (m)	164	185	155	8
Lateral yarding distance (m)	8	30	0	9
Deflection	5%	5%	5%	0

Koller 507 regression modelling

Delay free cycle time model

No factors were found to be significant predictors of overall cycle time. Factors which introduced variance were identified as the availability of pre-felled stems, the number of choker-setter attaching stems and the speed of the carriage passing over the intermediate support.

Productivity modelling

Using the average of significant factors, Equation 4.1.4 predicted a delay-free production rate of 7.7m^3/PMH; the observed average was 7.8m^3/PMH. The residual standard error of 1.9m^3/PMH indicates this model has poor accuracy. The distribution of residuals was considered sufficiently normal not to need transformation (Appendix K).

Piece count, lateral haul distance and piece size were found to be significant predictors of productivity, generating an R^2 value of 71%. Although distance is often a predictor of productivity, the narrow range of distances assessed at this site negated its value as a productivity predicting factor.

Table 4.1.25: Koller 507 factors and coefficients for productivity modelling (m^3/PMH).

Factors	p value	Coefficients
Intercept	> 0.001	-8.53
Piece count	> 0.001	2.61
Piece size (m^3)	> 0.001	19.70
Lateral haul distance (m)	0.1	-0.05
R squared value	74%	

Equation 4.1.4: Koller 507 delay-free productivity model.

$$\frac{m^3}{PMH} = -8.53 + (2.61 * piece\ count + (19.70 * piece\ size) + (-0.05 * lateral\ haul\ distance)$$

K507 discussion

The overall utilisation rate at 55% was below average New Zealand cable yarding utilisation rate of 65-70% (Harper, 1992); however utilisation was biased low because of the study capturing all of the machine and corridor set up time and only 20% of a corridor harvest. The majority of delays were operational (81%) and were associated with the corridor and yarder setup.

The delay rate of 55% contributed to the low productivity of 4.4m^3/SMH, well below the New Zealand average of 26.3t/SMH. The delay-free rate at 7.9m^3/PMH is also well beneath the New Zealand average and was due to a combination of machine limitations, operational differences and poor site factors.

Machine limitations were mainly the carriage being fitted with 3 chokers, which restricted the ability to efficiently attach more stems (piece count average 3.0) in each load. This combined with a small average piece size (0.45 m^3) resulted in a small average cycle volume of 1.3m^3, with no tension issues being noted, larger cycle volumes could have been retrieved. This indicates potential to increase cycle volume for similar work and time inputs in larger piece sized forests, which would result in in higher production rates. Significant operational differences to the New Zealand harvest methodology were noted, with the most significant difference being a lack of pre-felling, with stems generally being felled while the carriage was in the hook position for that cycle, resulting in extended hook periods. a 155m dead zone in front of the yarder increasing cycle distances and reducing the number of high productivity cycles.

No factors were found to be significant predictors of overall cycle time. Modelled results found a productivity rate of 7.7m^3/PMH which was similar to the observed rate of 7.9m^3/PMH. The residual standard error of 1.9m^3/PMH indicates that the model is of low accuracy. Log count, lateral haul distance and piece size were significant with an R^2 value of 74%. The most significant factor for introducing random variance noted was a lack of pre-felling of stems which resulted in highly variable hook times.

The productivity rates at this site indicate that this machine is not a viable alternative for the New Zealand forest industry. Although production rates will be higher in forests with larger piece sizes and shorter extraction distances, this rate will be too low to efficiently supply the average of 4.9 machines and 8.9 personnel found on New Zealand cable yarding sites in 2014 (Visser, 2015). However the low personnel and machine count and high mobility of the yarder indicated that in small, remote forests with correct machine and personnel pairings such as was used in this study this machine could be a viable option for the New Zealand forestry industry.

4.1.5. Koller 602h productivity analysis

During the study weather conditions were good, with intermittent light wind and very light rain showers over the week; effects of weather on productivity were not considered significant. Temperature was in the 10-20 degrees Celsius category for the majority of the study with periods in the 20-30 degrees Celsius range occurred for 20% of the study. The number and identity of choker-setters varied depending on availability and convenience. On three days one choker-setter worked, on the two other study days two choker-setters worked; although modelling found a relationship between choker-setter count and cycle times and productivity rates, the low model strengths and variations in extraction distances indicated that dividing the results into choker-setter count classes would be of low value. Terrain category scores and descriptions are in Table 4.1.26 and it was found felled trees, stumps and light undergrowth provided moderate ground obstructions for workers. The ground roughness was uneven. The inhaul corridor was largely smooth and free of objects that impacted on inhaul times. The ground slope that the choker-setters worked on varied between 18 degrees and 35 degrees, with an average of 25 degrees.

Table 4.1.26: Koller 602h site description scores.

Category	Score	Description
Ground roughness	3	Uneven
Obstacles over 60cm	Isolated	Spacing 1.6-5.0m
Obstacles up to 60cm	Moderate	Spacing 1.6-5.0m
Hindrance class	2.5	Moderately difficult to navigate

Over the five study days a total of 485m^3 was pulled over 41.9 SMH (23.0 PMH) in one corridor. Variation in haul distance and choker-setters between days indicated that dividing the data set into day sets would provide more insight into productivity and ergonomic trends.

Cycle statistics

Cycle measurements are shown in Table 4.1.27. The number of cycles per day varied with the average of 48 being influenced by a low number of cycles on day one and two, and higher number on days three to five. The low number of cycles on day one and two were due to mechanical delays that were largely caused by inexperience with the system; with the crew having spent less than a month operating it at the time of the study. An average cycle time of 5.72 minutes (SD 2.32 minutes) with the average of 48 cycles per day at 2.0 m^3 (SD 0.8m^3) per cycle resulting in an average daily extracted volume of 100m^3.

Table 4.1.27: Koller 602h cycle statistics.

Day/measurement	1	2	3	4	5	Average
Delay-free cycle time (minutes)	5.18	6.08	6.17	4.86	6.54	5.72
SD of delay-free cycle time (minutes)	2.96	2.02	2.03	1.41	2.93	2.32
Total day volume (m^3)	54	73	104	151	102	97
Cycles per day	23	31	53	72	60	48
Average cycle volume (m^3)	2.4	2.4	2.0	2.1	1.7	2.0
SD of cycle volume (m^3)	0.9	0.6	0.6	0.7	0.	0.8

Cycle element measurements

Cycle element times are shown in Table 4.1.28. Hook was the largest contributor to the overall time at 2.59 minutes, followed by inhaul at 1.44 minutes, unhook at 0.94 minutes and outhaul at 0.75 minutes.

Table 4.1.28: Koller 602h haul cycle element time (decimal minutes).

Time element	1	2	3	4	5	Average	SD
Outhaul	0.62	0.6	0.82	0.82	0.91	0.75	0.72
Hook	2.64	2.69	2.93	1.97	2.69	2.59	1.54
Inhaul	1.15	1.38	1.23	1.37	2.06	1.44	0.99
Unhook	1.27	1.34	1.17	0.7	0.23	0.94	1.02

Multiple factors influence the variability shown in the time elements. Factors that typically influence the time period of cycle elements are displayed in Table 4.1.32. Over the study period multiple factors were identified as introducing random variance in all cycle element areas.

During the hook periods there was frequently a small amount delay time due to repositioning of the carriage and due to poor lines of sight it was difficult to assess and was subsequently often not recorded.

It was also noted that similar to the other study sites the hook period walk in and out speeds varied on terrain, this is not a delay and was highly variable and unrelated to any assessed factors.

During the inhaul period the speed at which the carriage passed through the intermediate support varied significantly. It appeared this factor was chiefly related to the orientation of the logs at the intermediate support, log orientation was not assessed nor did it constitute an operational delay. With no measured cause of this issue it introduced significant random variance.

Some of the variance in the unhook period is likely to be random. This was because the operator was still in the training phase resulting in some loads taking longer to land than others for no notable reason.

Machine hours and utilisation rate

Table 4.1.29 displays machine hours and utilisation rates; the overall utilisation rate was 55%. Common utilisation rates for cable yarding systems are around 65-70% (Harper, 1992), indicating that the 602h was operating below the normal range.

Utilisation varied per day with a general trend showing an increase in utilisation over the week. This was due to some delays being attributed to the new corridor that was being harvested and as the week progressed these events decreased. These new corridor delays included; the servicing of the carriage on day one (done at the start of each new corridor) which due to a blocked grease nipple became a significant mechanical delay and adjusting the tower height on day two to increase log clearance in the chute (operational). Also occurring on day two was the skyline coming off the intermediate support jack and being unable to be rehung that day (mechanical) due to the tree climber not being present. The lower utilisation rate (64%) on day three was largely due to the rehanging of the skyline (mechanical) and adjustment of the intermediate support to match the increase in height of the yarder tower (operational). Day four and five recorded no major delays, resulting in high utilisation rates (72% and 80%).

Table 4.1.29: Koller 602h machine hours and utilisation rates.

Day	1	2	3	4	5	Sum
SMH	8.67	8.50	8.46	8.14	8.14	41.91
PMH	2.08	3.14	5.45	5.84	6.54	23.04
Delay hours	6.59	5.36	3.01	2.30	1.60	18.87
Utilisation rate	0.24	0.37	0.64	0.72	0.80	0.55

The majority of the delay time in this operation was the result of a lack of experience with the system, which contributed to a large portion of the mechanical (34%) and operational delays (50%). The crew was inexperienced with this machine type having only a month of operational usage at the time of the study. It is expected as the crew becomes more experienced the amount of experience related delays will decrease by 10% to 20% putting the utilisation rate in the normal range.

Table 4.1.30: Koller 602h delay time by category.

Delay type	Operation	Mechanical	Personal	Environmental
Proportion	50%	34%	16%	0%

Productivity analysis

Productivity measurements are shown in Table 4.1.31, production averaged 21.0m^3/PMH and 11.6m^3/SMH across the site, below the New Zealand average of 26.2 m^3/SMH for cable logging operations (Visser 2015). The delay free productivity standard deviation was high, at 15.1m^3/PMH, some of this variation is observable across the assessment days with a productivity range from 19.0 m^3/PMH to 26.0m^3/PMH. A decrease in daily m^3/PMH was noted over the course of the week due to the increase in average cycle distances resulting in extended inhaul and outhaul times.

Table 4.1.31: Koller 602h productivity assessment.

Corridor/measure	1	2	3	4	5	Average	SD
m^3/PMH	26.0	23.3	19.0	25.9	15.6	21.0	15.1
m^3/SMH	6.2	8.6	12.3	18.6	12.5	11.6	

Influential factors

Average extraction distance increased each day from 40 meters to 191 meters. The average distance of 117 meters and the inhaul period of 1.44 minutes (Table 4.1.28) gave an average inhaul velocity of 1.35m/s^{-1}. The average piece count per cycle was very consistent at 1.1 to 1.2 pieces per cycle. The number of choker-setters varied depending on the crew available, affecting the length of the hook periods and productivity. Although there was change to the height of the intermediate support during the study there was no change in deflection which at 6% was in the low to average range (Harrill & Visser, 2012). The average piece size varied from 2.2m^3 on day one to 1.6m^3 on day five, due to this the average cycle volume decreased over the study period.

Table 4.1.32: Koller 602h potentially influential factors of productivity.

Day	1	2	3	4	5	Average
Average distance (m)	40	55	91	127	191	117
Average piece size (m^3)	2.2	2.1	1.8	1.9	1.6	1.9
Average piece count	1.1	1.2	1.1	1.1	1.1	1.1
Choker-setter count	1	1	1	2	2	1.5
Deflection	6%	6%	6%	6%	6%	6%

Tension study Koller 602h

Figure 5.2.3 shows tension by 1 tonne groups in the skyline over 35 cycles. The Koller 602h was fitted with a 22mm swaged skyline with a breaking strain of 43 tonnes and a SWL of 14.3 tonnes (Shaw's Wire Ropes, 2016). For this study the peak tension experienced during the inhaul period was recorded. This peak was only experienced for very short periods of time; these were usually recorded at mid span where it is typical for the highest tensions to be recorded.

Over the 30 cycles recorded the average maximum tension per cycle was over the SWL of 14.3 tonnes at 15.7 tonnes indicating that tension was a production limiting factor. The overall recorded maximum of 18.0 tonnes equated to 42% of the breaking strain and of the 35 assessed cycles, 27 were over the SWL with only 7 under the safe working load. Of all cycles 19 of the 35 (55%) were within two tons of the SWL.

The tension monitoring system differs to that of the Active 70 as it allows the skyline to be pre-tensioned to a set level but does not provide tension data after the brake is applied and yarding operations have started.

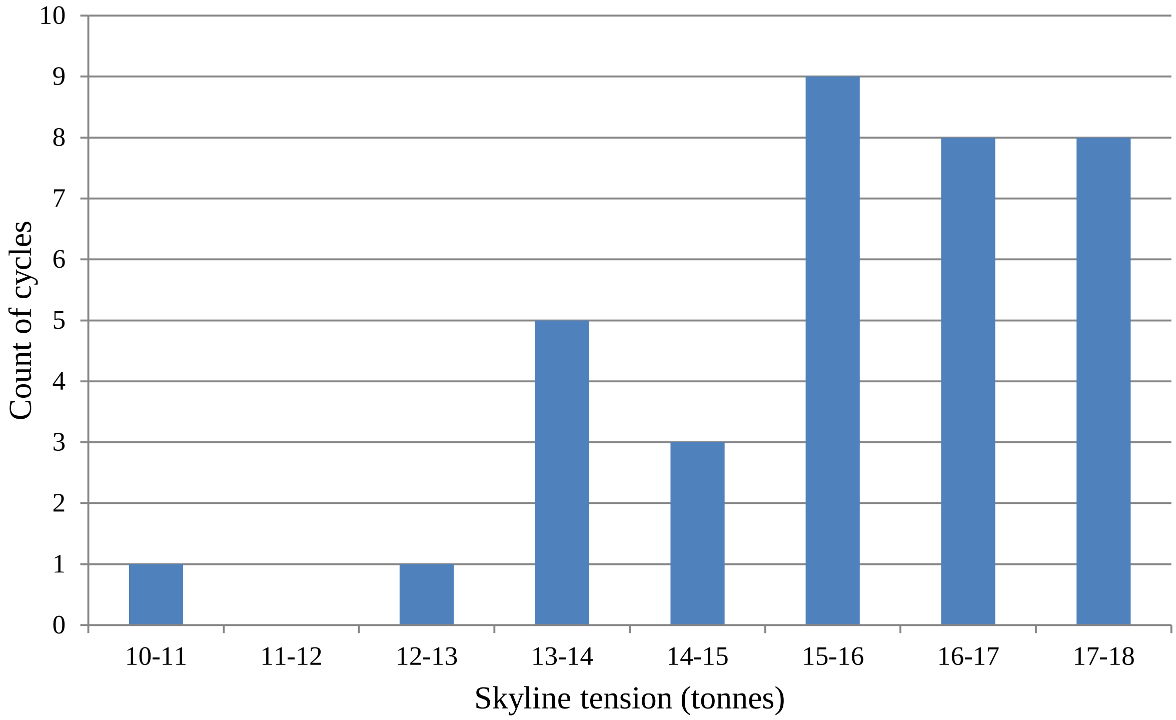

Figure 4.1.2: Koller 602h distribution of maximum skyline tension per cycle.

Koller 602h regression modelling

Delay free cycle time model

Equation 4.1.5 models delay-free cycle time for the 602h at this setting; choker-setter count (as a factor variable) and cycle distance were the significant factors. When the model used average cycle distances specific to the number of choker-setters (67 meters for one choker-setter, 156 meters for two choker-setters), it calculated delay free cycle times at 5.90 minutes with one choker-setter and 5.75 minutes with two choker-setters. These values are similar and follow the same pattern as the observed averages of 5.92 minutes with one choker-setter and 5.62 minutes with two choker-setters.

When the average cycle distances (117m) were used in Equation 4.1.5, a delay-free cycle time rate of 6.89 minutes when operating with one choker-setter and 4.97 minutes when operating with two choker-setters was calculated. This result indicated that in equal conditions having two choker-setters decreased total delay free cycle time due to a reduction in the hook period.

The R^2 value of 12% and residual standard error of 1.94 minutes indicates this model has poor accuracy. The distribution of residuals was considered sufficiently normal not to need transformation (Appendix L).

Table 4.1.33: Koller 602h factors and coefficients for delay-free cycle time modelling.

Factors	p value	Coefficients
Intercept	> 0.001	4.55
Choker-setter count = 2	> 0.001	-1.92
Cycle distance (m)	> 0.001	0.02
R squared value	12%	

Equation 4.1.5: Koller 602h delay-free cycle time model

$$Delay\ free\ cycle\ time\ (minutes)$$
$$= 4.55 + (-1.92 * choker\ setter\ count) + (0.02 * cycle\ distance)$$

Productivity modelling

Equation 4.1.6 models delay free productivity for the 602h at the study site; cycle volume, choker-setter count (factor variable) and cycle distance were found to be significant predictors. When the model used averages specific to the number of choker-setters (67 meter cycle distance and cycle volume of 2.15m^3 with one choker-setter, and 156 meter and cycle volume of 1.92m^3 with two choker-setters) a delay-free production rate of 20.3m^3/PMH was predicted when operating with one choker-setter and 20.5m^3/PMH when operating with two choker-setters. The lack of increase in production with two choker-setters is due to longer extraction distances and a slight decrease in piece size occurring when two choker-setters were working.

The observed average differed from the modelled results, with observed productivity rates of 21.6m^3/PMH with one choker-setter and 20.5m^3/PMH when operating with two choker-setters. However these values did not compensate for differences in predicting factors. When average cycle distances (117 meter) and cycle volumes (2.0m^3) were used in Equation 4.1.6, it predicted a delay-free production rate of 16.2m^3/PMH when operating with one choker-setter and 23.4m^3/PMH when operating with two choker-setters. This result indicated that in equal conditions having two choker-setters increased productivity.

The R^2 value of 29% and the residual standard error of 12.7m^3/PMH indicated this model has poor accuracy. The distribution of residuals was considered sufficiently normal not to need transformation (Appendix M).

Table 4.1.34: Koller 602h factors and coefficients for productivity modelling (m^3/PMH).

Factors	p value	Coefficients
Intercept	0.367	-3.62
Cycle volume (m^3)	> 0.001	11.01
Choker-setter count = 2	0.004	7.22
Cycle distance (m)	0.046	-0.05
R squared value	29%	

Equation 4.1.6: Koller 602h delay-free productivity model

$$\frac{m^3}{PMH} = -3.62 + (11.01 * Cycle\ volume) +$$

$$(7.22 * Choker\ setter\ count) + (-0.05 * Cycle\ distance)$$

602h Discussion

The average utilisation rate of 55% was below the standard level of 65-70% (Harper, 1992) for New Zealand cable yarding operations. Delays were mainly operational and mechanical, with the majority being caused by crew inexperience, with it being evident that the crew were still learning about the equipment. Utilisation rates in the future will increase as the crew becomes more skilled and familiar with the equipment.

The utilisation rate contributed to the average productivity level was 11.6m^3/SMH, which is below the New Zealand standard level of 26.2 m^3/SMH (Visser 2015). The delay-free productivity rate at 21.0 m^3/PMH shows that reducing delay time will not increase productivity to the New Zealand average. The site had a large piece size, moderate extraction distance and good terrain conditions, indicating site conditions were not a factor in the low productivity rate. Production rates are expected to increase slightly as the crew becomes more experienced; however it is very unlikely that this machine can produce at the national average rate. This was supported by the tension monitoring study finding that the system was operating over the safe working load for 78% of cycles, indicating that larger loads were not a viable option. However deflection was low to average at 6% (Harrill & Visser, 2012) and sites with better deflection are likely to allow larger payloads which is highly likely to increase production.

Multiple studies identified that European machines are typically used in smaller piece sized forests (Hochrein & Kellogg, 1988; Visser et al., 2011) and that the 602h and MSK 3 carriage are rated as 5 tonne and 3 tonne machines respectively (Koller Forsttechnik, 2010). These limitations had potential to reduce productivity. The effect of this limitation was noted with breaking out of large and obstructed loads occasionally causing the inhaul to stall and require carriage repositioning. To mitigate this issue larger stems were bucked on the hill side before being broken out and retrieved. With this method large piece sizes were not a production issue and a positive relationship between cycle volume and productivity exists in the productivity model. Although it is likely to exist, there was insufficient evidence to show when piece size would become a limiting productivity factor, however it is above the estimate of 1.6 tonnes provided by Evanson and Spencer (2015). In this setting high skyline tensions were a larger limiting factor than the overloading of the carriage and inhaul capabilities of the 602h.

There was no evidence for or against the motorised carriage having advantageously fast operating speeds, however it was noted that full butt suspension was achieved for all cycles resulting in minimal ground and load interference. The fully remote control yarder system allowed the operator to dually operate the processor and yarder and the operator was able to process and clear the chute at the needed rate. Although short inhaul delays did occasionally occur, these are expected to be reduced as the operator becomes more experienced.

Choker-setter count and haul distance were the significant predictors of the delay-free cycle time; a R^2 value of 12% and a high residual standard error of 1.94 minutes indicated low model accuracy. Log count, choker-setter count and piece size were significant factors in predicting productivity. The productivity model had a delay-free productivity rate of 17.3m^3/PMH and 24.5m^3/PMH for one and two choker-setters respectively; the residual standard error of 12.70m^3/PMH and R^2 value of 29% again indicated that the model has low accuracy.

An increase in productivity particularly through increased utilisation rates is expected as the crew becomes more experienced, although production levels are unlikely to reach the national average. Although the large piece size experienced at this site was not found to be a limiting productivity factor, limitations in productivity was due to the maximum cycle volume being smaller than that for typical New Zealand yarders.

As such the 602h is not recommended as a direct replacement for cable yarding operations in New Zealand as it is unable to supply wood at the rate needed for the supporting machines (averaging 4.9) and personnel (averaging 8.9) that were associated with New Zealand cable yarding systems in 2014 (Visser, 2015). However in lower cost systems with fewer supporting machines and personnel that require lower supply rates, this machine has potential to be highly efficient and competitive. This potential is due to the full remote control system reducing personnel requirements and small yarder size and weight reducing the transport component of harvest costs. This is particularly valuable for smaller forest areas were harvest cost is highly influenced by fixed costs. These findings are very similar to previous findings on the 602h in the New Zealand setting (Evanson & Hill, 2015) which made similar recommendations regarding conditions needed for successful application.

4.1.6. Koller combined sites productivity discussion

Both studies captured the utilisation rate at 55%, below the historical normal of 65-70% (Harper, 1992). The low 507 rate was due to the limited study period occurring over the corridor rigging period, while the 602h rate was largely due to extended delays as a result of crew inexperience. As such both are of low indicative value of normal utilisation rates for these machines and it is likely that future utilisation rates will be in the normal range. There were large differences in productivity (7.9m^3/PMH versus 21.0m^3/PMH) between the systems studied. The sites and operational methods were very different and are likely to be key factors. This was expected with there being significant differences in the Austrian and New Zealand forestry systems.

The piece size in the 507 study was considerably smaller (0.45m^3) than that found in the 602h study (1.9m^3), this is thought to be typical of European versus New Zealand forests. Even with a higher piece count at the 507 site (3.0 versus 1.1), the 507 had a smaller cycle volume at 1.3m^3 versus 2.0m^3 for the 602h. More pieces indicate longer hook periods reducing productivity. Carriage inhaul velocities were very similar between sites (1.31m/$^{s-1}$ versus 1.35m/$^{s-1}$) indicating that differences in cycle distance had a similar effect on cycle times. There were marked differences in operating styles at each site, with no pre-felling or pre-stropping occurring for the 507 resulting in longer average hook times versus the 602h at 5.05 and 2.69 minutes respectively.

To reduce site effects, site conditions from the 602h study were applied to the 507 delay free production model (Appendix C). With the larger piece size, lower piece count and shorter haul distances from the 602h site, delay-free productivity for the Koller 507 was calculated at 31.4m^3/PMH. This was higher than the observed average found for the 602h (21.0m^3/PMH). However the limited range of piece sizes at the 507 site (maximum piece size 1.0m^3) and the average piece size used from the 602hsite (1.9m^3) indicates that this value was an extrapolation of the data and productivity values would not be this high. This result does however indicate that in similar sites, even with operational differences, the 507 was capable of similar production rates to the 602h. Highlighting the the similarity of the 507 and 602h yarder systems.

Higher productivity rates are expected for both machines when operating with experienced crews in New Zealand settings and it was thought that they would have similar productivity levels. However due to the lower productivity rates it is unlikely that either machine would be suitable as a direct replacement for typical New Zealand cable yarders. This was highlighted with the 507 having one supporting machine and the 602hhaving two supporting machines, well below the New Zealand average of 4.9 supporting machines (Visser, 2015). This indicated that these yarders could not extract enough wood to efficiently supply an average New Zealand cable yarding skid.

Consideration and further research into applications for these yarders in non-typical New Zealand forest operations is advised, with literature highlighting safety, operational and efficiency benefits of these machines particularly in smaller piece size and area forests, a number of which are unlikely to be economically viable to harvest (Park et al., 2012). Research into the system and harvest costing of these machines is particularly advised, with this study only considering productivity measurements and therefore being unable to make recommendations on machine efficiencies.

4.2. Choker-setter work rate statistics

4.2.1. Effect of site on choker-setter work rate

Both Active 70 studies recorded very similar hindrance, terrain roughness, slopes and weather conditions, an example of terrain the Active 70 was assessed in is shown in Figure 4.2.1. Consequently environmental factors are believed to have caused minimal work rate differences between sites. The Koller 602h site had lower hindrance, terrain roughness scores, slopes and the weather conditions were significantly warmer than the Active 70 sites. The lower terrain and hindrance scores could potentially reduce the work rate, while the temperature increase is likely to cause a slight increase in work rates. Site effects on work rate are likely to be minimal and were ignored.

4.2.2. Active 70 site one choker-setter work rate statistics

Two choker-setters worked for the full extent of the study. Both were assessed over the full five days of the study (Table 4.2.1). A previous study (Sripraram & Tasaka, 1999) indicated that the ability of the Boman motorised drop-line carriage to feed out line would likely reduce work loads of choker-setters compared with traditional systems.

Table 4.2.1: Active 70 site one average work rate statistics.

Day	1	2	3	4	5	Average
Relative heart rate at work (%)	35.8	33.2	31.4	28.5	28.4	31.5
50% of heart rate reserve	1.05	1.00	0.97	0.92	0.92	0.97
Ratio of working to resting	1.7	1.6	1.5	1.5	1.5	1.6

This study had a ‘relative heart rate’ score of 31.5 %, within the 30-40% range that indicates prolonged continuous work. This site had a ‘50% of heart rate reserve’ score of 0.97, this was just below the hard continuous work category indicated by scores above 1.0. The ‘ratio of working to resting’ score had an average of 1.6, scores above 1.3 are considered to be very labour intensive roles. Overall the choker-setters working with the Active 70 at study site one, worked hard and for prolonged periods and the system required a high rate of human input.

4.2.3. Active 70 site two choker-setter work rate statistics

Two choker-setters worked over the three day period of the study. Due to equipment malfunction only the head choker-setter was assessed, results are presented in Table 4.2.2. The North Bend configuration used in this study was expected to require a higher work rate compared with the more modern motorised carriage systems used at the other two study sites due to the choker-setters having to manually pull out the chokers to reach stems.

Table 4.2.2: Active 70 site two heart and work rate statistics.

Day/measure	1	2	3	Average
Relative heart rate at work (%)	31.9	28.6	28.2	29.6
50% of heart rate reserve	0.81	0.92	0.91	0.88
Ratio of working to resting	1.7	1.5	1.6	1.6

Over the study period the head choker-setter had a 'relative heart rate' score of 29.6%, just below the 30-40% range that indicates prolonged continuous work. His '50% of heart rate reserve' score of 0.88 was below the hard continuous work category of above 1.0. The 'ratio of working to resting' score had an average of 1.6, scores above 1.3 are considered to be very labour intensive roles, indicating that choker-setting at the study site required a high level human work input. Over the study period the head choker-setter worked hard for intermittent to prolonged periods and a high level of human work input was required over the study period

Figure 4.2.1: Example of steep and brushy terrain at Active 70 site one.

4.2.4. Koller 602h choker-setter work rate statistics

The head choker-setter for each day wore the heart rate monitor, the head choker-setter varied over the study period and the number of choker-setters also varied between one and two. Data collected over the five study days is presented in Table 4.2.3.

There was insufficient evidence to indicate any differences in work rates between the choker-setters assessed. Higher work rates were expected when the choker-setters were working solo, however the two days where two choker-setters were present were split above and below the overall single choker-setter average. As a result of this, work rate was assumed not to be effected by choker-setter count.

Table 4.2.3: Koller 602h heart and work rate statistics.

Day	1	2	3	4	5	Average
No. choker-setters	1	1	1	2	2	1.4
Identity	A	B	A	A	B	-
Relative heart rate at work (%)	33.8	35.8	46.1	36.0	46.0	39.6
50% of heart rate reserve	0.90	0.92	1.16	1.04	1.04	1.00
Ratio of working to resting	1.4	1.8	1.5	1.6	1.5	1.6

Choker-setting for the 602h fitted with the MSK 3 slack pulling carriage had a ‘relative heart rate’ score of 36.9%, inside the 30-40% range that indicates prolonged continuous work. The choker-setter had a ‘50% of heart rate reserve’ score of 1.0, this is just in the hard continuous work category indicated by scores above 1.0. The ‘ratio of working to resting’ score had an average of 1.6 above the benchmark of 1.3 that is considered to be very labour intensive roles, indicating that choker-setting at the study site required a high level human work input. The choker-setters worked hard and for prolonged periods over the time period of the study (Kirk & Sullman, 2001).

4.2.5. Comparative work rate discussion

Studies indicated that motorised slack pulling carriages compared with traditional systems (Sripraram & Tasaka, 1999) would have lower human work requirements and the work rate of the choker-setters would be lower as a result. It was also thought that the remote control of the Koller 602h yarder and carriage might reduce work rates due to more accurate placement of the carriage reducing choker pull distances. Based on these theories work rate levels should have been lower at the Active study site one and the Koller 602h site compared with the second Active 70 site that was set up in the North Bend configuration, and a previous New Zealand based choker-setter work rate study that also did not use a motorised carriage.

Contrary to previous research the ‘ratio of working to resting’ rate showed no significant differences and averaged 1.6 at all sites; indicating that high levels of human input was required for all systems assessed. The ‘50% of heart rate reserve’ found the Active 70 at site one and the Koller 602hsite to be very similar at 0.97 and 1.00. It was lower at Active 70 site two, indicating lower average work levels. This is thought to be due to the shorter inhaul periods of 1.04 minutes at the first Active 70 site versus 2.30 minutes at the second Active 70 site reducing the rest periods between choker-setting activities, effectively increasing the continuity of work. The ‘relative heart rate at work scores’ found that the Active 70 sites scored similarly at 31.5% and 29.6%, while the Koller site scored higher than both at 39.6%. This was unexpected as motorised carriages were expected to reduce workloads. At the Koller site, stems were pre-choked during inhaul periods, which was not performed at the other sites resulting in less rest time between cycles at the 602h site. This factor increased the prolonged nature of the work, resulting in longer periods spent with higher heart rates.

A previous work rate study (Kirk & Sullman, 2001) operating a typical yarder without a motorised carriage had ‘relative heart rate’ scores at 36.4% equal to the Koller at 36.9% and higher than the two Active 70 sites at 31.5% and 29.6%. The average ‘50% of heart rate’ finding at 0.85 was lower than the Koller at 1.0 and Active 70 site one at 0.97, and similar to the Active 70 site two at 0.88. The ‘ratio of working to resting’ score found in the study was higher at 1.84 than all the results gained (1.6) in this study. The variability in the comparison of results indicates that there was no clear advantage of the modern systems versus the older system utilized in the comparison study.

The results of this study indicate that there was no human work rate advantage gained through using motorised carriages or remote control systems versus the more traditional methods. However this does not indicate that the modern motorised carriage systems are not advantageous. This is because although workloads are similar between sites, there were likely productivity advantages of the slack pulling carriage systems, with the choker-setters being able to work faster due to less effort being needed to pull line. Although insufficient evidence exists to identify if there were any differences in productivity levels due to choker-setter work rates this theory is consistent with previous studies (Sullman & Byers, 2000).

4.3.Decibel monitoring

4.3.1. Active 70 decibel emission analysis

The sound emissions of the Active 70 during normal working operations at varying distances are shown in Table 4.3.1. It was found that if personnel are within a 5 meter distance for extended time periods without hearing protection, there were sufficient decibels to cause hearing damage to 95% of workers and that within a 10 meter range over extended time periods there is also a moderate chance of hearing damage (Accident Compensation Corporation, 2013). Based on these findings anyone working within 10 meters of the yarder should wear hearing protection. The sound proofed cab reduced the noise volume to the level where a standard conversation could be had, indicating a safe and comfortable environment for the yarder operator (Occupational Safety and Health Service, 2002).

Table 4.3.1: Active 70 estimated decibel ratings.

Distance from yarder (m)	Volume (dB, A)	Risk of hearing damage
1	100	Significant
5	86	Significant
10	80	Moderate
20	74	Minimal
50	66	Minimal
100	60	Minimal

4.3.2. Koller 602h decibel emission analysis

The decibels of the yarder at varying distances are shown in Table 4.3.2. It was found that if personnel were within a 2.5 meter range of the machine over extended time periods there was a substantial risk of hearing damage for 95% of unprotected workers (Accident Compensation Corporation, 2013). Based on these findings anyone working within 2.5 meters of the yarder should wear hearing protection.

Table 4.3.2: Koller 602h estimated decibel ratings.

Distance from yarder (m)	Volume (dB, A)	Risk of hearing damage
1	85	significant
2.5	77	Moderate - minimal
5	70	Minimal
10	65	Minimal
20	50	Minimal
50	50	Minimal
100	45	Minimal

4.3.3. Thunderbird TSY 255 yarder decibel emission analysis

The Thunderbird TSY 255 was assessed as it is a typical example of a New Zealand cable yarder and provided a reference point from which to assess the Active 70 and Koller 602h as no other data on noise emissions of yarders could be found. The Thunderbird had an engine rebuild one month prior to the assessment and was operating well.

The decibels of the yarder at varying distances are shown in Table 4.3.3. It was found that if personnel were within 50 meters of the machine for extended time periods without hearing protection, there was sufficient decibels to cause hearing damage to 95% of unprotected workers (Accident Compensation Corporation, 2013). Based on these findings anyone working within 50 meters of the yarder should wear hearing protection.

Table 4.3.3: Thunderbird TSY 255 estimated decibel ratings.

Distance from yarder (m)	Volume (dB, A)	Risk of hearing damage
1	112	Significant
5	98	Significant
10	92	Significant
20	86	Significant
50	79	Moderate
100	73	Minimal

4.3.4. Decibel analysis discussion

Both the modern machines studied produce significantly less noise than the typical New Zealand yarder assessed (Thunderbird TSY 255). The Koller was the quietest machine assessed with a 10 meter decibel reading of 65 decibels versus 80 decibels for the Active and 92 decibels for the Thunderbird. The distance in which newer machines produce decibel levels high enough to cause hearing damage are considerably smaller than the older machines. As continued exposure to high levels of noise can result in fatigue (Inoue, 1996), the decrease in noise emissions are also likely to decrease fatigue of workers operating in the nearby vicinity for extended periods of time, potentially reducing accident rates (Lilley et al., 2002). This study does not indicate that hearing protection should not be worn on logging sites operating modern machinery as back ground noise (such as log processors and chainsaws) are likely to generate enough noise to cause hearing damage.

5. Conclusions

The increasing cost of cable yarding and the health and safety risks of current operations will in time necessitate a shift toward newer technology. In this study three modern cable yarders that may offer cost and safety benefits were studied to provide insight into their suitability for steep terrain extraction within New Zealand logging paradigms. This study examined the Active 70, Koller 507 and Koller 602h across four sites in New Zealand and Austria. These machines are all fitted with a range of advanced features designed to make them safer and more efficient than the typical yarder currently used in New Zealand operations. The work adds to a growing body of international literature on efficiency and worker safety of cable yarding (Harrill & Visser, 2014a).

The ability of machines to compete can largely be divided into two categories; cost per unit produced and ergonomic performance. Cost per unit involves a large range of variables with the cost of production being heavily reliant on the supporting system. As such this study only focused on productivity. Time and motion studies were undertaken to assess the productive and scheduled machine hours, elemental cycle time and load volume. To assess any ergonomic benefits it was decided to focus primarily on the work-rates of choker-setters through measurement of heart-rate. Choker-setting is a highly hazardous occupation, which is partially due to high work rates resulting in high levels of fatigue. Variation in decibel emissions was also assessed as typical machines produce large zones in which decibels are considered excessive and can cause hearing damage and fatigue.

The Active 70 at 58 tonnes and 384 kW is similar to existing New Zealand machinery in weight and power. Differentiating features included; an ergonomic cab, GPS choker-setter tracking, automatic cycle data storage and tension monitoring. These features separate it from traditional machines and are highly likely to offer safety and long term productivity advantages. The Koller 602h and 507 are similar machines and smaller than existing New Zealand machinery in weight and power. They possess a range of features uncommon to New Zealand, including: fully remote controlled yarder operation, tension monitoring and ease of transport, that separate them from the more traditional machines and are likely to offer safety and productivity advantages.

At the two Active 70 study sites the productivity achieved was 15.3m^3/SMH and 18.6m^3/SMH, and for the New Zealand based Koller 602h, 11.6m^3/SMH. These values are below the average New Zealand productivity rate of 26.2m^3/SMH (Visser 2015). This comparative value includes both pole and swing yarders and a number of very high production systems and as such caution should be used for any direct comparison. The Active 70 is expected to have a higher productivity rate at more average sites and is likely to be a viable direct replacement for current yarders in New Zealand. The Koller 602h is unlikely to increase productivity far past the delay free rate of 21.0m^3/PMH and is unlikely to be a viable direct replacement for New Zealand yarders, however it has a number of advantages which may make it a highly efficient system if applied correctly.

There was no work rate advantage for the choker-setters when using either the Boman Z7850 motorised drop line carriage or the MSK 3 motorised slack pulling carriage compared with the North Bend system used at the second Active 70 site and past work rate literature that also used traditional systems (Kirk & Sullman, 2001). Work rate results indicated due to pre-stropping of loads, work was more continuous on the Koller 602h site than the Active sites.

The decibel monitoring found the Active 70 to be quieter than the benchmarking machine (Thunderbird TSY 255), while the Koller 602h was found to be quieter than the Active 70. Consequently modern machines were found to have a considerably smaller dangerous noise exposure area and may offer reduced fatigue advantages.

Productivity and choker-setter work rates are only a component of system efficiency and as such conclusions on the overall efficiency of these systems could not be made. It is recommended that a future study focusing on system costing is done on all machines. This would enable the viability of applying these machines in the New Zealand setting to be fully assessed.

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Appendix

Appendix A: Intermediate support rigging time assessment

The Koller 507 study provided the opportunity to examine the time required to rig spar trees for cable yarding. The use of spar trees as intermediate or tail supports is limited in New Zealand. Even though this technique has the potential to improve deflection and the navigation of difficult terrain, the belief that rigging time is excessive for the benefits results in this technique being very uncommon. As such this data provides insight to time requirements for rigging trees.

Timing of rigging support trees

This was measured by recording the time from start of preparing both the mid span and tail tree spars to when the next task was started.

Due to limited data this section only provides a snap shot of the time taken to set up the system. It shows that the average time to rig a spar tree was 1.18 hours, which allowed access to the harvet zone with no new earthworks. The total time to set and get the machine operational was 4.72 hours after being driven at a similar speed to a log truck to the site.

Table A.1: Time analysis of Koller 507 set up

Activity	Time (decimal hours)
Releasing and tightening guy lines	0.22
Rigging intermediate support	1.2
Rigging tail tree	1.17
Other tasks	2.13
Total time to set up machine	4.72

Appendix B: Active 70 applied productivity modelling modified factors

The Active 70 had very similar productivity rates for the two systems trialled, but factors that commonly influence productivity differed significantly between sites. To reduce the effect of site differences on system productivity, the productivity models presented were applied with modified input data. Input data for factors that were significant was modified so that the sites had the same significant factors.

To compare the sites, significant model factors had to be equal. For site one log count, piece size and distance was significant, while for site two only cycle volume was significant.

The average cycle distance of site two was used as the input for the site one model, negating distance differences. Piece size and log count were averaged across both sites and used for the other site one model inputs. Cycle volume for the site two model was the piece size and log count average multiple together.

This means that the assessment distance, piece size, log count and cycle volume are the same across the two sites trialled. Table B.1 displays the inputs and modelled delay-free productivity values at sites with identical significant factors.

Table B.1: Active 70 site equalised productivity model data

Factor	Site one	Site two	Model inputs
Piece size (m^3)	1.1	1.5	1.3
Piece count	3.3	3.0	3.2
Volume (m^3)	3.6	4.5	4.1
Distance (m)	not relevant	351	351

Equation B.1: Active 70 site one delay-free productivity equation with average inputs

$$\frac{m^3}{PMH} = 0.55 + (5.52 * 4.1\ (cycle\ volume)$$

$$= 23.04$$

Equation B.2: Active 70 site two delay-free productivity equation with average inputs

$$m3/PMH = -25.36 + (9.06 * 3.2\ (piece\ count)) +$$

$$(20.58 * 1.3\ (piece\ size)) + (-0.02 * 351\ (haul\ distance))$$

$$= 23.02$$

Appendix C: Koller 507 applied productivity modelling with 602h site factors.

This method created sites that were as similar as possible to allow the machines to be directly compared. For the 507, log count, piece size and lateral haul distance was significant, Input data was taken from the 602h site. As no lateral haul distance figure was measured for the 602h site it remained at 7.7 meters.

Table C.1: 507 site equalisation productivity model inputs

Factor	602
Piece count	1.1
Piece size(m^3)	1.9
Lateral haul distance (m)	7.7m (not assessed)

Equation C.1: 507 average productivity model

$$m^3/PMH = -8.56 + (2.61 * 1.1 \text{ (piece count)} + (19.7*1.9 \text{ (piece size)})$$

$$+ (-0.05* 7.7 \text{ (lateral haul distance)})$$

$$= 31.4$$

Appendix D: Koller 300h specifications.

K 300 H / K 303 H Trailer

Trailer mounted yarder - for uphill and downhill logging

The K300H is a yarder for uphill logging with an optional haulbackline drum (K303H).
Also for downhill logging and for flat terrain. It assures easy handling, reliable and rugged design, as well as very short rig up and dismantling times.

- lightweight and compact yarder mounted on a single axle trailer
- for thinning, selective cuts and small wood harvesting operations
- cost-effective and lightweight 3-drum yarder

TECHNICAL DATA:

Line pull:

Skyline	9700 lbs / 44 kN (tension section)
Mainline	3970 lbs / 18 kN (average drum)
Haulbackline	3970 lbs / 18 kN (average drum)

Line capacity:

Skyline	1650' Ø 9/16" / 500 m Ø 14 mm swaged (1300' Ø 5/8" / 450 m Ø 15 mm)
Mainline	2250' Ø 5/16" / 550 m Ø 8,5 mm swaged (1450' Ø 3/8" / 450 m Ø 9,5 mm)
Haulbackline (only K303H)	2900' Ø 3/8" / 980 m Ø 9 mm (2050' Ø 7/16" / 800 m Ø 10 mm)
Guyline	3 or 4x100' Ø 5/8" / 3 or 4x30 m Ø 16 mm 2x30' / 2x10 m extensions

Line speed:

Mainline	
Unloaded drive	user defined (by brake) or up to 1115 ft/min / 340 m/min hydrostatic
Loaded drive	up to 1115 ft/min / 340m/min
Haulbackline	
Unloaded drive	up to 1500 ft/min / 460m/min
Loaded drive	up to 750 ft/min / 230m/min

Tower:

Standard	24' / 7,2 m
With tower extension	28' / 8,4 m
Operating range	on the left side of the yarder

Power station:

- Deutz 4-cylinder diesel engine with 101 HP (75 kW)
- Continuous hydrostatic transmission for all winches
- Hydraulically operated single disk dry clutches on the skyline / mainline drum and oil motor on the haulbackline drum

Brakes:
Skyline: manually actuated band brake
Mainline: hydraulically actuated band brake
Haulbackline: hydraulically actuated shoe brake

Operation:
hydromechanical / electro-hydraulic single lever operation with dead-man's control for up and downhill logging with hydraulic interlock

Carriage:
SKA 1 / SKA 1-Z / USKA 1,5

Total weight including cables:

K300	8,400 lbs / 3.800 kg
K303	10,600 lbs / 4.800 kg

K303H with tower extension

K300H with standard tower

K303H with standard tower

4

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Appendix E: Koller 602h specifications.

K 602 H Trailer

Trailer mounted yarder - for uphill and downhill logging – THE INNOVATION!!!

The K602H is a powerful yarder for uphill, downhill or flat terrain logging with an optional haulbackline. It is principally used for selective cuts and for general wood harvesting operations. A tandem axle trailer with pressure air-brakes is used as a carrier. The trailer supports are hydraulic.

- new development with proven components and maximum power – long reach and high line pull power
- optional with hydrostatic axle drive – electrically controlled by the engine of the trailer
- optional with collapsible tower (no overlap of the tower above the centre pole)

TECHNICAL DATA:

Line pull:	
Skyline	20940 lbs / 95 kN (tension section)
Mainline	11020 lbs / 50 kN (average drum)
Haulbackline	9480 lbs / 43 kN (average drum)
Line capacity:	
Skyline	3100' Ø 3/4" swaged / 720m Ø22mm 860 m Ø 20 mm swaged
Mainline	2100' Ø 1/2" / 730 m Ø 12 mm swaged
Haulbackline	3950' Ø 1/2" / 1350 m Ø 12 mm swaged (5150' Ø 7/16" / 1600m Ø 11mm swaged)
Straw line	5200' Ø 1/4" / 1700 m Ø 6 mm
Guyline	4x160' Ø 3/4" / 4x50 m Ø 20 mm 2x50' / 2x15 m extensions
Line speed:	
Mainline	up to 1640 ft/min / 500 m/min
Haulbackline	
Unloaded drive	up to 1655 ft/min / 504 m/min
Loaded drive	up to 1260 ft/min / 384 m/min
Tower:	
Standard	34' / 10,5 m (optional collapsible)
With tower extension	38' / 11,5 m (optional collapsible)
Operating range	360°

Power station:
- Deutz 6-cylinder diesel engine with 197 HP (147 kW)
- Continuous hydrostatic transmission for all winches
- Pneumatically operated radial clutches on the skyline / mainline drum

Brakes:
Skyline: 2 hydraulically actuated spring-applied disk brakes
Mainline: pneumatically actuated spring-applied band brake
Haulbackline: hydraulically actuated spring-applied multi-disk brake
Straw line: hydraulically actuated spring-applied multi-disk brake

Operation:
KOLLER MULTIMATIK
Radio control for auxiliary functions

Carriage:
SKA 2,5-Z / USKA 2,5 / MSK 3

Total weight including lines:
Trailer for uphill logging: 28,700 lbs / 13.000 kg
Trailer for up and downhill logging: 32,600 lbs /14.000 kg
add. Weight – tool boxes (optional): 660 lbs / 300 kg
add. Weight – powered axle (optional): 2,000lbs / 900kg
add. Weight – foldable tower (optional): 660 lbs / 300 kg

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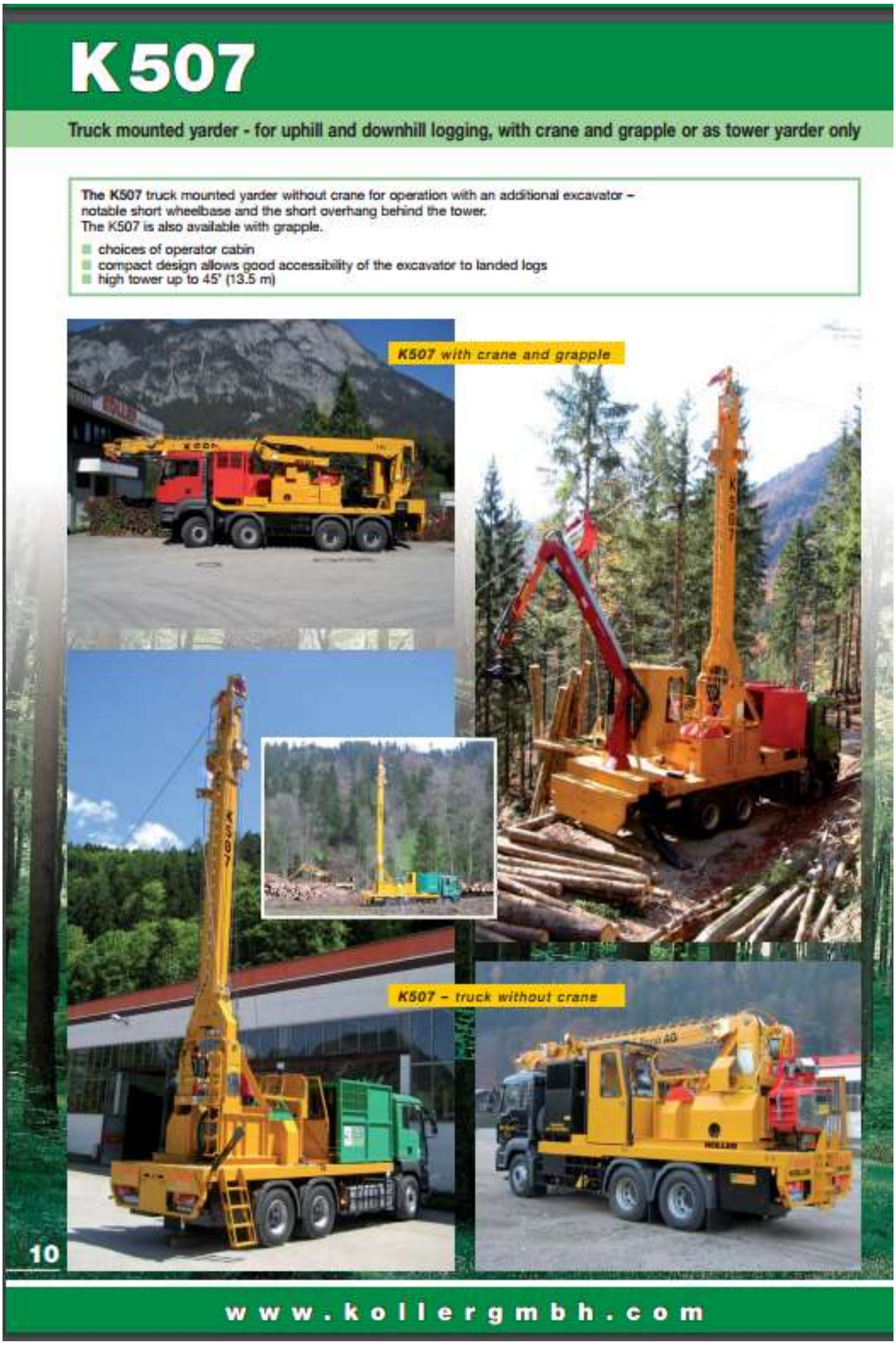
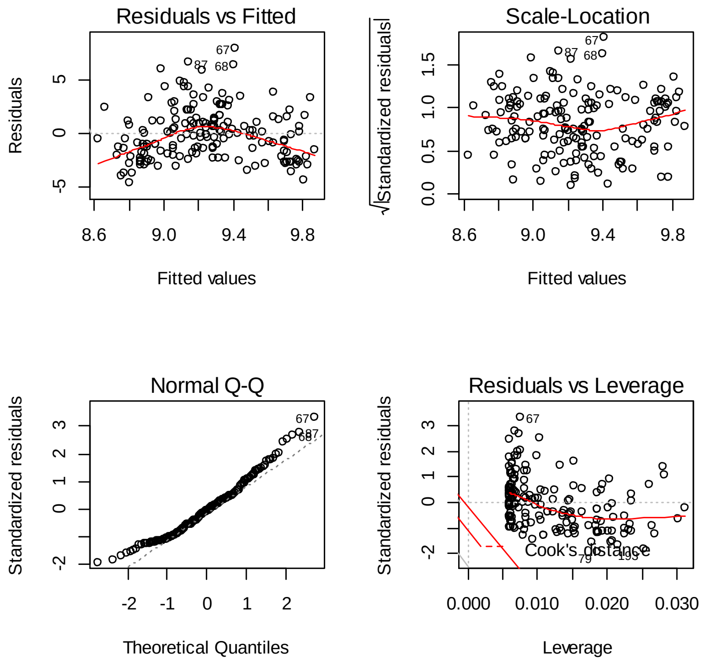
Appendix F: Koller 507h specifications.

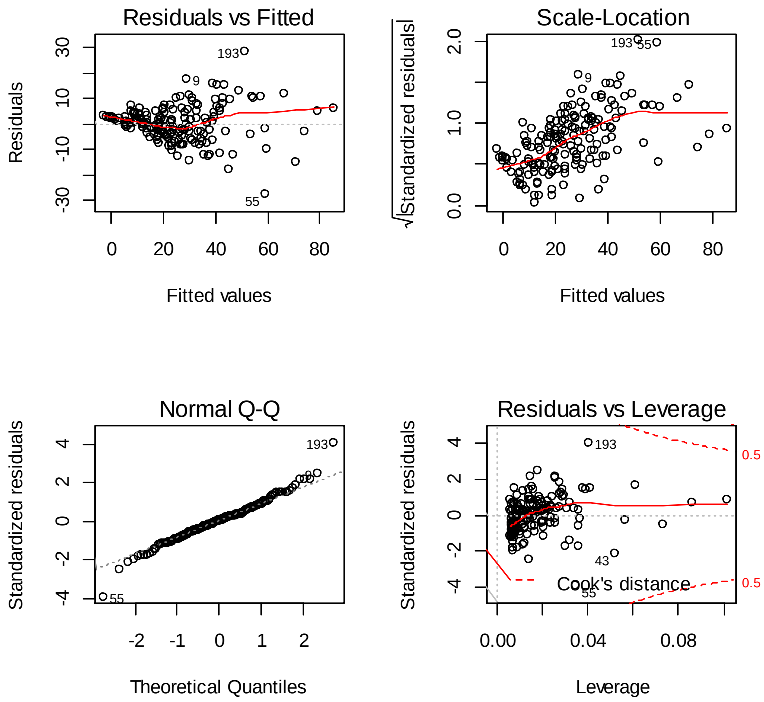


Appendix G: Koller MSK 3 carriage specifications.

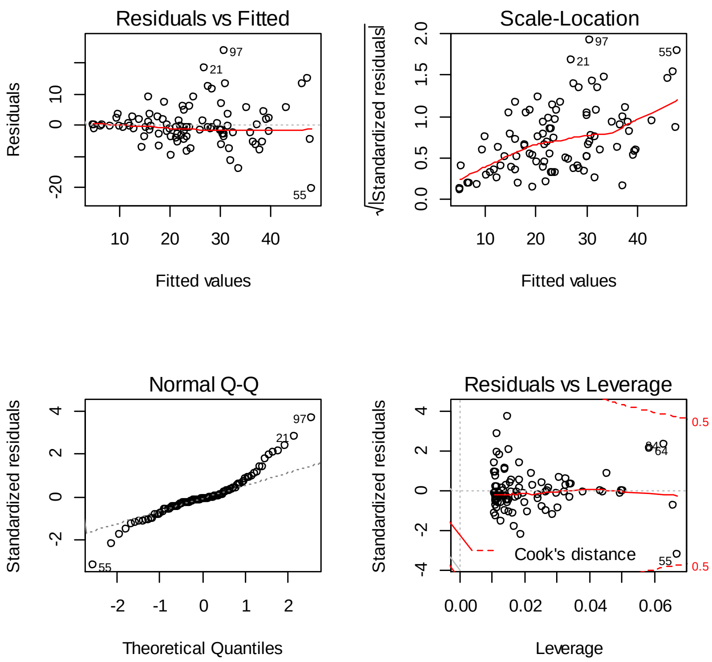
Appendix H: Active 70 at site one delay-free cycle time model residuals.



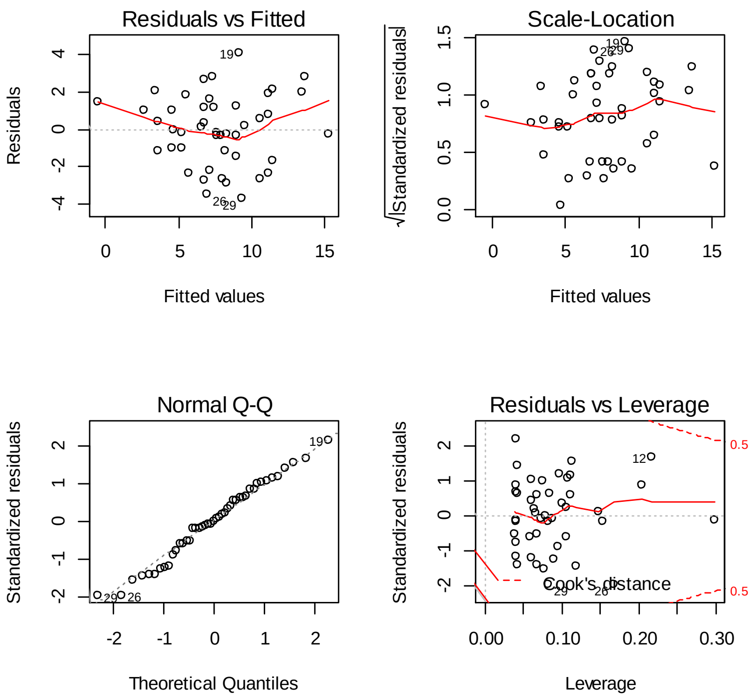
Appendix I: Active site one delay-free productivity model residuals.



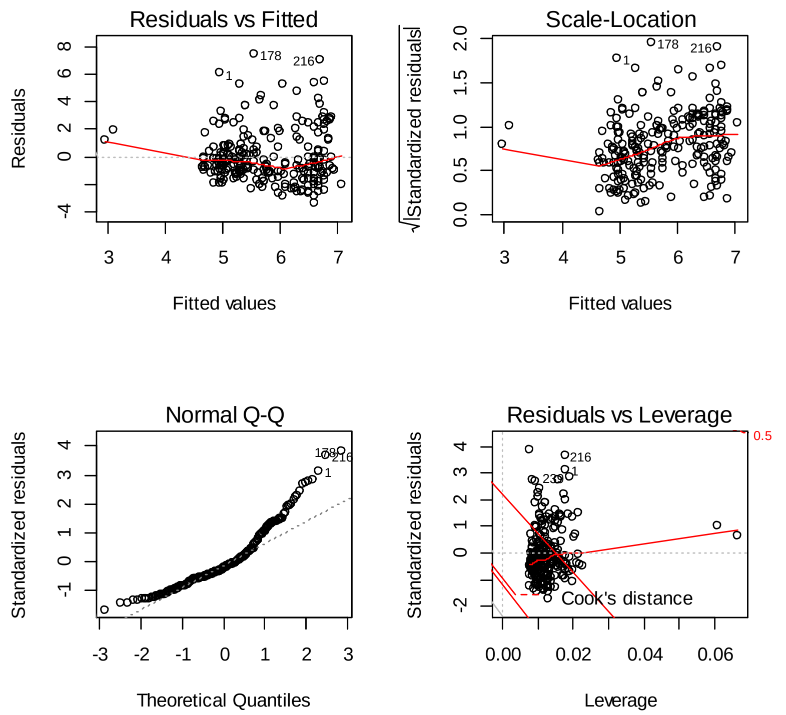
Appendix J: Active 70 at site two delay-free productivity model residuals.



Appendix K: 507 delay-free productivity model residuals.



Appendix L: 602h delay-free cycle time model residuals.



Appendix M: 602h delay-free productivity model residuals.