Productivity analysis of fully mechanised cable logging operations in New Zealand

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Executive summary

Modern day production requirements are continually increasing for logging crews throughout New Zealand. Growth in mechanisation, driven by the demand for a safer work place, requires large capital investments, and thus the demand for higher production to justify the increased cost. This analysis investigates fully mechanised extraction systems currently operating in the country and compares how the next generation of swing yarders may increase operational efficiently and productivity. Elemental time studies were used to quantify cycle time and calculate productivity for the purpose of comparing operations.

Four elemental time studies were completed for cable yarder operations with over 200 cycles being recorded for each machine. These were conducted by Luke Holmes and Hunter Harrill during the first half of 2017. The focus was on the two new T-Mar 'Log Champ' swing yarders that have recently been imported to NZ (both 650 and 550 models) and an older style Madill 124 swing yarder which is a commonly found machine among NZ forests. These machines were all operating a mechanical grapple with a mobile tail hold. The studies also included one tower yarder operation which was using a Bellis BE 60 LT track based yarder This crew were using an innovative standing skyline system, operating the Block in the Bight rigging configuration, but replaced the chokers with a *Helihawk* grapple adapted for use on a cable logging system.

Following an analysis of the time study data the Madill 124 performed the best overall and reinforces why this is one of the premium swing yarders within the industry. This machine had the lowest delay time accompanied by high line speeds and good overall productivity, averaging 52.7 t/PMH. Although it must be noted that this operation had the largest piece size as well as good deflection. The new T-Mar 650 'Log champ' which is of similar size to the Madill 124 also performed well with an average productivity of 46.4 t/PMH. This machine did however have a slower observed line speed than the Madill 124 and had a shorter average extraction distance. The Bellis 60 performed relatively well considering the small piece size in which it was operating (average of 0.8 tonnes/stem) and still managed to achieve an average productivity of 30 t/PMH, which was closely followed by the smaller T-Mar 550 with 28.3 t/PMH. The Bellis did however have the largest proportion of delay time (49% of total study time) which reflects the nature of older tower yarders. They are complex machines and are slow to reposition and set up compared to swing yarders.

Through a regression analysis of all study data, an important outcome of the investigation was that when average extraction distance was increased by 100m, productivity is estimated to drop by 13 tonnes per PMH. This is likely to affect planning of future operations and reinforces the benefit of keeping extraction distances under 300m; primarily for swing yarders, if productivity is to be kept high.

A number of different stem presentations were observed during the studies including bunched, surge piled, manual and mechanically felled and directly fed into the grapple. Unfortunately each different layout could not be tested under the different machines and settings however it became clear that manually felled stems were the least productive (i.e. had the longest grapple time and lowest payload). The regression analysis indicated that it was on average 5 t/PMH more productive to have the stems either bunched, fed or surge piled.

Based on this study of operations and the conditions observed, there is no strong trend that clearly indicates the new T-Mar 'Log Champ" swing yarders are significantly more productive than the older style Madill. However these machines are very new and may take time before operations become refined. Furthermore, when well planned tower yarders operating grapples can be productive especially if delays are minimised.

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Introduction

Cable yarding within New Zealand is currently experiencing a change in preference from older North-American style tower yarders, to smaller more versatile swing yarders. This has largely been driven by the increase in mechanisation and the capability of a swing yarder to operate a grapple configuration more efficiently than a tower. However, some contractors have developed systems to increase the productivity of older tower yarders. Rayonier I matariki have expressed interest in comparing the productivity of an older style tower yarder which has incorporated the use of a *Heli-hawk* grapple, with a high productivity swing yarder grapple operation, and performance of new swing yarders recently imported to New Zealand. This analysis will provide an insight into the direction the logging industry within New Zealand may be taking to tackle the steep slope timber crops of the future.

In New Zealand the tower yarder has historically been the preferred extraction machine on steep slopes; and most of the machines currently used were imported from the Pacific Northwest in used condition. Once imported many yarders were rebuilt while some were put straight to work; these yarders are now around 20 years old and due to the closure of many North America manufacturers, there have been few replacement machines imported over the last decade (Visser, 2012). However, due to increasing productivity demands and the growth in steep slope timber becoming ready for harvest, it is unlikely the trend of using and rebuilding worn equipment will continue.

We are seeing an increase in the amount of steep terrain harvesting in NZ and an associated increase in the amount of cable yarding operations. Tower yarding on steep terrain is coming under increasing pressure to reduce logging rates and increase productivity, these systems are often old, thus requiring high maintenance costs and require significant set up time which all contribute to lost productive time (Olund, 2001). Swing yarder popularity in New Zealand is increasing with a number of former tower yarder crews converting to these types of machines, in most cases in conjunction with a grapple carriage and mechanised felling, as grapple productivity is highly dependent on piece size and whether or not stems are pre-bunched. In situations where all factors are in the crews favour (i.e. large piece size, bunched wood, short distance pulls) modern swing yarders can produced as much as 1,000 tonnes per day (Olund, 2001). A survey of yarders used in New Zealand in 2012 indicated that out of a total of 305 yarder operations, 92 (30%) were swing yarders, this was a significant increase from 23% in 2002 (Visser, 2012). The trend has continued to increase, while exact numbers are not known at the present point in time, it is believed swing yarders could comprise 50% of all yarding operations.

Many contractors are investigating the potential of a new generation yarder. Recently T-Mar Industries of Vancouver Island, Canada, have released their 'Log Champ' range of swing yarders. These include a 45 tonne model and a larger 64 tonne design; which has sparked interest amongst contractors, planners and industry professionals alike.

Contractors are looking for machines with more up to date technology which will ultimately make the forest a safer place to work (Ellegard, 2017). However, some contractors are choosing to remain with their tower yarders but replace conventional chokers/strops with grapple carriages which, with the correct additional features, are thought to be productive enough to meet today standards (Visser, Raymond, & Harril, 2014). This study will give a viewpoint on if this is true, or if investing in a more modern system is a better option.

Background

Cable yarding is the preferred method of steep terrain harvesting in New Zealand, in general it consists of lower productivity and higher costs than ground-based harvesting. Due to the nature of the terrain, manual tasks are more common in cable harvesting operations, such as breaking out and manual tree falling (Raymond 2010). One of the important messages that has been adopted by the industry in recent years is "no worker on the slope, no hand on the saw" and this stems from Raymond's *Innovative harvesting systems* report from 2010. This essentially paved the way for the gradual demise of manual breaking out and falling, with the aim of improving worker safer and social wellbeing.

The tower yarder has historically been the preferred extraction machine and most of the machines currently used in NZ were imported from the Pacific Northwest in used condition. Once in New Zealand many yarders were rebuilt while some were put straight to work, these yarders are now around 20 years old and due to the closure of many North America manufacturers, there have been few replacement machines imported over the last decade (Visser, Survey of Cable Yarders Used in New Zealand, 2012). However due to increasing productivity demands and the growth in steep slope timber becoming ready for harvest, it is unlikely the trend of using and rebuilding worn equipment will continue.

We are seeing an increase in the amount of steep terrain harvesting in NZ and an associated increase in the amount of cable yarding operations. Tower yarding on steep terrain is coming under increasing pressure to reduce logging rates and increase productivity, these systems are often old, thus requiring high maintenance costs and require significant set up time which all contribute to lost productive time (Olund, 2001). Swing yarder popularity in New Zealand is increasing with a number of former tower yarder crews converting to this form of extraction system, in most cases in conjunction with a grapple and mechanised felling, as grapple productivity is highly dependent on whether or not stems are pre-bunched. In situations where all factors are in the crews favour (i.e. large piece size, bunched wood, short distance pulls) modern swing yarders can produced as much as 1,000 tonnes per day (Olund, 2001). A study conducted in Australia during 2011 involved a Madill 124 swing yarder and showed the potential productivity of such a machine, when used in conjunction with mechanised falling. (Acuna, Skinnell, Evanson, & Mitchell, 2011). The productivity values are shown below in figure 1.

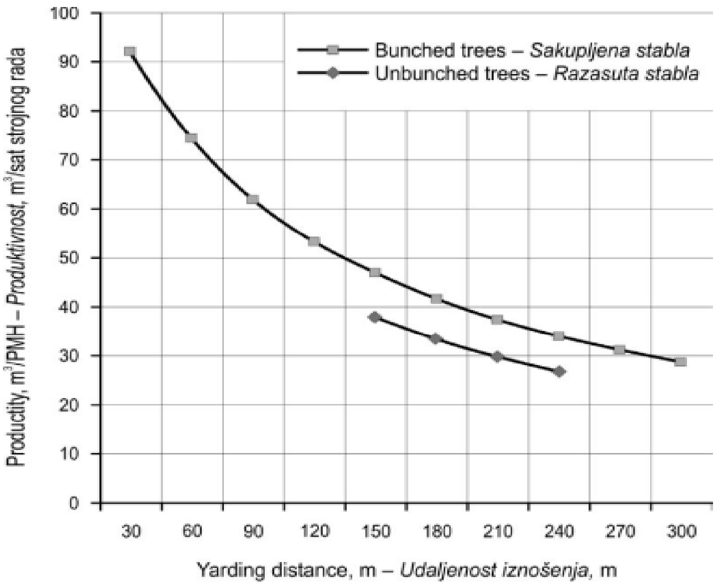


Figure 1: Madill 124 productivity values for a particular study (Acuna, Skinnell, Evanson, & Mitchell, 2011).

Figure 1 provides a ballpark value for what could be expected from a similar operation within New Zealand, however as with any logging operation many factors have an influenced on final productivity.

Using swing yarders enables the extraction component of a logging operation to no longer be the bottleneck as they are often faster especially over short distances. A survey of yarders used in New Zealand in 2012 indicated that out of a total of 305 yarder operations, 92 (30%) were swing yarders, this was a significant increase from 23% in 2002 (Visser, Survey of Cable Yarders Used in New Zealand, 2012). The trend has continued to increase, however exact numbers are not known at the present point in time but it is assumed it is around the 50% mark (Visser, 2016).

Many contractors are investigating the potential of a new generation yarder. Recently T-Mar Industries of Vancouver Island, Canada, have released their ‘Log Champ’ range of swing yarders. These including a 45 tonne model and a larger 64 tonne design, this has sparked interest amongst contractors, planners and industry professionals alike. Two of these machines have already arrived in NZ and are at work in the North Island, with four more orders currently under construction. Contractors are looking for machines with more up to date technology which will ultimately make the forest a safer place to work (Ellegard, 2017). This technology includes grapple mounted cameras, radio controlled guylines, real-time tension monitors and motorized hydraulic grapple carriages to name just a few. Although new swing yarders are powerful, versatile and fast, it does not deny the fact that they are also extremely expensive, generally the cost is over $2 million dollars. Several contractors are choosing to remain with their tower yarders but replace conventional chokers/strops with grapple carriages which, with the correct additional features, it is thought can be productive enough to meet today standards (Visser, Raymond, & Harril, 2014). This study will give a definitive viewpoint on if this is true, or if investing in a more modern system is a better option.

A number of previous productivity studies were analysed to gain an insight into what the key areas should be looked at to understand the productivity of such an operation. It was indicated that a detailed time study is the preferred method for gaining productivity data and that this would enable suitable comparisons with other systems (Olsen, Hossain, & Miller, 1998). Each portion of the cycle time (i.e. inhaul, grapple, outhaul and unload) should be timed so that specific insight can be made during the analysis. All minor (<10 min) and major (>10 min) delays should be recorded so that the overall efficiency of the system can be estimated (Harrill, 2016). A similar study carried out on one of the T-Mar swing yarders mentioned earlier, provided a good basis for the concept of the study and subsequent analysis so that the studies could be easily comparable. This again requires the recording of all sections of each turn as well as the classification of as delays based on their nature (Harrill, 2016).

Objectives

The primary objective of these combined studies was to assess the performance of the T-Mar 'Log Champ' 650 and 550 swing yarders as well as the Madill 124 swing yarder and Bellis BE 60 LT tower yarder. Once the performance assessment was complete, comparisons were made between these yarders. In order to assess performance several questions were investigated for each machine:

1. What is the productivity rate and utilization under the current operating conditions?
2. What observations can be made about each cycle component?
3. What observations can be made about the overall system?

Methodology

Time study

Elemental time studies of each extraction system were carried out over all available time while on site at each operation. A large number of cycles were observed at each site to try and capture some of the variation that occurs during harvesting. The productive work cycle of the yarder was broken down into four basic elements as described below.

Yarding elements

Outhaul – Begins when grapple moves away from the yarder. Ends when grapple is slowed and lowered in the cutover towards the stems on the ground.

Grapple (Load) – Begins when the grapple is slowed close to the stems on the ground. Ends when the grapple is raised with the stems intact, ready for inhaul. Sometimes multiple attempts at raising and lowering the grapple to secure the payload were required, this was included in grapple time.

Inhaul – Begins when grapple is raised enough for stem(s) to be inhauled and the grapple begins to move towards the yarder. Ends when grapple arrives at landing and begins to be lowered.

Unhook (Unload) - Begins when grapple is lowered onto the landing, often involved yarder slewing, ends when yarder turns back to the cutover and ropes and grapple are raised ready for outhaul.

A number of factors were recorded during each cycle, this helps give an indication of loading on the yarder and overall output as well as why productivity may vary. These factors were:

- Extraction distance (m)
- Number of stems, tops & logs (#)
- Types of delays and their respective times
- If stems were:
  Fed – If the stems were directly places in the grapple jaws.
  Bunched – Laid out under the ropes by the falling machine, or in piles of 2/3.
  Surge piled – Picked from a surge pile.
  Mechanically felled – Grappled from scattered stems throughout cutover.
  Manually felled – Chainsaw felled with a very spread out pattern as a result.

*Note the 'Mechanically felled' classification still means a felling pattern has been carried out, so butt ends of stems are generally all the same direction and where possible stems laid perpendicular to the ropes.

Stepwise linear regression was used to evaluate the systems on common ground and this will also determine which variables are the most important for cable yarding productivity. This analysis determines the variables of the most importance and hence where future improvements could be concentrated to increase productivity or reduce the total cycle time.

Delays

Although not the primary focus of this investigation, a delay analysis was conducted to give an estimate on the average utilization for all machines which included recording the times of all delays that occurred and categorising them as personal, mechanical or operational. Delay analysis also indicates if there is a significant difference between the yarder configurations in terms of daily use.

Study support

Due to time constraints Hunter Harrill observed the two T-Mar 'Log Champ' operations and provided the preliminary reports for each machine which were returned to the contractors and managers soon after the studies. Luke Holmes carried out similar studies on the Bellis BE 60 and Madill 124 and also returned a summary report to those involved. Data on all studies was then collated into this final report using analytical approaches including a statistical regression program. This enabled the comparisons to be drawn between machines, stem layouts and other important factors such piecesize.

Study Sites & Machines

T-Mar 650 - Hawkes Bay

The 'Log Champ 650' swing yarder is a new machine manufactured by T-Mar Industries (Vancouver Island, Canada). It weights approximately 64 tonnes (140,000 lbs) has a 354 kW (475 hp) engine with a fuel tank capacity of 1,300 litres. The machine is equipped with three operating drums including a split side-by-side main drum, all of which run 22mm (7/8th inch) ropes and is primarily designed for mechanical grapple yarding. The machine has a 60 ft (18.3 m) tower and is equipped with three walking 1 and 1/8th inch (28 mm) guy lines and requires a two piece move (i.e. tower transported separately). Unique features of this swing yarder include the new electronic over air/hydraulic control system integrated with the engine and transmission, which is precise and customisable providing smooth control of the grapple as well as many other features including a touch screen with machine and engine diagnostics. Details on machine can be viewed at www.tmarequipment.com/yarders/log-champ-650/.

Figure 2: T-Mar 'Log Champ' 650 at the study site.

The study site was harvest unit 415-012-01 in Rukumoana Forest, Hawkes Bay. Yarding was observed by Hunter Harrill from Wednesday the 8th – Friday the 10th of February, 2017. Yarding took place across three different skyline corridors (Figure 2) ranging from 60-347m and 17-18% chord slope with good deflection greater than 15%. The slope was concave with a prominent 20+ meter bluff directly under the landing.

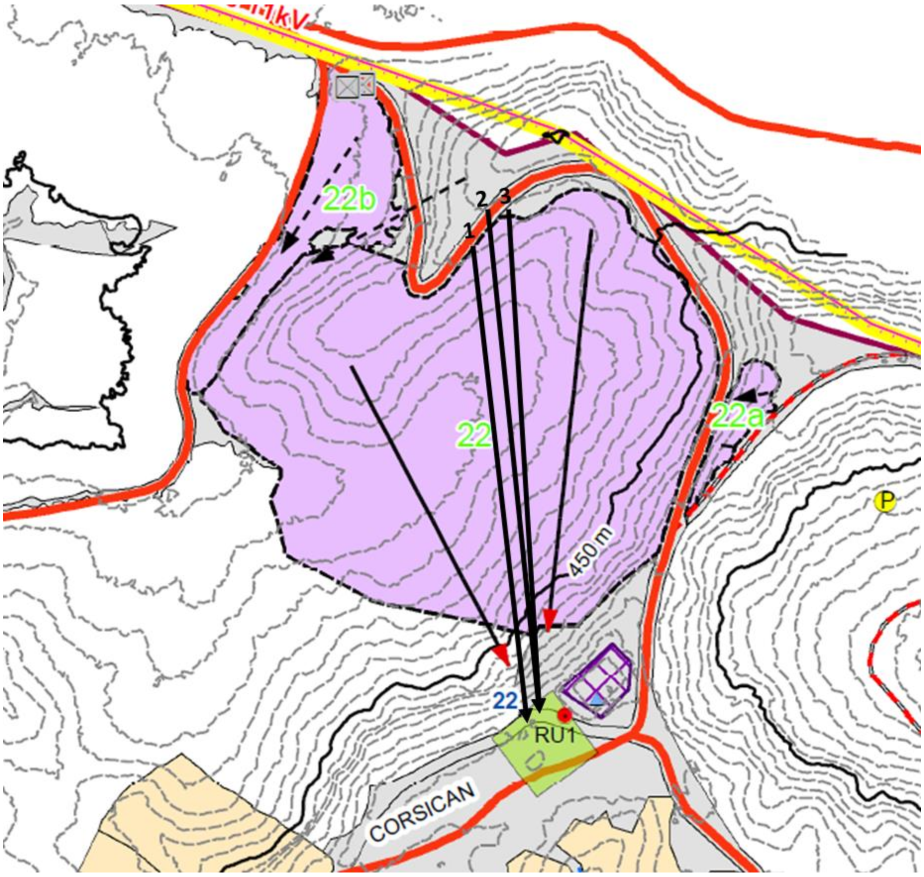


Figure 3: Log Champ 650 study area at Rukumoana Forest with yarding occurring at skyline corridors one, two and three

Piece Size*:* Data was gathered from the processor to establish average piece size of the stems extracted. The file contained 415 stems that were processed into 1760 logs (4.2 logs per stem). Summing all the log volumes in the file equated to 719.1 m3, or 1.73 m3 average piece size (70% & 30% of the average piece size was assumed for the estimated volume of logs and tops, respectively). Note that average merchantable tree size from company records was 2.2 m3, whereby most of that difference is expected to be due to stem breakage.

Table 1: Piece size (tonnes) for T-Mar 650 study.

Stem	Log	Top
1.73	1.21	0.52

Bellis 60 LT – Southland

The 'Bellis BE 60 LT' tower yarder was built in 2001 by Brightwater Engineering (Nelson). It is powered by a Cummins M11 six cylinder diesel delivering approximately 300 hp to a 23mm skyline, 20mm mainline, 16mm haul back, and 26mm guy lines, on a tracked base.

The first study site was in Castle Downs Forest in Northern Southland (Rayonier sale area 706-883-02), the terrain was moderately steep (approximately 40%) but excavators with modified tracks could move on the slope with relative ease. The skyline remained in the same position for the length of the study at this setting. However, due to the ability to move the haul back via the excavator connection, combined with shovelling stems, a large area was harvested without the need to shift the skyline. Yarding distance ranged between 100 and 365 m. The second study site was also in Castle downs forest (Rayonier sale area 708-893-03) and is shown in Figure 3. Terrain was moderately steep but excavators could still move around the slope with relative ease. Yarding distances ranged from 130-320m.

Figure 4: Setting #2 at Castle Downs Forest, Southland

Piece size: Data provided by Rayonier indicated a piece size of 0.46 tonnes at the first setting and 1.25 tonnes at the second setting. Files gathered from the processor indicated similar values thus confirming the inventory data was suitable for use in the analysis. It was assumed that 'logs' and 'tops' comprise of 70% and 30% of the piece size respectively, shown in Table 2.

Table 2: Piece size (tonnes) for Bellis BE60 study.

Setting	Stem	Log	Top
706-883-02 (1)	0.46	0.23	0.09
706-893-03 (2)	1.25	0.63	0.25

T-Mar 550 – Taupo

The 'Log Champ 550' Swing Yarder is a new machine and is the slightly smaller version of the 650 discussed earlier. Also manufactured by T-Mar Industries (Vancouver Island, Canada), it weights approximately 48 tonnes and has a 261 kW (350 hp) engine with a fuel tank capacity of 860 litres. The machine is equipped with three operating drums including a split side-by-side main drum, all of which run 19mm (3/4 inch) ropes and is primarily designed for mechanical grapple yarding The machine has a 50 ft (15.2 m) tower and is equipped with three walking 1 inch (25 mm) guylines. Details on machine can be viewed at www.tmarequipment.com/yarders/log-champ-550/.

The study site was harvest unit TDC 0116 in Taupo Distric Council's Forest, Southeast of Whakamaru. Yarding was observed by Hunter Harrill from Tuesday the 23rd – Wednesday the 24th of May, 2017. Stems were previously felled by hand downhill and all yarding performed was also downhill. Yarding took place across 13 different skyline corridors ranging from 80-343m and approximately 50% chord slope with poor deflection <6%. There was also one yarder shift on the first day (approx. 40m) which was simplified by the bulldozer being used as a guyline anchor. The slope was convex with steep straight terrain in front of the yarder but flattening at the top of the slope in the last 50 or so meters to the mobile anchor.

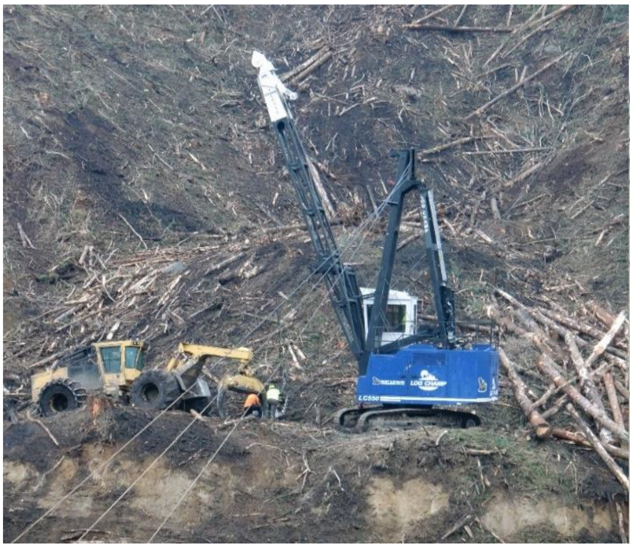
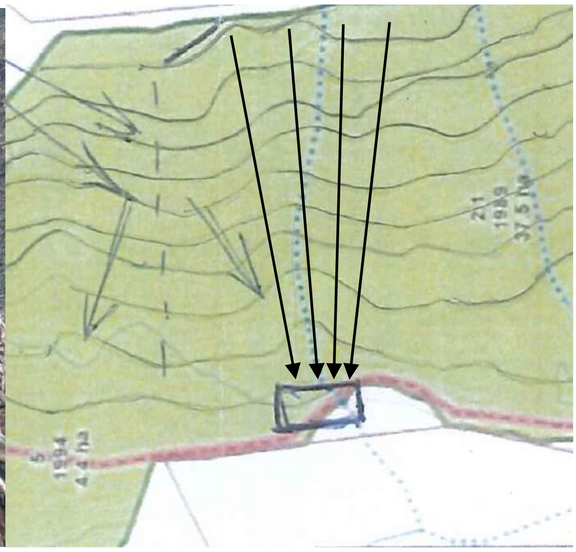



Figure 5 & 6: Log Champ 550 study area at Taupo District Council's forest with downhill yarding corridors shown towards the landing (note; contours are 20m).

Piece size*:* Payload was estimated for each cycle by summing the volume of stems, logs and tops yarded each cycle. Forest owner inventory data found the average stem size to be 1.8 m^3 (70% & 30% of the average stem size was assumed for the estimated volume of logs and tops, respectively).

Table 3: Piece size (tonnes) for T-Mar 550 study.

Stem	Log	Top
1.8	1.26	0.54

Madill 124 – Northland

The Madill 124 Swing yarder is the largest swing yarder in the Madill range and this particular model was imported from Canada approximately 2 years ago. It was completely overhauled prior to transportation to New Zealand with a new engine being fitted, rigging and a paint job. The machine is in very good overall condition. The yarder has 3, 1 1/8th inch guy ropes and 3 drums, in this case a haul back, mainline and slackline which are all 7/8 inch (22mm).

The study occurred in Pouto Topu Forest in Northland (Rayonier sale area 209-001-01) and stems came from a combination of settings 3, 4 and 5. Figure 6 shows the study site, note the large surge piles at the bottom of the picture and also directly in front of the tailhold position, and the scattered stems towards the back slopes. These two different types of stem layout formed an important part of the data collection however there was also a period of time when stems where placed under the ropes by the felling machine which was also identified in the data collection. The furthest distance recorded was 390m, this was along the ridge to the left of the standing trees in Figure 6. The site had a number of different slopes, with a steep (70%) slope directly below the hauler, this then flattened out to the basin, with 40% slopes towards the far side. Chord slope was approximately 12%.

Figure 7: View from landing to mobile tailhold at the study site in Pouto Forest.

Piece size: Data supplied by Rayonier (via plots from the forest) was used in conjunction with the amount of stems, logs and tops recorded to give an indication of the total tonnage harvested during the study. It was assumed logs and tops were 70% and 30% of a full stem respectively. Although the average piece size for the entire forest was 2.6 t/stem yarding occurred throughout settings 3, 4 and 5 during the study. Plots in settings 3 and 5 indicated a slightly smaller piece size. Therefore, the piece size of 1.85 t/stem presented in Table 4 was used for productivity calculations. The smaller piece size may also give a more conservative productivity value.

Table 4: Piece size (tonnes) for Madill 124 study.

Stem	Log	Top
1.85	1.30	0.56

Results

Utilization

An important contributing factor to how productive a cable logging operation is, can be found in the utilization rate of the yarder. Specifically, how many productive machine hours (PMH) are actually achieved from the scheduled machine hours (SMH). This section provides a brief indication of the utilization rates of the observed systems. It is important to note that for a proper delay analysis to be conducted a much longer study would be required, to account for wider variation.

Table 5: Utilization rates for all machines and what the delays compromised of.

Machine	Study length (hrs)	Utilization (%)	Total delays (%)	Mechanical (%)	Operational (%)	Personal (%)
T-Mar 650	20.7	69	31	7	14	10
Bellis BE60	50.5	51	49	16	24	9
T-Mar 550	14.0	62	38	23	12	3
Madill 124	42.5	84	16	2	12	2

The T-Mar 650 achieved 69% for overall utilization and one that is consistent with utilization rates for yarders operating in New Zealand, which commonly average 70% (Harper 1992; Harrill 2014). Operational delays included morning grease and safety checks, as well as fuelling. Longer operational delays included waiting for stems to be shovelled and bunched under ropes, retrieving stems that were lost over the bluff during inhaul and a clean-up line shifts. Personal delays were also high in comparison to the other operations.

Previous production studies of new model swing yarders have also found large mechanical delay issues and are not uncommon to newly delivered machines (Prebble, 1989), and this was found to be the case for the T-Mar 550. Mechanical delays included issues with the main drum clutch bolts, which were observed to be loose at the end of the work day previous to the study. A service technician spent 3 hrs locating the problem and then finding the correct tools for the job before work could resume Tuesday morning. These contributed to give a utilization rate of 62% for the T-Mar 550. Large tower yarders such as the Bellis 60, inevitably have frequent mechanical issues, which generally increase with age. As Table 5 shows, 16% of the total time was composed of mechanical delays, this also included any time the machine on the slope was broken-down as this also meant the yarder could not function. Twenty four percent of the total delay time was a result of operational delays, this included health and safety meetings, waiting for the skyline to be adjusted and mainlines replaced/repaired. Surprisingly, there were few delays for the Madill 124 over the course of the week and the utilization during the observed time was 84%, considered high for any cable yarding operation. Tail hold shifts formed the majority of the operational delays while personal delays were limited. It is believed that the lack of mechanical delays are what gave this yarder such a good operational efficiency as in many operations breakdowns can be frequent and time consuming. Although this is an older style machine, it shows the importance of preventative repair and maintenance.

Learning

Table 5 indicates that out of all the yarders observed, the tower yarder had the most time consuming operational delays this may reflect the more complicated nature of operating a large tower yarder.

Outhaul

While there is a strong relationship between extraction distance and outhaul time, there is also a lot of variability in the time taken to go out a specific distance.

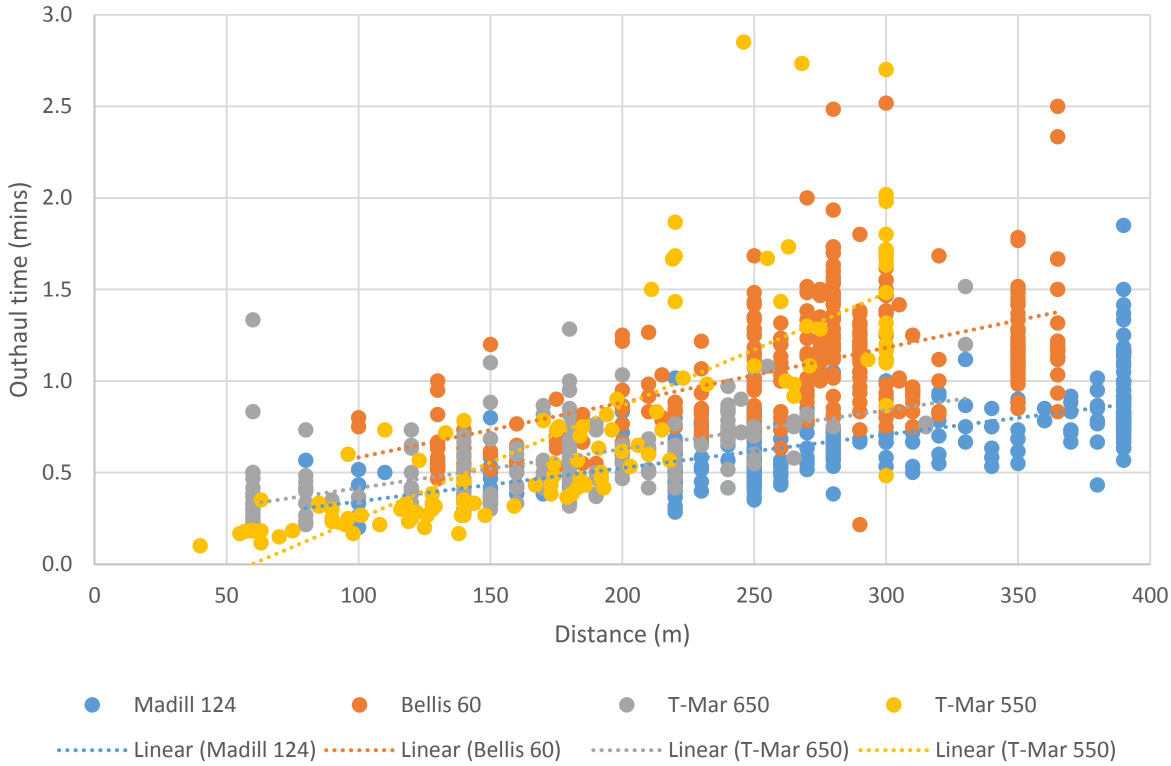


Figure 8: Outhaul times for each cycle across all studies

Outhaul distances of less than 200m provided little variation across the different yarders, however it is at the further yarding limits that the differences become clearer. The Madill 124 and T-Mar 650 have similar trends and show the fastest outhaul times as well as the fastest line speeds, reflecting their large engine size and power. Outhaul variation occurred when rope wraps slowed the process down or the camera was being used to scan for logs in blind spots.

Table 6: Outhaul values for the various systems studied.

Machine	Average Distance (m)	Average time (mins)	Line speed (m/s)	10th Percentile (m/s)	90th Percentile (m/s)
Bellis 60	267.3	1.1	4.1	3.0	5.6
Madill 124	277.4	0.7	6.9	5.0	9.3
T-Mar 650	166.0	0.6	5.0	3.0	7.6
T-Mar 550	185.9	0.8	4.0	2.5	8.1

Outhaul line speeds were generally greater for the swing yarders. This is most likely a reflection of the larger engines that were found in these swing yarders, compared to the Bellis. The Madill 124 outperformed the other systems dramatically, having one of the lowest average outhaul times over the greatest average yarding distance.

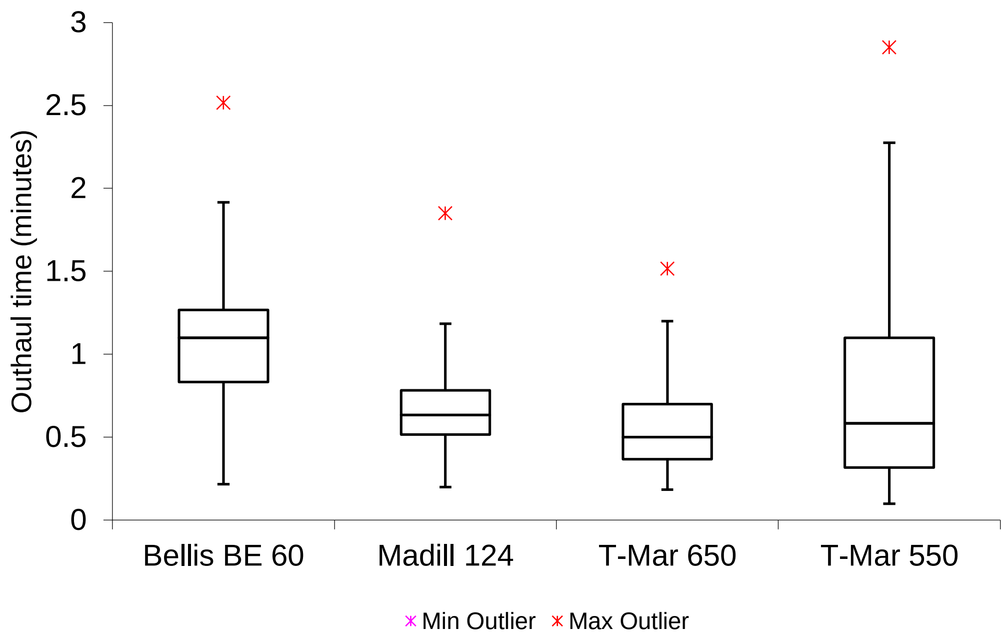


Figure 9: Median and range of outhaul times for each machine.

Grapple (Load)

Grappling (or loading) was a large component of overall cycle time. In all of the observed swing yarder operations, a great number of cycles consisted of only one stem. However due to the relatively large piece size, in most cases productivity remained reasonably high for these cycles. In the tower yarder operation in Southland the piece size was much smaller so it was more common for multiple stems to be yarded in each cycle.

Although the majority of the stems grappled were mechanically felled and placed throughout the cutover, there were a number of cycles where the stems were grappled from large surge piles, laid out by the excavator (bunched), directly placed in the jaws of the grapple (fed), or grappled from a manual felling operation (T-Mar 550 only). Average grapple times for are shown in Table 7.

Table 7: Average grapple times for each machine.

Machine	Average time (mins)	10th Percentile (mins)	90th Percentile (mins)
Bellis 60	0.41	0.22	0.67
Madill 124	0.69	0.27	1.20
T-Mar 650	1.24	0.40	2.67
T-Mar 550	0.76	0.17	1.15
T-Mar 550 (with chokers)	3.11	1.67	5.48

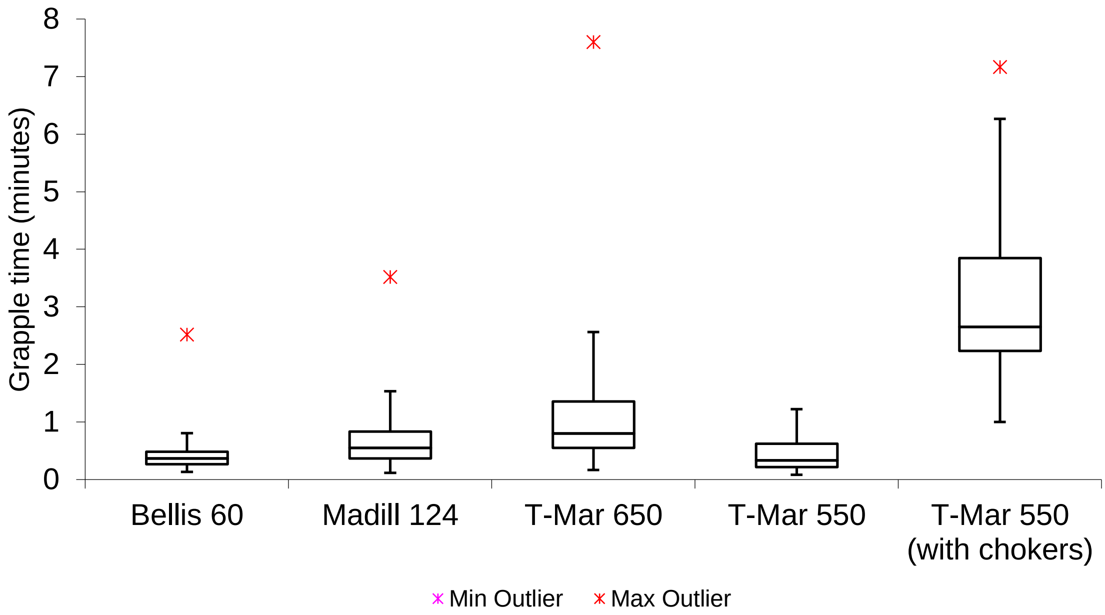


Figure 10: Median and range of grapple times for each machine

An important factor influencing the relatively fast grapple time of the BE 60 was the ability of an excavator to directly feed all stems into the *Helihawk* grapple. This may not be practical in many parts of NZ especially in very steep terrain unless the machine was also tethered to another winch-assist machine. However, this brings many other challenges into the operation. A significant advantage of this operation was that the felling machine, a Sumitomo 240, was able to fell trees, slew with the tree in the felling head and then place directly in the yarder grapple. Significantly reducing constant shovelling and multiple handling.

When the stems where fed directly the grapple time was on average 25 seconds, shown in Table 8. This is obviously not practical in all settings, however it shows the kind of times that can be achieved with effective feeding. Although the payload for this operation was low, in most cases 2 stems were yarded per cycle; it is the result of a small piece size (average of approximately 0.8 tonnes/stem), not the limiting capacity of the grapple or yarder. It is estimated this yarder could easily pull 4 tonnes payloads.

The Madill 124 also had a reasonable grapple time which reflects the skill of the operator and that most of the logs were mechanically felled and laid perpendicular to the ropes. Longer grapple times were experienced when large surge piles were encountered, as shown in Table 8. However, this was accompanied by slight increases in payload, which did off-set some of the longer times.

A number of stems in the T-Mar 650 operation had to be re-grappled multiple times, this often occurred when the stems were either in a surge pile, or the ropes weren't positioned adequately over the stems. The practice involved grappling one stem, pulling it into lead and then regrappling it once in a better position, or then grappling one or more stems, pulling them into lead and stacking them on the first stem and then grappling all of them in an attempt to generate a larger payload. When stems were stacked and re-grappled the average Grapple time was 3.65 minutes, but the average estimated payload was only 0.1 tonnes greater than all other cycles. This is a situation where prior planning of stem layout (through contractor – planner consultation) would have helped to keep the yarder working at maximum output.

Table 8: Stem presentation and respective average load times and payloads.

Stem Presentation	Observed Cycles (#)	Average Time (minutes)	Average Payload (tonnes)
Fed	341	0.41	1.7
Mechanically felled	252	0.65	2.3
Surge pile	114	0.75	2.5
Bunched	220	1.14	2.8
Manually felled	101	0.76	1.7
Choked	24	3.11	1.8

Unsurprisingly when the stand was manually felled, the average grapple time was the largest, this was the case during the T-Mar 550 study and was accompanied by one of the smallest payloads. This reinforces that manually felling timber is much more unproductive than mechanised felling operations as there is little control of stem placement, resulting in 'birds nests' of stems which are extremely difficult and time consuming to grapple effectively from. As mentioned earlier a number of stems were choked during the 550 study, this caused a significantly longer average grapple time, however, when the results are separated the average grapple time for the 550 with grapple is much similar to the other machines.

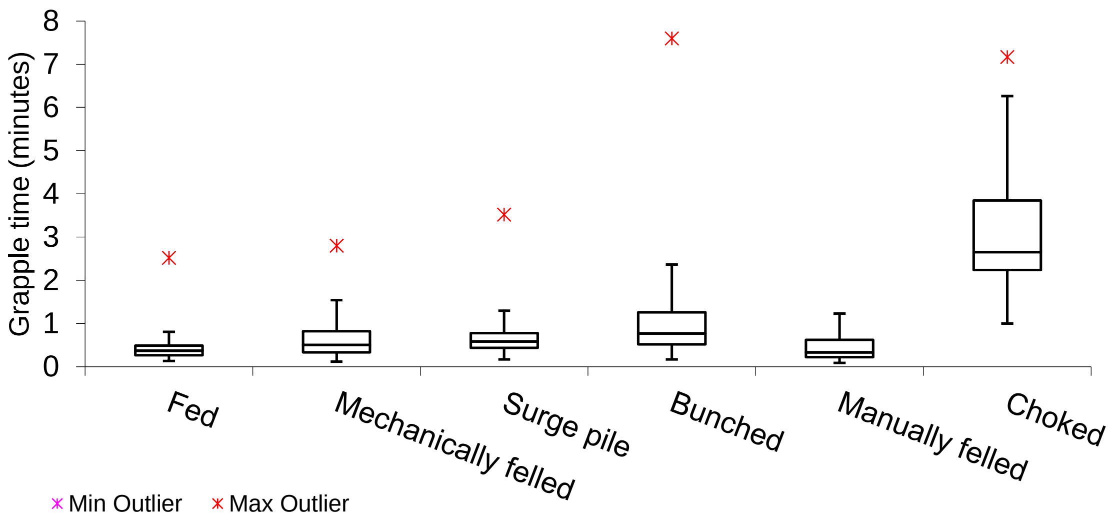


Figure 11: Median and range of grapple times for each type of stem presentation

Because we were unable to test all types of stem presentation on all sites, the raw results are somewhat bias, as the majority where mechanically felled and paced. A regression analysis was implemented to gain a further insight into which method of stem presentation is the best. The results of this showed that the amount of manually felled data (only occurring at the T-Mar 550 site) was insufficient to have any statistical significance. However, the regression analysis indicated when stems were either bunched, fed, or in surge piles, productivity was improved by approximately 5 tonnes per PMH when compared to mechanically placing individual stems (mechanically felled). There was no confirmed advantage between surge piles or bunching. However based on other studies and visual experience from these studies it is likely bunching is the most efficient form a yarding perspective (Harrill, 2016) & (Acuna, Skinnell, Evanson, & Mitchell, 2011).

Learning

The importance of correct planning and yarder/tail hold placement. In the T-Mar 550 operation the ridge where the tail hold was stationed was blind to the hauler and required some of the stems to be choked into a suitable grappling position. This dramatically increased grappling time and significantly impacted productivity. If these stems could have been shovelled closer to the ropes, or transported to another skid it would have ensured that the hauler kept operating closer to optimum capacity. It makes little sense to have a machine such as this using chains to pull stems as in most cable yarding operations it is the yarder which is the bottleneck. Hence it is important to keep it working as productively as possible.

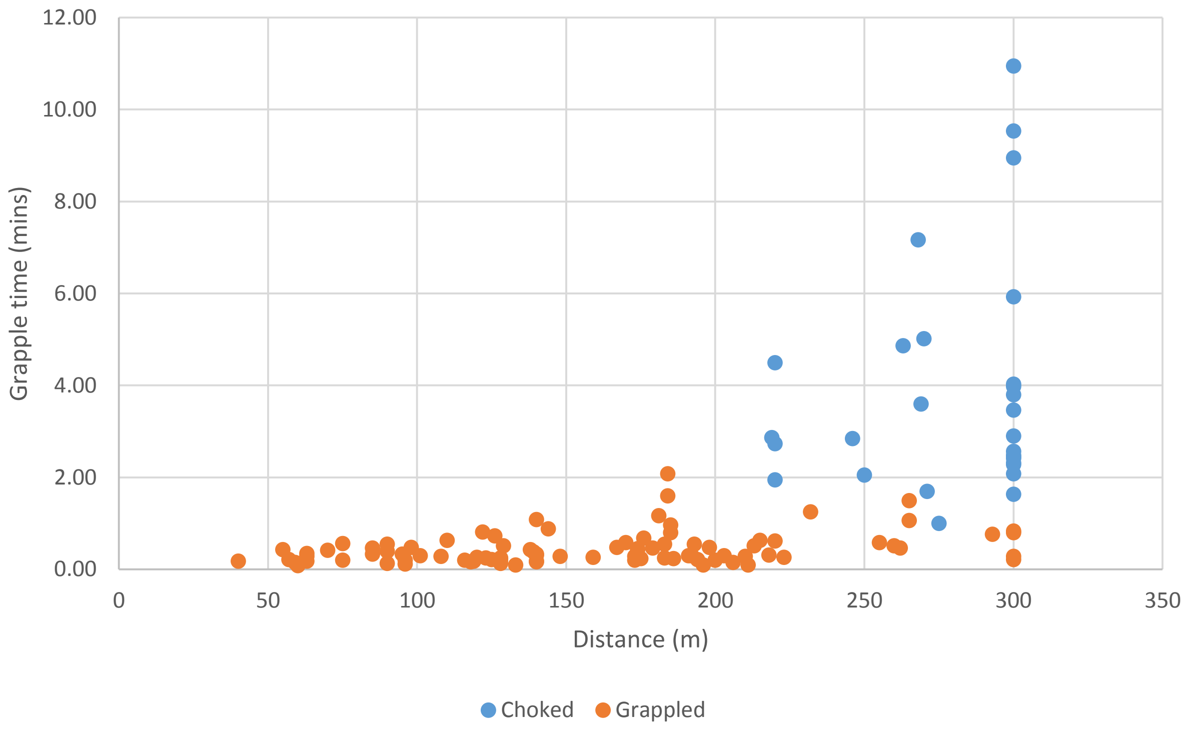


Figure 12: Grapple times for the T-Mar 550 where stems where directly grappled and also choked

The very long times are associated with stems at the back half of the span. Stems from this area were mostly choked and were hard to pull because of poor clearance (i.e. ground leading). When stems were grappled as normal the average time was 0.57 mins. However, when the stems had to be choked first the average time was 3.9 mins. Many of the choked stems in these cycles were pulled forward 25-50 meters to an area with greater clearance and then re-grappled by the operator to help avoid hang-ups during inhaul; which were more common with reduced lift from the excess choker length. The starting and stopping of inhaul to grapple the stem after it had been choked adds time to the inhaul process, but may help avoid time consuming hang-ups, so there is a trade-off.

Inhaul

Inhaul times were affected by intermediate ridges, payload differences, available deflection and engine power of the yarders. Similar to other studies, some variability also occurred when stems came loose from the grapple and needed to be re-grappled, this was a contributing factor to some of the high grapple and inhaul times (Harrill & Visser, 2017).

An interesting point made by Rien Visser (University of Canterbury) is that in North America it is relatively uncommon for swing yarders to operate at distances greater than 250m and historically tower yarders have had much greater ability to perform a faster inhaul over long extraction distances. Looking at Figure 12 there is a clear trend showing more variability once that margin is reached. No yarder drastically outperformed another over the shorter distances.

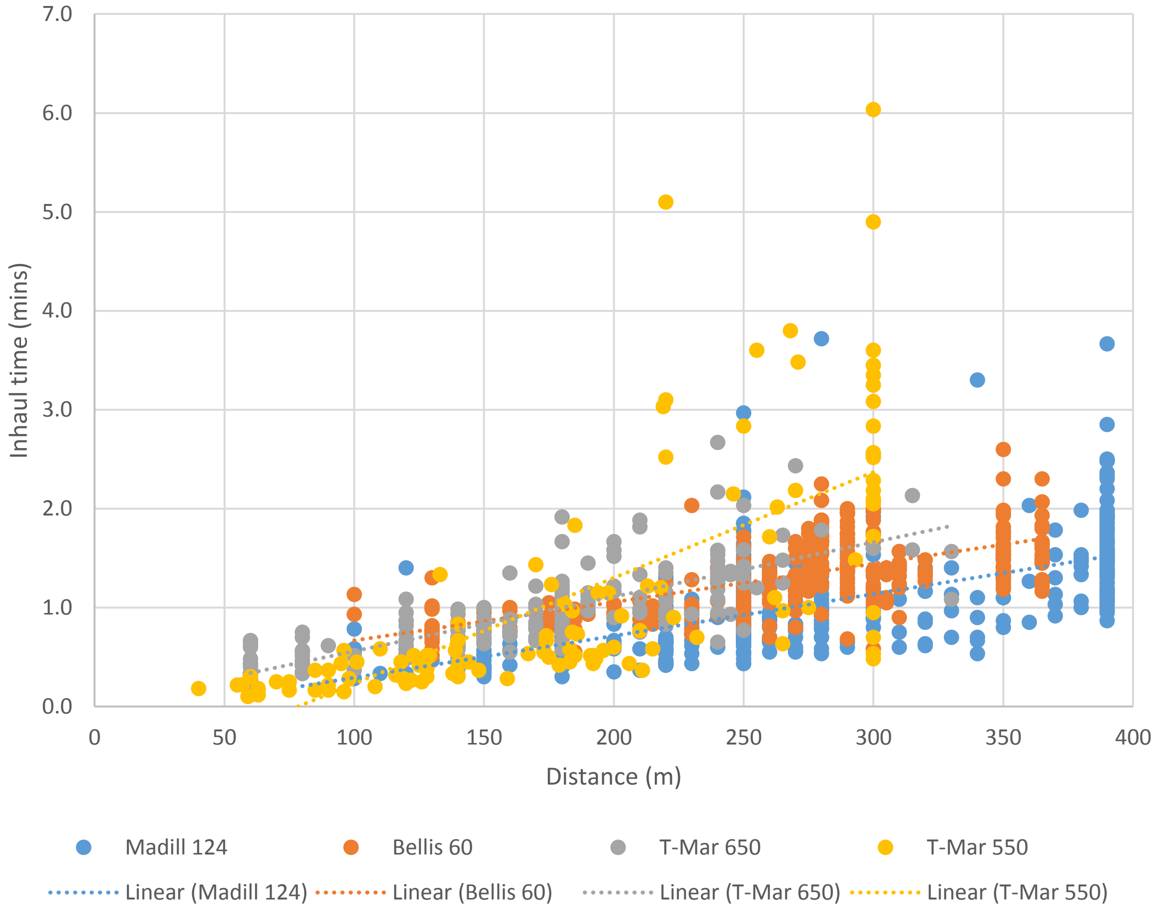


Figure 13: Inhaul times for each cycle across all studies.

Again the Madill 124 was the top performing machine in the inhaul section of the cycle, I suspect this is a result of the high power output from the large engine, and the skill of the operator; also good deflection was achieved at this site. The line speed of the Madill 124 was far superior to any of the other yarders studied with an average of 4.4 m/s loaded, shown in Table 9. Over long distances the inhaul section of a cycle contributes to a large proportion of the total time, thus it is vital to have a machine capable of good loaded line speeds. This is one of the factors that enabled the crew to maintain such high productivity with the longest average extraction distance of the four studies.

All machines had similar inhaul times over the shorter haul distance (<200m). The T-Mar 550 had the slowest line speed of all the studied machines, however this is likely a result of downhill yarding. This requires more care to be taken during inhaul as momentum can be difficult to stop at the landing if the logs are brought in to quickly. This machine also had the most variability which may be a function of the choker/regrappling process.

Table 9: Inhaul line speed values for each machine

Machine	Average Distance (m)	Average time (mins)	Line speed (m/s)	10th Percentile (m/s)	90th Percentile (m/s)
Bellis 60	267	1.3	3.4	2.6	4.4
Madill 124	277	1.0	4.4	3.1	7.3
T-Mar 650	166	0.9	3.0	2.1	4.6
T-Mar 550	186	1.2	2.7	1.2	8.1

The Bellis 60 had a good loaded line speed when compared to the other machines, this was most likely a result of the slightly flatter terrain and also the smaller piece size resulting in less strain on the ropes as loads were not commonly as heavy as experienced by the swing yarder operations.

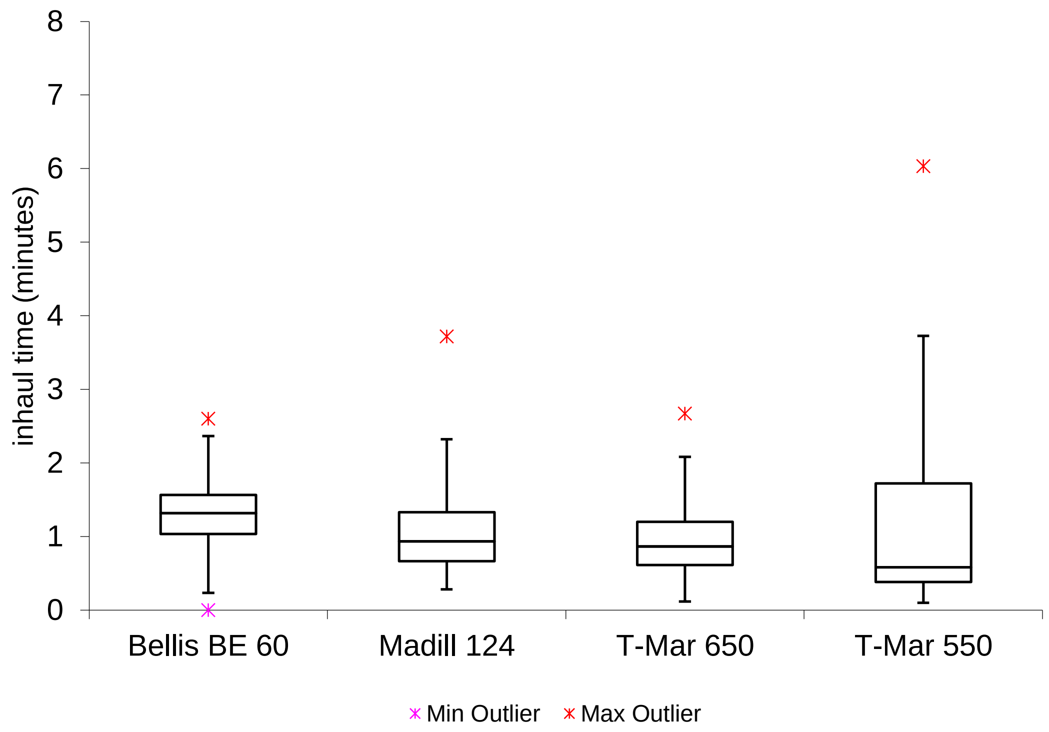


Figure 14: Median and range of inhaul times for each machine.

Unhook

The unhook times provided a large source of variation, the individual cycle values for all studies are shown below on Figure 14.

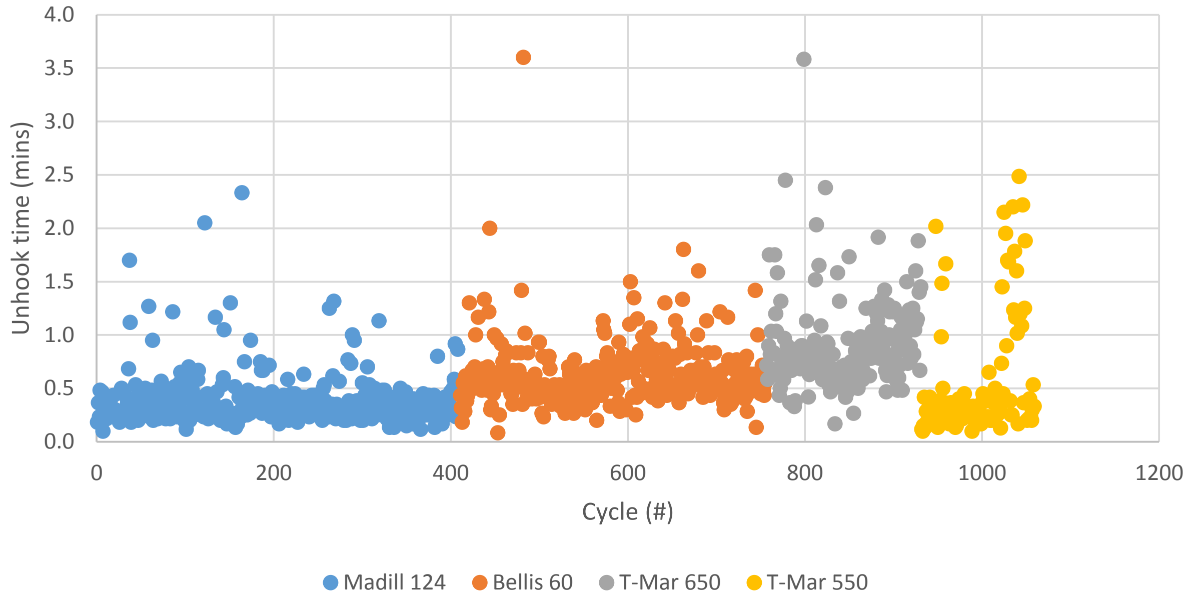


Figure 15: Unhook times for all recorded cycles.

Each system had different reasons for the variation, ideally unhook times would always be occurring at the 10th percentile times shown on Table 10. Unhook times are often the period when small issues are fixed or personal things taken care of. These delays were difficult to pick up on from an observers perspective and may contribute to some of the variation.

Table 10: Average unhook times for each machine.

Machine	Average time (mins)	10th Percentile (mins)	90th Percentile (mins)
Bellis 60	0.62	0.37	0.93
Madill 124	0.38	0.22	0.56
T-Mar 650	0.90	0.52	1.41
T-Mar 550	0.52	0.17	1.53

T-Mar 650: Difficulty was encountered as the yarder was setup very close to a steep bluff and stems often slid backwards into the cutover so the operator was often slewing 90˚ to the side which takes more time as the ropes need to be lowered and then raised again before outhaul. Delays alleviating line twist before outhaul also contributed to the higher unhook times. The fastest Unhook time 0.17 minutes occurred when the machine was able to land the stem without slewing to the side.

Bellis 60: The grapple system that was being used *(Helihawk*) relied on the weight on the grapple being taken away before the grapple mechanism mechanically opened is via an internal spring mechanism. This often meant the stems had to be lifted up and dropped multiple times before the mechanism would open, substantially increasing the unhook time. This issue may be improved with continued development of the grapple system by *HeliHawk Ltd*.

T-Mar 550: Similar to grappling, the longer unhook times were generally associated with having to unhook chokers on the landing. The average Unhook time when stems were choked was 1.46 minutes compared to 0.30 minutes when they were grappled only. The downhill setting is believed to contribute to relatively fast Unhook times when stems were not choked because of the minimal amount of slewing and lowering/raising the rigging.

Madill 124: The longer unhook times in this case were generally a result of difficulty encountered finding room on the landing due to the yarder being quite close to the edge and having to do a 90˚ slew in many cases. However, of all the surveyed machines, the Madill provided the lowest consistent unhook time.

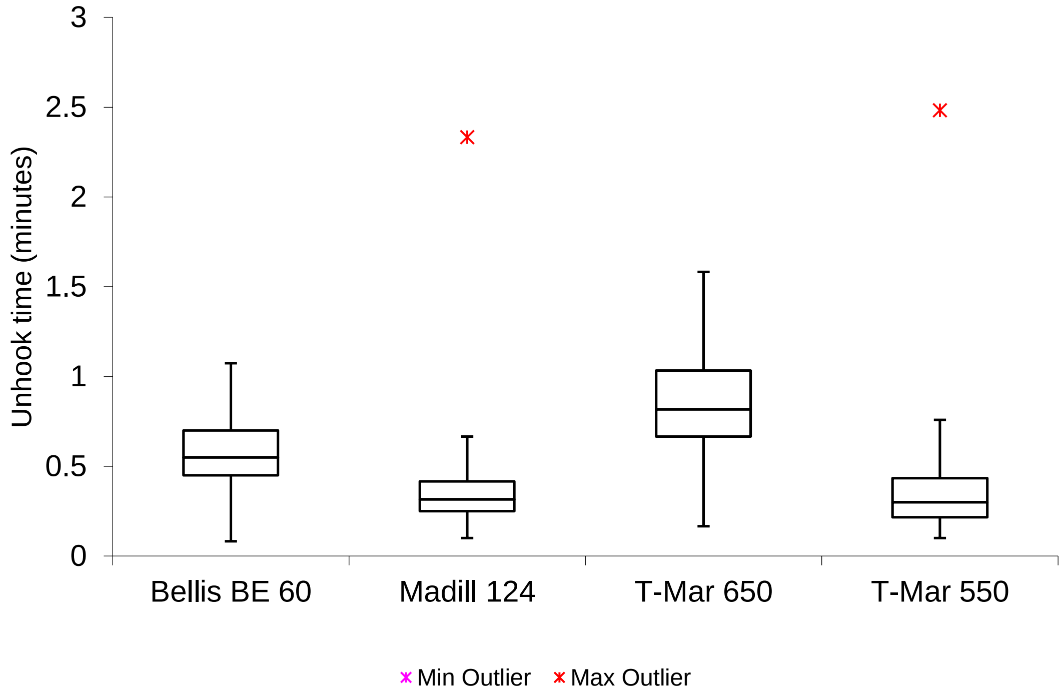


Figure 15: Median and range of unhook times for each machine.

Overall unhook time is a highly variable part of the yarder cycle, by reducing the number of long unhook times there is a real opportunity to improved overall productivity. This can be achieved through correct yarder placement and planning. By reducing the slew distance of the yarder or the improving the distance between the yarder and edge of landing these times can be reduced.

Productivity

Table 11: Productivity values for each machine studied.

Machine	Average productivity (t/PMH)	Average Distance (m)	10th Percentile (t/PMH)	90th Percentile (t/PMH)
Madill 124	52.7	277	26.7	88.8
Bellis 60	30.0	267	11.6	60.0
T-Mar 650	46.4	166	22.0	81.7
T-Mar 550	28.3	186	11.0	107.7

Following the data analysis the Madill 124 swing yarder achieved an average productivity of 52.7 t/PMH. With the difficult ground conditions this relatively high productivity is a representation of how effective the crew were as operators but also the large piece size (1.85 tonne per stem). The average haul distance of 279m is somewhat long for a swing yarder operation but shows these machines are still highly productive at that range. This machine also had the highest 10th percentile value indicating that 90% of the time this yarder was operating with a productivity over 26.7 t/PMH. This was closely followed by the T-Mar 650 and reflects the similar size of the machines as well as the similar stem layouts (combination of bunched, surge piled and mechanically felled). The main difference was the average distance varied by 100m between the Madill and T-Mar this makes the productivity of the Madill even more substantial.

A similar study carried out in 2011 on a Madill 124 indicated than for an average extraction distance of 280 (approximately the same as the Madill 124 observed in this study) the average productivity was 30 t/PMH for bunched stems and approximately 24 t/PMH for unbunched stems, (Acuna, Skinnell, Evanson, & Mitchell, 2011). Comparing the results of that study to these, the 2 larger swing yarders studied are performing at a more than satisfactory level.

The Bellis 60 and T-mar 550 again performed very similarly, the main difference being at the high production end of the scale. The T-Mar was able to produce some cycles that were in the order of 100 t/PMH as shown by the 90th percentile value in Table 11. This occurred when the extraction distance was approximately 100m, stems where grappled at the first attempt and the downhill yarding sped up the inhaul process, resulting in a fast cycle time and good payload. This is a snapshot of what can be achieved with this machine under favourable circumstances.

Coupled with higher levels of mechanisation (such as a mobile tail hold, pre-bunching and mechanised processing on the landing), the average daily production of swing yarders is higher than that of tower yarders in New Zealand (Visser, 2011). This analysis is evidence to support this claim and the increasing numbers of swing yarders operating in NZ forests is a further indication.

Additional regression was implemented to develop an estimation of machine productivity when all distance (m), piece size (t/stem) and stem layout were taken into account. Based on the information provided from the four short time studies, the regression analysis indicates that the Madill 124 and bellis BE 60 outperformed the two T-Mar yarders when all factors were considered equal. The most significant result of the analysis was the identification that with every 100m increase in extraction distance, average productivity decreased by approximately 13 t/PMH. This is an important outcome that may influence how blocks are planned in the future.

Learning

At the study site for the Bellis hauler in Southland, the ability to observe the yarder at two different settings was available. This provided a good chance to observe how differences in piece size effect output for the same system. Fortunately there were no dramatic changes between settings so a relatively fair comparison can be made between sites. The same system was used at both settings and Table 12 shows how dramatically productivity changed.

Table 12: Productivity differences between settings for the Bellis 60

Setting	Piece size (t/stem)	Average productivity (t/PMH)
1	0.46	16.9
2	1.25	51.7

This is important for contractors and managers when rate estimates are being calculated. It shows how significantly piece size will affect a crews output.

Observations & Comments

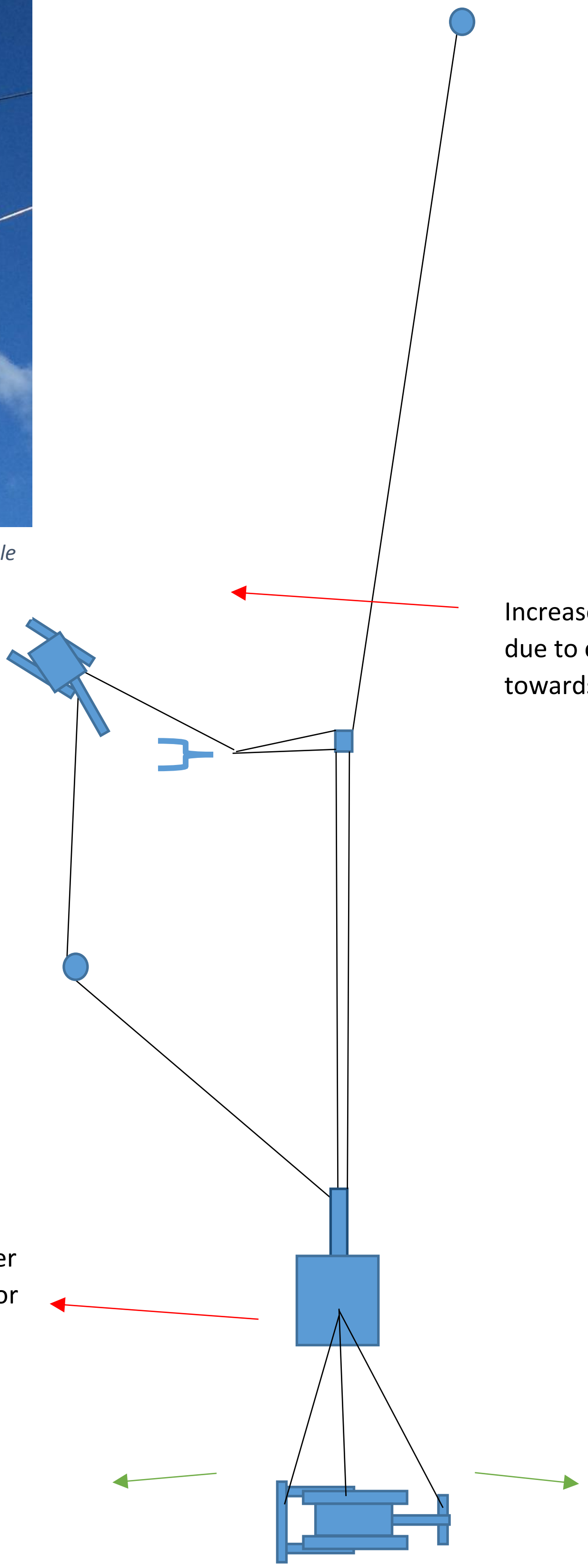
Based on the four completed studies, there is no overwhelming evidence to say that the new generation of T-Mar 'Log Champ' yarders are substantially more productive or faster than the older Madill swing yarder (note the Madill had been recently refurbished). Although some consideration must be made that new operators were only just learning the new machines and that site conditions may not have been perfect, which they seldom are. The Bellis was able to perform extremely well and reinforces that these machines still have a place in our forests especially when innovative system such as the block in the bight grapple are being implemented.

A notable benefit of the Block in the Bight grapple configuration observed was the fast change over times when converting the tail rope tail hold from stump to excavator (7.9 mins). This enables the excavator to convert to shovelling duties without a significant delay to yarder productivity. The main limitation of using the *HeliHawk* grapple is that it is very difficult to grapple logs directly from the ground, the lightweight nature of the grapple makes it problematic to efficiently get the tongs around stem(s) on the ground thus the need for an excavator to be feeding it directly.

These studies highlighted the importance of yarder placement on the landing: poor space in the chute and the steep angle caused logs to slip over the 20+ meter bluff and were difficult to recover, also required operator to slew 90+ degrees which takes excess time to lower ropes to ground and raise again with frequent delays associated with operating ropes getting stuck underneath stems in chute and/or bunched stems near mid-span.

Unsure if a swing yarder would be suitable to the block in the bight grapple configuration with a machine attached to the tail rope as stability may become a problem. There would need to be limits set on working distances from the skyline to ensure the risk of overturning the hauler is minimised due to the reduction in guy lines, and hence potential for increased stress on individual guys. The diagram below shows how this may happen. This may also be avoided if increased shovelling can be achieved or more skyline shifts to ensure the lateral strain on the skyline is minimised.

Figure 16: Close up of HeliHawk Grapple logging setup



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