Grapple Feeding: Case Studies in New Zealand

Angus Howden

Forest Engineering Honours Project 2023

Supervised by: Prof Rien Visser

NZ School of Forestry, Christchurch, New Zealand

University of Canterbury

Summary

This project aims to investigate the utilisation and productivity of an excavator-based shovelling machine feeding stems to a mechanical or motorised grapple carriage. Increased mechanisation is leading to decreased use of breaker-outs and choker systems, meaning that feeding the grapple is likely to become a popular harvesting/extraction method in the future. There is little published about this system in New Zealand (NZ). A time study and a survey were conducted to better understand the benefits of feeding stems to the grapple.

Time study data was recorded over nine days and four different harvesting crews operating across a range of slopes, extraction distances, piece size and cutover layouts/bunching levels. Average slopes ranged from 42-75%, while extraction distances ranged from 70-200 metres with averages of 126-175 metres. Average piece size varied from 0.5-3.5 tonne depending on the site. Some crews bunched the stems on the cutover for easy feeding of the grapple, while others would feed stems as they fell onto the cutover with no additional preparation.

Productivity was found by multiplying the number of stems per cycle by the average piece size for the site. Productivity ranged from 18-67t/SMH (36-232t/PMH), with an average of 44.3t/SMH (142.3t/PMH). For this study, the primary tasks were preparing to feed the grapple and feeding the grapple. Time spent doing other activities was labelled as a delay. This led to low utilisation figures as often the machine would be taken away from the primary task due to tailhold shifts, felling or shovelling for extended periods to bunch stems closer to the yarding corridor. Utilisations range from 26-50%, with an average of 35%.

A survey was also conducted with either the shovelling machine operator, crew boss or harvest planner around the benefits of feeding the grapple. This found that while breaker-outs and chokers had been considered as an effective extraction system, safety concerns had led to feeding the grapple being the preferred method. Limitations were the skyline or winch assist rope length for extraction distance, as well as average slope limits of 30 and 45 degrees depending on whether winch assist was used. The perceived limits were encountered when stems had to be shovelled for more than 50 metres to get to the yarding corridor. Feeding the grapple is especially beneficial for flat areas and back faces where access and deflection are an issue otherwise. Reduced road and landing construction was seen in some scenarios where back faces and flat areas could be shovelled and no new skids had to be built.

As mechanisation increases in the NZ forest industry, feeding the grapple looks to be an extraction method that aids productivity while keeping workers safe. This is especially relevant with the recent regulation changes, where smaller residues must be removed after harvesting in erosion prone areas.

Acknowledgements

This study would not have been possible without support from University of Canterbury and industry professionals. Firstly, thank you to Prof. Rien Visser for supervising this study and providing industry contacts. Secondly, thank you to Forest Growers Research for providing funding to assist in the completion of the study. Thank you to OneFortyOne (Matthew), Port Blakely (Barry), Gillion Logging (Tony), Nelson Marlborough Harvesting/Moutere Logging (Hayden), Barns Grapple Yarding (Eddie) and Cable Logging Geraldine (Glen) for engaging in the study. Lastly, thank you to Cassandra Hetherington and Patrick Humphrey for providing data from a previous time study.

Table of Contents

1. Introduction

Forestry is responsible for over $6.6 billion of New Zealand's (NZ) Gross Domestic Product (MPI, 2023), employing 40,000 people. Safety has become a focus, especially after 10 deaths in the industry in 2013. This has led to increasing mechanisation, one form of which has been winch assist. This has allowed machinery to work on steeper slopes in a safe manner (Visser & Stampfer, 2015).

Increasing mechanisation has meant that less workers are outside of a machine. Machines used in NZ forests must have a Falling Object Protection System and Rollover Protection System (FOPS and ROPS) to ensure operator safety. Increasing mechanisation has meant that some contractors are moving away from the traditional system used in NZ of breaker-outs and chokers. This system has been replaced by mechanised and motorised grapples as well as winch-assist felling to reduce the number of manual fallers.

Feeding the grapple is an extraction method that involves a mechanical or motorised grapple extracting stems which are passed to it by a machine on the cutover. This machine can be supported by winch assist depending on the slope encountered. The grapple then closes around the stem and extracts it to the landing. This system can be implemented in tower and swing yarder crews, with both being investigated. The stems can also be shovelled and bunched by the machine on the cutover.

Figure 1 shows a typical tower harvesting crew utilising feeding the grapple, with this diagram depicting the system used by Gillion Logging.

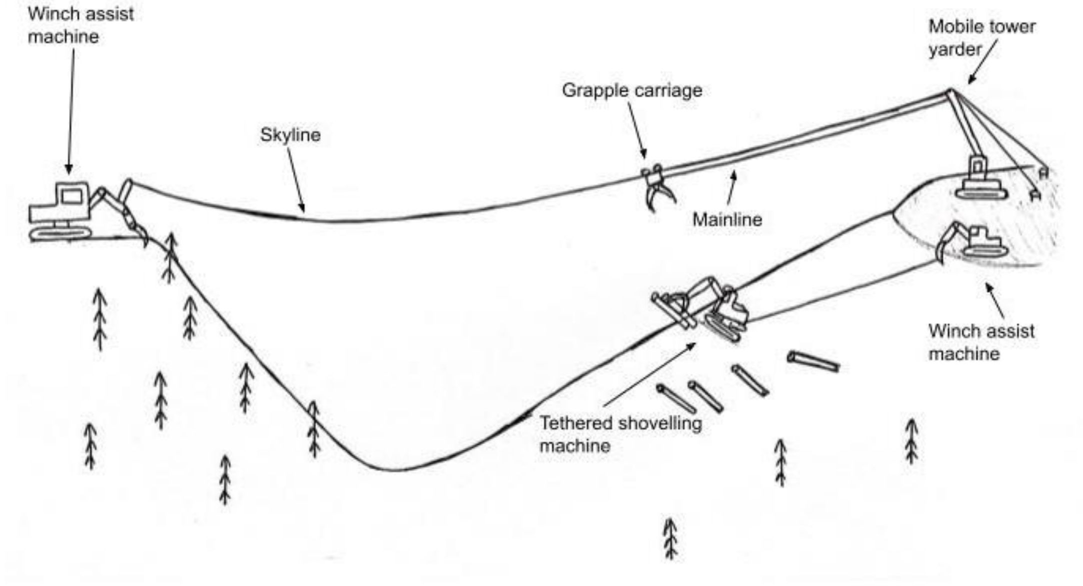

Figure 1: Typical grapple feeding system (Gillion Logging).

Winch assist is a method of supporting a machine to climb a steep slope via a winch system utilising wire rope. Winch assist is claimed to be capable of assisting a machine on up to 100% (45-degree) slopes (DC Equipment, 2023). This allows machines such as harvesters, skidders and forwarders to expand into areas that would otherwise be harvested via cable yarding systems. Winch assist also means that fewer forestry workers are outside and less protected when compared to being in a machine. This has led to increased safety in the forest industry. Winch assist is widely used across NZ for felling machines and more recently skidders (Pedofsky & Visser, 2019).

This study was originally planned to investigate winch assist forwarding, however, due to no suitable logging operations being available, grapple feeding has been investigated. The literature review has been left largely unchanged as most concepts in winch-assisted forwarding also apply to winch-assisted shovelling.

Most winch assist operations in New Zealand consist of an excavator-mounted winch unit, with one e.g., Falcon Forestry Equipment (FFE) or two e.g., Electrical and Mechanical Services (EMS) Tractionline wire ropes to a felling machine. There are more than 250 systems in New Zealand utilising winch assist technology (Visser & Leslie, 2021). The Best Practice Guide for Ground-Based Logging outlines that forwarders should not be operated on any slope over 30% unless specified by the manufacturer (SafeTree, 2005). This guide specifies that 'where the stability of the machine cannot be assured and slopes exceed those stated in the Code, specific hazard control measures shall be put into place.' This allows winch assist to be used as a type of hazard control measure. There is a best practice manual for winch-assisted harvesting (SafeTree, 2005).

A winch-assisted skidder operation in a Gisborne case study found the productivity of a winch assist skidder to be 51.4t/SMH, 65.35t/PMH. The t/SMH is lower due to an update being installed in the winch assist machine (Pedofsky & Visser, 2019). The production values are above the average grapple skidder production of 331m^3/day or 42.6t/PMH, assuming a seven-hour workday and wood density of 0.9t/m^3 (Harrill & Visser, 2019). A survey of the harvest planner, crew boss, and skidder operator was also conducted. This outlined the benefits that had been realised by using the skidder in terms of reduced road construction (720m), reduced skid sites (2), riparian area condition, and other savings such as reduced culvert construction. A soil survey was also conducted over 902 points to find the level of soil disturbance caused by the skidder. Soil disturbance will not be monitored in this study due to forwarders operating in cut-to-length (CTL) operations, thus debris is left on the trails the forwarder follows, reducing the impact of forwarder travel. Forwarders are used on defined trails, as opposed to skidders that often traverse the cutover (Visser, 2023). Skidders are used in whole tree extraction operations where the head of the tree(s) drags over the soil, disturbing the area. Another study investigated opportunities surrounding winch assist skidding (Visser & Spinelli, 2023). Parallels can be drawn between skidding and forwarding in this scenario as they are both extraction methods uncommonly used on winch assist machines. The study showed on a 40% slope a non-winch-assisted skidder was more productive due to the higher empty speed exhibited. On a 30% slope, the winch-assisted skidder was more productive by 8%. A similar productivity increase can be expected for winch-assisted forwarders; however, results will differ depending on the winch system as maximum line speed will vary between manufacturers. EcoForst advertises its T-Winch 10.2 with a maximum line speed of 4km/h (EcoForst, 2023). Their newest T-Winch 30.2 can go up to 8km/h (EcoForst, 2023), meaning this problem may be solved. As the study has been modified to investigate feeding the grapple, line speed is less important as the machine does not travel a significant distance during a cycle, unlike a forwarder.

The only NZ-based case study on winch assist forwarding was completed with Cox Forestry Services in 2021 (Visser & Leslie, 2021). This study found extraction distance, slope and unloading method (assisted with loader vs. unassisted) affected cycle time. The average productivity was 41.6m^3/PMH. Utilisation was 78% over a two-day period, which is greater than winch-assisted harvesting operations studied in (Leslie, 2019), at 52%. The John Deere 1910E was working on slopes averaging 46%, around 6% above the threshold where cable yarder systems are used. Only 16% of ground-based crews in NZ use forwarders (Harrill & Visser, 2019).

Many different anchor and winch systems have been used across winch-assist forwarder studies. Some studies have incorporated a HAAS winch system using 14mm rope on a small forwarder (John Deere 1210E, 13t payload) (Holzfeind, Kanzian, Stampfer, & Holzleitner, 2019). This system utilises a winch that is integral to the forwarder and was anchored to stumps, standing trees, excavators and deadman systems during the study. A larger T-Winch 10.2 using 20mm rope was used on a John Deere 1910E (21t payload) (Visser & Leslie, 2021). Due to forestry-specific winch assist machines being unavailable, a PistenBully snow grooming machine was used as a winch in one study, supporting a forwarder on slopes of up to 85% (Bombosch, Sohns, Nollan, & Kanzler, 2003). This is very steep compared to other studies, in which the maximum slope experienced has been around 80%. This was likely due to the nature of the study, which aimed to test the limits of a winch assist machine as opposed to producing the maximum volume possible. After communication with industry, it was found that most large winch assist machines (such as the FFE and EMS offerings) would be considered 'overkill' for a winch assist forwarder due to the large ropes (1 1/8" and two ¾" ropes respectively) (Hancock, 2023).

Studies such as (Visser & Leslie, 2021) and (Holzfeind, Stampfer, & Holzleitner, 2018) have found that slope affects forwarder production. (Bombosch, et al., 2003) displayed as low as 6.1m^3/h with a skidding distance of 200 metres. It was also mentioned productivity would be lower due to a lack of operator familiarity with such steep slopes in such a scenario, and as this was a testing environment, production was not the aim. (Dyson & Strimbu, 2017) mentioned the forwarder in their study 'didn't perform well' on slopes above 80%. At an average slope of 40% and an average extraction distance of 78m, productivity averaged 21.4m^3/PMH (15.6m^3/SMH). Utilisation was similar to (Visser & Leslie, 2021) at 73%. In another study investigating three forwarder operations, it was found that the unloaded speed going downhill was almost twice as fast as loaded uphill speed (Proto, et al., 2018). An Austrian study measured the rope tension and machine slope for two forwarders (Holzfeind, et al., 2019). The highest slope recorded was 80% during loading/driving during loading for a John Deere 1210E, while a Komatsu 840TX experienced an average slope of 49%. While it is uncommon for manufacturers to specify specific slope limits for their machinery, Komatsu specified 55%, which was exceeded twice during the study. The John Deere operated above the maximum recommended slope for the Haas winch system of 50% for almost 4 hours. This equated to around 30% of the survey time. A 14mm winch rope failed during this test due to non-synchronised movements of the operator and winch, highlighting the importance of a skilled operator and a winch assist system that is well integrated. This indicates a far larger rope is required for use with forwarders such as the John Deere 1910E used by Cox Forestry Services in (Visser & Leslie, 2021).

Extraction distance also affects forwarder productivity (Visser & Leslie, 2021). Average productivity at 250m was 55m^3/PMH, reducing to 35m^3/PMH at 1100 meters, showing a negative correlation between production and extraction distance. This was also found to be the case in (Proto, et al., 2018) which investigated three different operations, one small forwarder in a selective cut operation in Italy, and three large forwarders (two in the same operation) in clearcut operations in NZ. The trend continued in (Holzfeind, et al., 2018).

A large piece size has the potential to increase production (Holzfeind, et al., 2018). Finding piece size would also be beneficial for calculating production, as many other mentioned studies have found an average piece size for their operations (Raymond, 1988), (Cadei, Mologni, Roser, Cavalli, & Grigolato, 2020).

The average forwarder crew in NZ uses 4.1 machines (Harrill & Visser, 2019), while a typical cable yarder crew averages eight people (Harrill & Visser, 2018). Assuming a level of mechanisation, the following machines are likely to be found in a cable yarding operation, with the potential for a greater number:

- Yarder
- Processor
- Harvester
- Loader
- Winch assist machine
- Felling machine

The reduction in machine numbers will lead to a lower logging rate. A typical cable yarding system in NZ will cost $41.25/t, while a ground-based system is over $10/t less at $28.35/t (Visser, 2019). Adding a machine to shovel stems to the yarding corridor can add up to $2,000 to the daily cost of an operation, and when used with a winch assist machine, an additional cost of up to $1,600 per day (Forme, 2023).

The benefits to using a forwarder included reduced landings as there was no processing required on-landing, harvesting costs ‘may be lower’ than cable yarding, and only two pieces of equipment were needed in the study; a harvester-processor and a forwarder (Strimbu & Boswell, 2018). This is similar to the findings of (Pedofsky & Visser, 2019). Winch-assist skidding also saved 1.1km of road construction in a past study conducted in Canada (Strimbu & Boswell, 2018). Due to forwarders being practical for longer extraction distances than skidders because of their higher travel speeds and less environmental impact due to stems dragging on soil, it may be possible to save further roading costs.

The harvesting method and quality of the site layout were also found to affect productivity in a study conducted in Northern Italy (Cadei, et al., 2020). The location contained approximately 24 hectares of damaged wood on a 60 hectare site. Due to the damage, productivity would be lower as many pieces would have broken ends. The average slope was 33%, with productivity of 29.4m^3/PMH_{15} (PMH_{15} is productivity with system delays of under 15 minutes per hour). This was working in a piece size of $0.36m^3$/log, with an average of 434m travelled (217m extraction distance). The logs were well-grouped around the forwarder trail in this scenario, which aided productivity as there was decreased travel while loading. An increase in distance travelled while loading was found to increase cycle time and decrease productivity (Holzfeind, et al., 2018). Distance travelled while loading will not be measured in this study as this would further expand the scope of the time study and may require entering the cutover, which is a health and safety risk. Often forwarders operate in selective cut environments, such as in (Holzfeind, et al., 2018) where a forwarder operated in a stand with a piece size of $0.1m^3$ and a load volume of $9.25m^3$. The productivity was $13.7m^3/PSH_{15}$ (PSH_{15} is productivity with system delays of under 15 minutes per hour). This is very low compared to studies mentioned previously (Visser & Leslie, 2021) and is likely due to the low piece size and the fact the forwarder was not being used in a clear fell environment as it would likely be in New Zealand. Cox Forestry Services advertises that they have operated in both selective cut operations for production thinning, as well as clear-fell environments (Cox Forestry Services, 2023). Operating in a selective harvesting operation means the operator would have to navigate more complex trails while on the winch assist as some stems have been left standing. In a study on pre-bunching stems for extraction via grapple yarder, bunched stems led to 33% more stems being recovered per drag, increasing productivity by $23m^3$/PMH (Evanson & Amishev, 2009).

An increased forwarder payload resulted in increased productivity (Proto, et al., 2018). It was mentioned there were opportunities for operations in Italy to adopt increased mechanisation to improve productivity. While steeper terrain and increased extraction distance combat this aim, the increased mechanisation would lead to an increase overall. In one Australian-based study, it was found that operators would often overload the forwarder (Raymond, 1988). The rated payload of the large forwarder used in this study was 18 tonnes, while the study found that a 21.3 tonne payload would be carried. This allowed the forwarder to produce 51t/PMH in $0.62m^3$ piece size material. A smaller 9-tonne payload forwarder working on slopes of up to 35% produced 20t/PMH despite a small piece size of $0.08m^3$ (Raymond, 1988). Both were used on 150m haul distances.

Increasing mechanisation can lead to increased ground disturbance, especially on steep terrain as a machine must travel over more ground as opposed to when people are used (Harrill, Visser, & Raymond, 2019). Soil disturbance was investigated in (Pedofsky & Visser, 2019), with 11-17% subsoil exposed while using a winch assist skidder. Winch assist is meant to decrease ground disturbance by providing an additional force that helps the machine remain stable on the slope. Changes to the National Environmental Standard for Production Forestry (now Commercial Forestry) (NES-PF/NES-CF) now require residues longer than 2 metres with a large-end diameter of more than 10 centimetres to be removed after harvest in erosion prone areas (Parker & Henare, 2023), which has the potential to decrease production in these areas. Shovelling and feeding the grapple may be an option for these areas as these smaller residues can be bunched and fed to the grapple instead of extracting one-by-one.

This study will focus on a shovelling machine with the primary purpose of feeding the grapple, as relatively little is known about the productivity, advantages and limitations of such a system in the NZ forestry environment.

2. Objective

Investigate the utilisation of a shovelling machine being used to feed stems to a mechanical or motorised grapple via an elemental time study. This will also include a survey of the harvest planner, crew boss or shovelling machine operator regarding the advantages and disadvantages of shovelling systems and feeding the grapple.

3. Methodology

3.1. Elemental Time Study

A time study was conducted to determine the utilisation and production of the shovelling system by recording time spent completing certain tasks.

Table 2 outlines the method undertaken for the time study. This is similar to that of (Deans, 2013), however, some parts have been modified to reflect the variable nature of shovelling machine tasks and give a broader overview of a winch-assisted shovelling system.

Table 1: Time Study Definitions

	Description
Shovelling	Any travel or time spent with the primary purpose of shovelling stems within the yarding corridor to feed the grapple. Does not include time spent shovelling stems to the yarding corridor. *Starts when machine grabs the first stem to shovel. Stops when machine releases final stem to be shovelled.*
Feeding	Any time spent feeding stems into a grapple carriage. *Starts when first movement to feed the carriage is seen, stops when machine releases stems for final time once carriage is returning.*
Felling	Any travel or time spent with the primary purpose of felling. *Starts when machine grabs the first standing tree to fell. Stops when machine releases final felled stem.*
Travel/Transition	Any time spent travelling while between tasks, for example transitioning from felling to shovelling and returning to the ridge for breaks.
Other	When the shovelling machine is completing another productive task that is not defined as any of the above, e.g., shovelling to the yarding corridor.
Delay	Any operational, mechanical, personal/social, or other delays.

3.1.1. Delay Breakdown

Delay times were recorded whenever the machine was not working. Delays will be categorised into four groups: operational, mechanical, personal/social, and other. Even small delays were recorded as, if this delay is cyclical, it may accumulate into a significant amount of time at the completion of a workday.

Operational: When the machine is delayed by another part of the operation, such as the winch assist machine moving (if applicable) or communicating with the other parties in a manner which stops the shovelling machine from working.

Mechanical: When the machine requires repair or maintenance. This only applies to the shovelling machine. Examples include greasing the machine and replacing hoses or other wear items.

Personal/Social: When the machine is not working due to food/rest breaks, or personal communication.

Other: When the delay cannot be placed into any other category. Reasons for the delay will be noted if clear.

Utilisation will be calculated by dividing the time spent 'Shovelling' and 'Feeding' by the total time recorded in the study. This assumes the machine's primary task is feeding the grapple.

3.1.2. Non-time Variables

Non-time variables that were recorded are as follows:

- Extraction distance
- Slope
- Piece size

Extraction distance was found using a rangefinder, which was also used to find the average slope for the setting. Average piece size was found by consulting with the processor operator. Productivity was then found by capturing the number of stems moved every cycle and then multiplying this value by the average piece size.

3.2. Survey

To gather more information about the benefits of winch-assist shovelling, the harvest planner, crew boss, or shovelling machine operator were asked a series of questions. This will complement the literature that has been reviewed on the topic and get the opinions of end users. The survey questions have been based on that conducted in Pedofsky & Visser (2019), who conducted a similar survery on the benefits of winch assisted skidders. The following questions were asked through appropriate communication channels.

- When do you decide to shovel and feed the grapple?
- When do you reach the system's operating limit with or without winch assist?
- What is your maximum extraction distance? Why are you limited to this distance?
- Has there been reduced road construction or maintenance when utilising the shovelling system? If so, how much?
- Do you see a reduced impact on the environment when using the winch-assist machine (if used)? In what way(s)?
- Is there a significant fuel saving when the shovelling machine is attached to the winch (if used)?
- Have you found other benefits when using a shovelling machine attached to a winch-assist machine (if used)? If so, what are they?
- Do the benefits outweigh the operating costs of the winch assist machine (if used)?
- Have you considered other extraction methods? If so, what are they and why was shovelling used?

4. Results and Discussion

4.1. Gillion Logging

The study took place in Herbert Forest in a second rotation Radiata pine stand with an average piece size of 0.5 tonnes. The study was undertaken over three days. The setting was steep with an approximately 30-degree dominant slope under the skyline. It is situated in a high erosion susceptibility class (ESC) zone with the fish spawning Waianakarua River at the bottom of the face. The skid site layout is shown in Figure 2.

Figure 2: Skid site in Herbert Forest.

In the operation, stems were felled mechanically. A winch-assisted live skyline runs from a Madill 171 tower yarder on the skid to a Doosan DX300LC excavator with a Waka Engineering winch to raise and lower the skyline. The yarder operator controls this with a joystick. A modified ACME motorised grapple carriage was used in a shotgun configuration. Stems were prepped and fed to the grapple by a Tigercat 855 self-levelling machine on the cutover. This machine was tethered to a Waka Engineering winch machine on a Hyundai excavator base which sits on the skid. The system was shown previously in Figure 1. To get adequate deflection, the distance between yarder and tailhold was approximately

950m, however, the maximum extraction distance was only 250m. Figure 3 shows the view of the harvest area from the tailhold.

Figure 3: View of harvest area from tailhold location.

The average cycle time over the three day study was 3 minutes 16 seconds. This was broken down into components (Figure 4). The extraction distance increased as the machine moved down the slope. During the study the number of stems extracted per drag changed from two on day 1 to three on days 2 and 3. The shovelling machine was also used for felling on part of the third day.

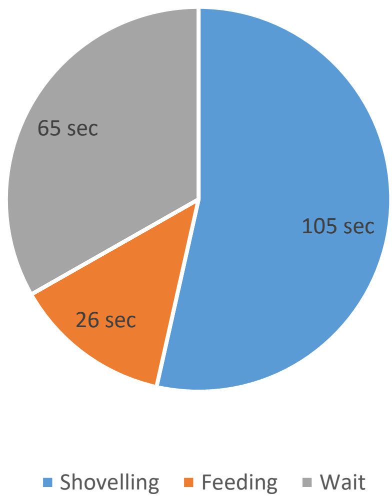

Figure 4: Breakdown of average cycle times by task.

The extraction distance increased with increasing cycle number as the machine moved down the slope (Figure 5). There is a clear increase in cycle time with distance as given by cycle number. This increase is less than expected due to the processor being less of a bottleneck in the system when it had more time between drags as extraction distance increased to process. As a result of this, the system was more balanced and there was an increase in instances where the shovelling machine did not have to wait for the carriage to return. Cycle times throughout the study are shown in Figure 5. This does not include the data from day three as the machine moved up the slope and began felling as well as sporadically feeding the grapple, leading to highly variable cycle times.

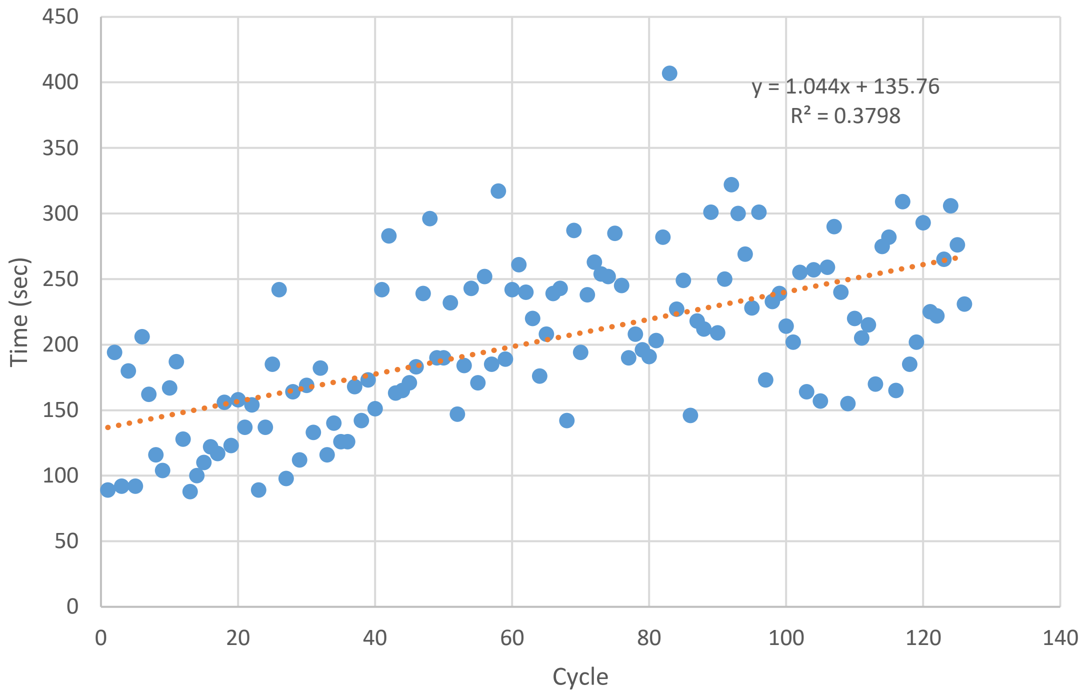

Figure 5: Cycle time with increasing extraction distance.

The utilisation of the machine shovelling was 50%. This was found by dividing the time spent shovelling and feeding during the study by the total time recorded in the study. There were four operational delays resulting from machine movements to clear the yarder chute or required routine maintenance of the processor. A chute is the area where the stems are placed before being moved by another machine, often the processor. These ranged in time from 3 to 8.5 minutes. 2.5 stems were shovelled per cycle on average across the three days, leading to a productivity of 18.0 t/SMH (Scheduled Machine Hour) or 36.4 t/PMH (Productive Machine Hour).

The majority of the wait time was a result of the processor having not finished processing when the carriage returned with a new drag, which caused the carriage to wait. This would then delay the shovelling machine. This was more of an issue at shorter extraction distances. Figures 6-8 show a breakdown of cycle time by task for each day. During the large peak where the machine was shovelling for 8 minutes on day two, the yarder would continue to extract stems that had been laid out along the corridor. Day three saw the machine move closer to the landing and begin felling some of the stand, where it would sometimes transition from felling to feeding the grapple, hence the lower cycle times.

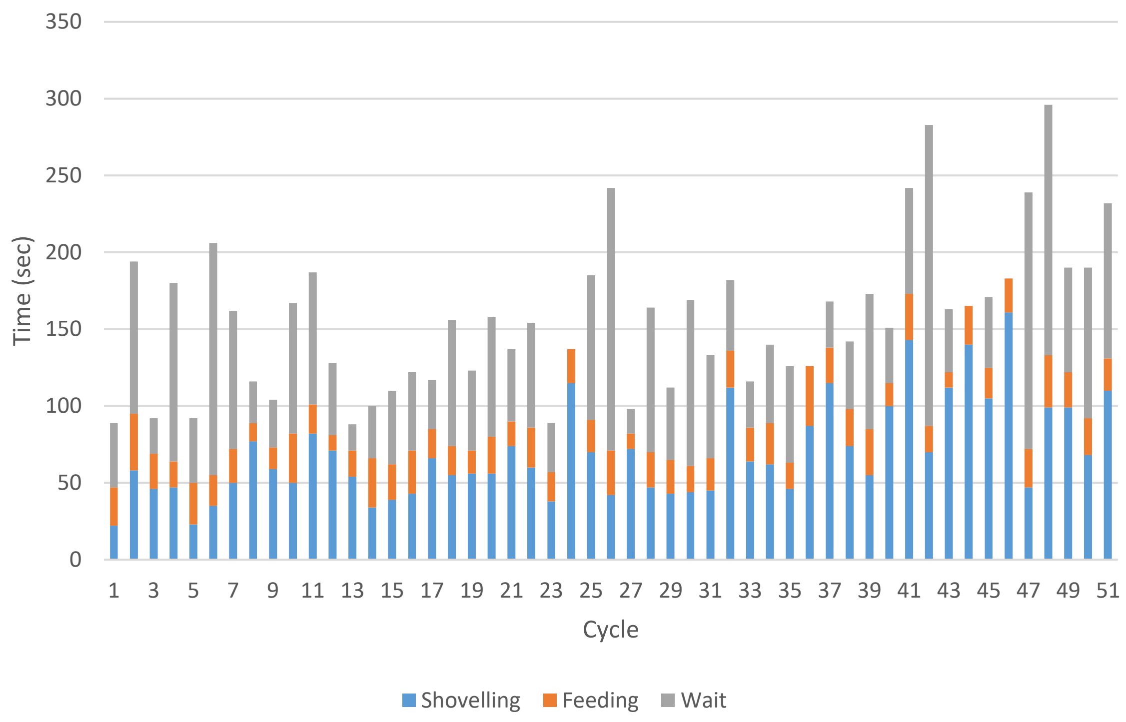

Figure 6: Breakdown of cycle times by task (Day 1).

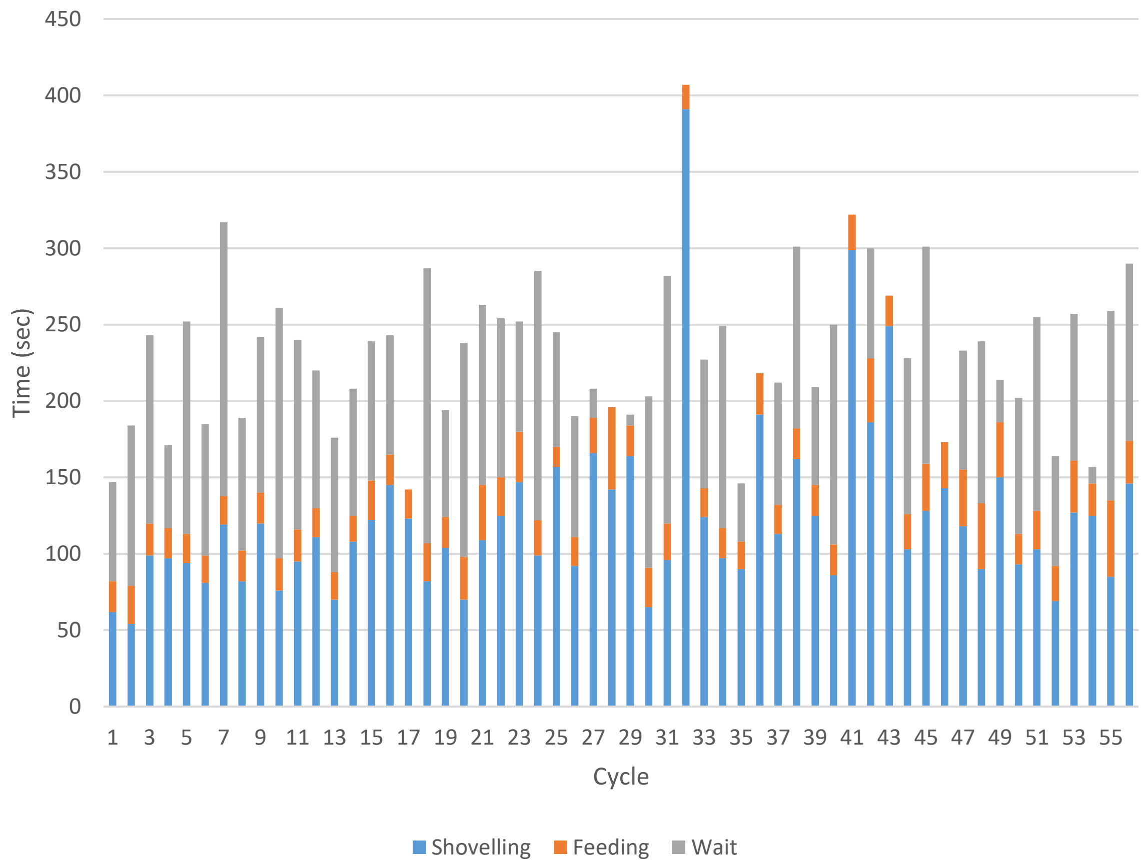

Figure 7: Breakdown of cycle times by task (Day 2).

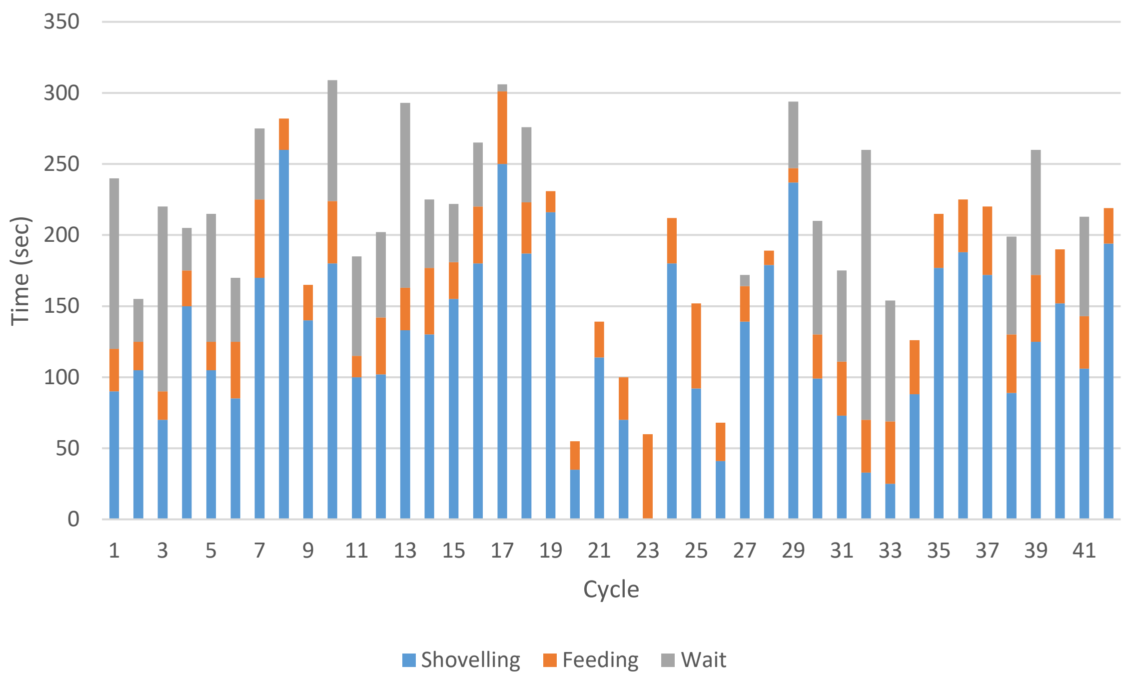

Figure 8: Breakdown of cycle times by task (Day 3).

Preparation times were the most significant driver in the increase in cycle time with extraction distance. There was a clear increase in preparation time between day one, where two stems per drag were extracted, and day two, where three stems per drag were extracted. This increased preparation time is a result of having an additional stem to prepare to present to the grapple. Additionally, the distance the shovelling machine had to move the stems before feeding them to the grapple increased further down the slope. The large variation in cycle time shown on day three was due to the machine feeding the grapple at multiple different extraction distances on the slope as well as some areas being felled then immediately fed to the grapple.

Feeding time increased throughout the study. This could be due to an increased number of stems being fed to the grapple per cycle, as shown in Figure 9.

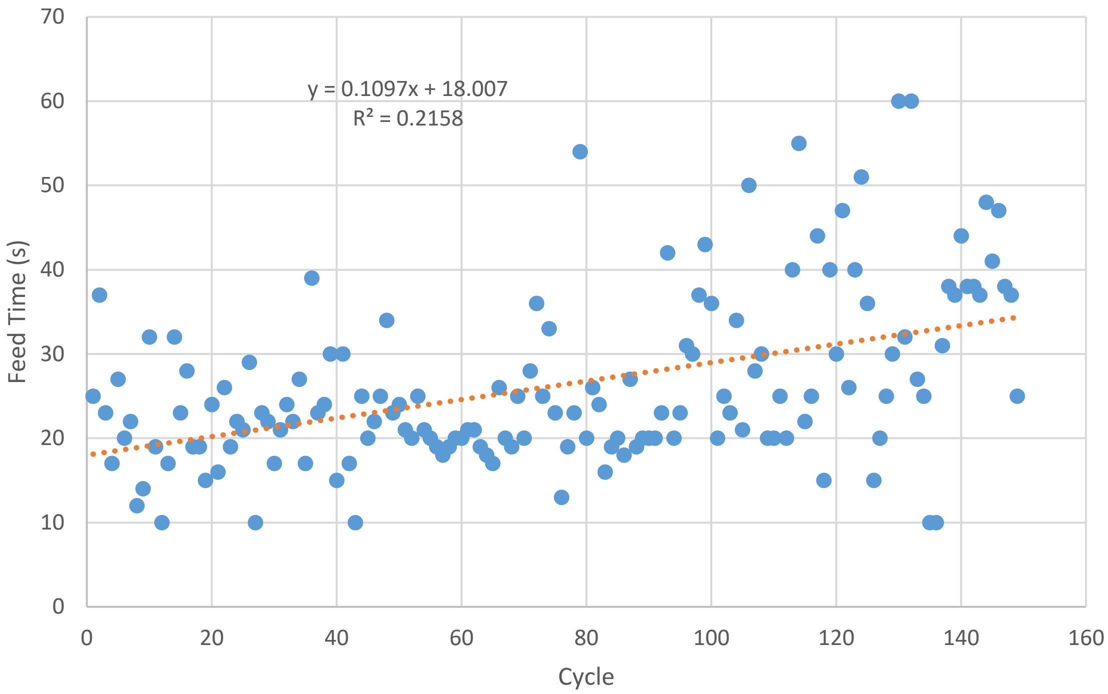

Figure 9: Feeding time with an increasing number of stems being fed to the grapple.

Improvements that could be made to the system to increase productivity include using an additional machine to clear the yarder chute at shorter extraction distances. The chute needs to be cleared to ensure the yarder operator can place the next load of stems easily, which can reduce yarder cycle time and increase productivity.

The operational delays due to routine maintenance on the processor are unavoidable. The effect that these delays have on the shovelling machine could decrease if an additional machine was employed to clear the chute and stems could be stored in a safe location until the processor was ready to resume operating. The addition of another machine is impractical for most operations due to cost. The consequence of this would be a potential backlog of stems on the skid however these could be processed during any downtime such as tailhold shifts or yarder repair and maintenance.

4.2. Nelson Marlborough Harvesting

This study took place in Pigeon Valley South in a third rotation Radiata Pine forest with an average piece size of 1.3 tonnes. The setting was variable in slope, with the average being 23 degrees (42%). It is situated in a low ESC zone. The operation was harvesting at the end of a ridge, with the yarder located on a pad and an excavator feeding stems to the grapple as shown in Figure 10.

Figure 10: Swing yarder and shovelling machine.

In the operation, stems were felled mechanically. The skyline runs from a Madill 124 swing yarder on the skid to a Caterpillar excavator with a T-bar that was used as a tailhold. A mechanical grapple was used in a running skyline configuration typical of swing yarders. Stems were prepped and fed to the grapple by a Hitachi ZX290 on the cutover. This machine was not attached to a winch assist machine due to the slopes being less than 30 degrees. Once the stems were extracted to the pad, a skidder was used to remove stems from the pad to a skid further up the ridge to be processed. The processor boom can be seen beneath the grapple in Figure 10 above.

The study was undertaken over two days. At each tailhold shift, the shovelling machine would work its way down the slope towards the stream while feeding the grapple. The shovelling machine was also used to tidy the cutover and remove any residues near the streambed. Stumps were also moved by the shovelling machine to tidy the cutover and make yarding easier, as the less steep areas would be prone to snagging due to lack of deflection.

The average cycle time over the two days of the study was 1 minute 45 seconds. This was broken down into components (Figure 11). Note that these cycle times exclude delays and other activities unrelated to the process of feeding the grapple. Cycle times with are shown in Figure 12.

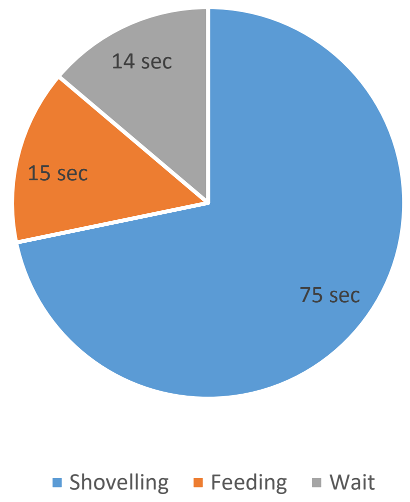

Figure 11: Breakdown of average cycle times by task.

The extraction distance was variable over the two days but decreased as the machine moved up the slope towards the end of the setting. There is a clear decrease in cycle time with distance as given by cycle number as shown in Figure 12. Figure 13 shows the shortest extraction distance that the grapple was being fed at 90 metres. The wait times have increased with decreasing extraction distance; however, the cycle time has decreased as there is less time spent shovelling per cycle. This is likely because the stems are laid out in an organised manner compared to the areas further down the slope where trees are lying over one another.

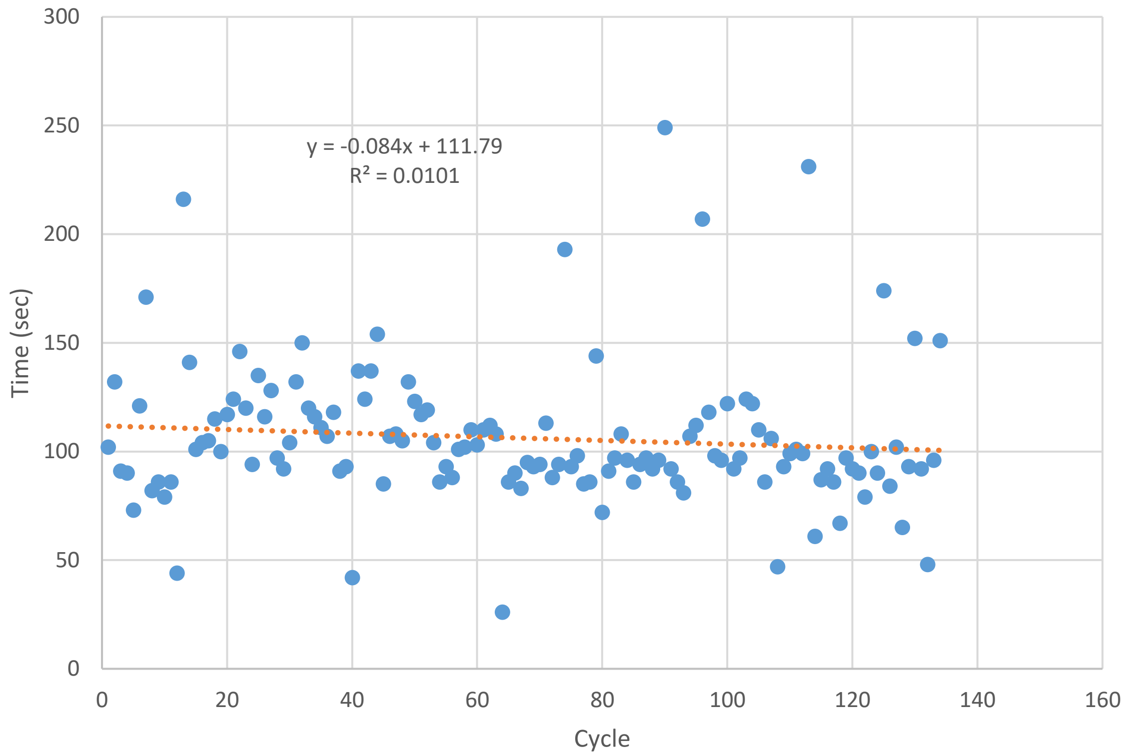

Figure 12: Cycle times with decreasing extraction distance given by cycle number.

Figure 13: Shortest extraction distance (90 metres).

The utilisation of the machine shovelling was 36% when considering all delays and activities unrelated to shovelling and feeding the grapple. There were four operational delays due to tailhold shifts, and another due to the grapple opening line breaking. The tailhold shifts ranged in time from 8.3 to 16.1 minutes, while repairing the opening line took 37.5 minutes. The average number of stems per shovelling cycle was 2.0, leading to a production value of 37.8t/SMH or 104t/PMH.

Most of the wait time was a result of the excavator on the pad not clearing the area fast enough for the next drag to be placed which caused the carriage to wait and a flow-on effect to the shovelling machine. This was more of an issue at shorter extraction distances, as for some of this time, the machine clearing the pad had to load trucks on the skid due to the other loader being unserviceable. Figures 14 and 15 show the breakdown of cycle times by task for each day.

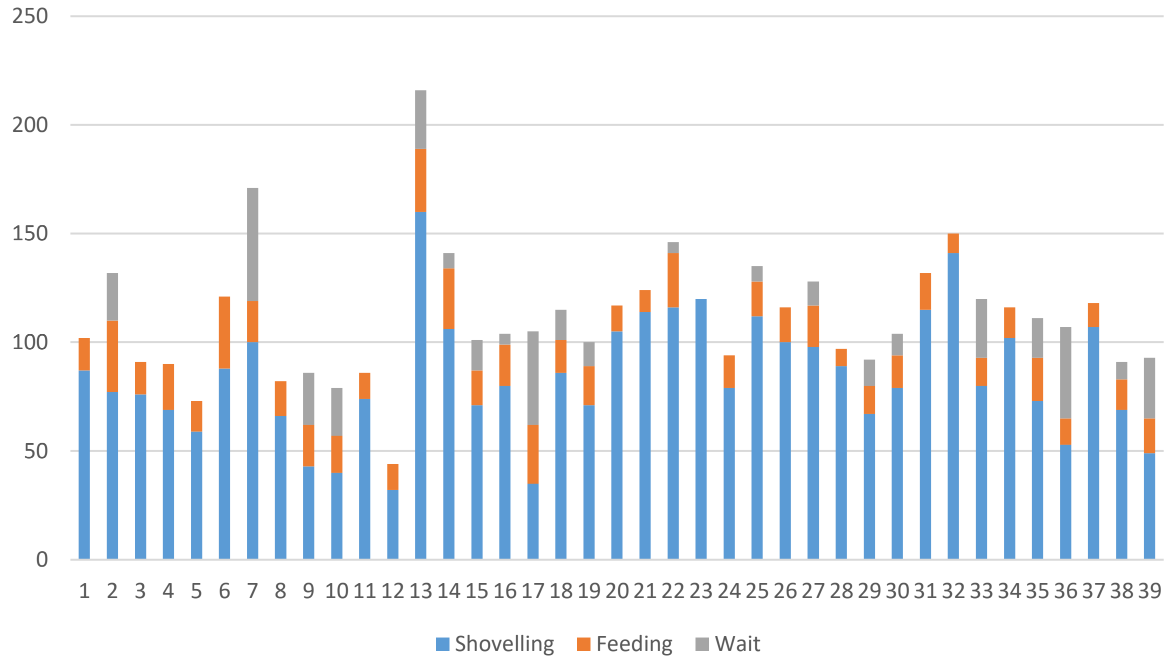

Figure 14: Breakdown of cycle times by task (Day 1).

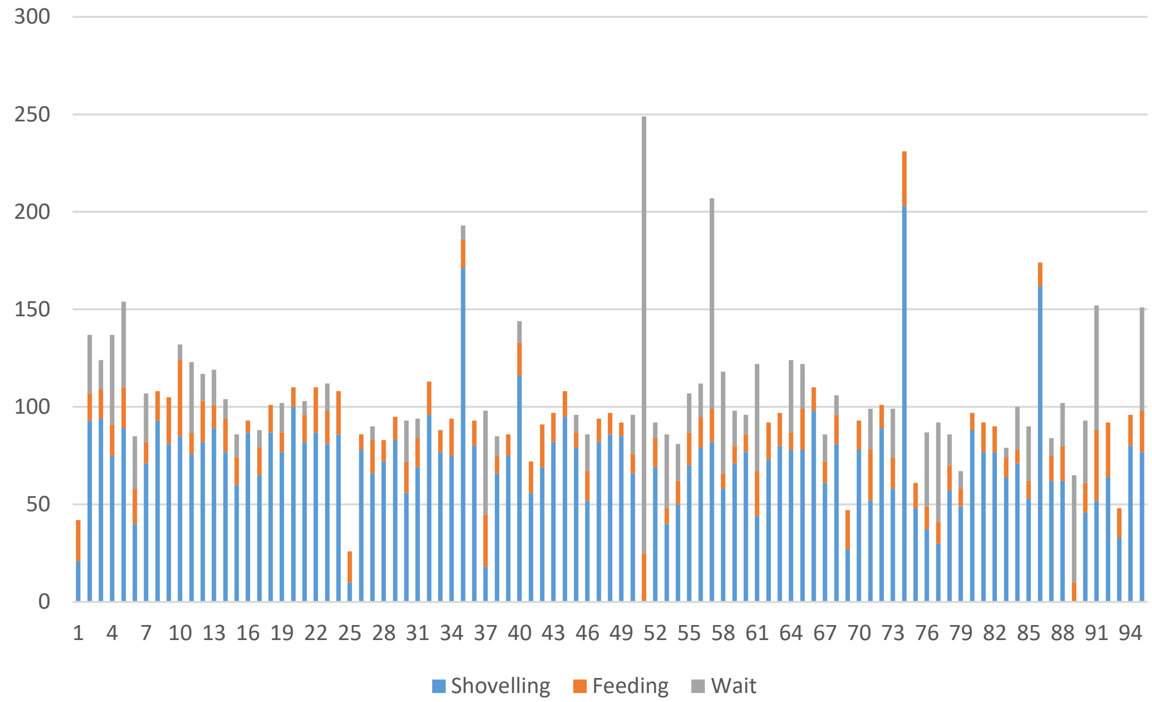

Figure 15: Breakdown of cycle times by task (Day 2).

4.3. Barns Grapple Yarding

This study took place in Golden Downs Forest in third rotation Radiata Pine with an average piece size of 1.99 tonnes. The setting was variable in slope, with the average being 24 degrees (45%). It is situated in a moderate ESC zone. The operation was harvesting from a ridge, with the yarder located on the skid. Eddie is in the shovelling machine feeding stems to the grapple, shown in Figure 16.

Figure 16: Shovelling machine and tailhold.

In the operation, stems were felled mechanically. The skyline runs from a Madill 124 swing yarder on the skid to an excavator with a T-bar that is used as a tailhold. A mechanical grapple was used in a running skyline configuration typical of swing yarders. Stems were prepped and fed to the grapple by a Sumitomo SH240 with a live heel incorporated into the grapple. The live heel was not used while the study was conducted. This machine was not attached to a winch assist machine due to slopes being under 30 degrees. Once the stems were extracted to the skid, the stems were processed and stored to be loaded on to trucks. Figure 17 shows the yarder/landing location from the time study vantage point.

Figure 17: Yarder/landing location.

The study was undertaken over a single day. This means that the data on items such as utilisation gathered in this section should not be considered reliable due to delays taking up a larger portion of the time spent gathering data when compared to the Gillion or NMH sections of the study. The extraction distance in this study was less variable than Gillion and NMH as the shovelling machine would shovel stems to a set pile before feeding the grapple. At each tailhold shift, the shovelling machine would work its way across the slope to extract more stems from areas the skyline was otherwise unable to reach due to lack of deflection or no stable tailhold area. The shovelling machine was also used to tidy the cutover as in previous crews.

The average cycle time for the study was 2 minutes 23 seconds. This was broken down into components (Figure 18). Note that these cycle times exclude delays and other activities unrelated to the process of feeding the grapple.

Figure 19 shows the cycle time with increasing extraction distance. The extraction distance remained relatively constant throughout the day, with the machine moving towards the tailhold, covering around 30 metres while feeding the grapple. Due to the variable extraction distance, there was no clear trend for cycle time with distance in this study. While the cycle time decreased as the study progressed as in Figure 19, this is likely because stems were bunched near the corridor as the machine worked its way toward the tailhold, meaning less time was spent shovelling the stems to the corridor.

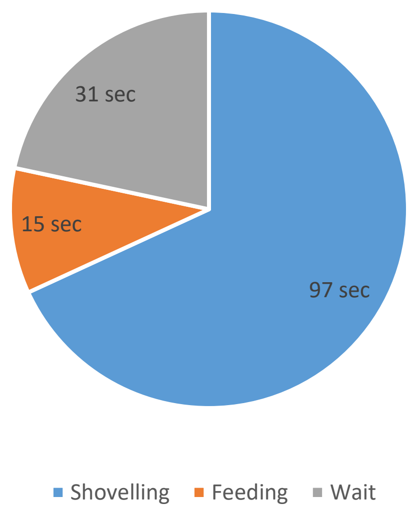

Figure 18: Average cycle times by task.

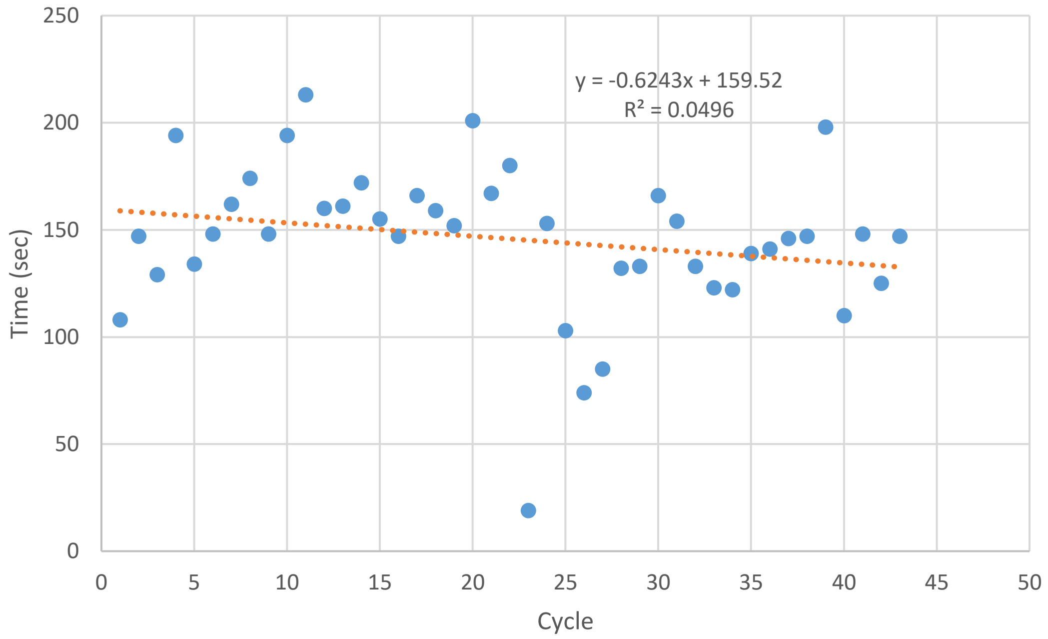

Figure 19: Cycle time with increasing extraction distance given by cycle number.

The utilisation of the machine shovelling was 26% when considering all delays and activities unrelated to feeding the grapple. This is low due to the 1 hour and 45 minutes the machine spent clearing the cutover compared to the entire study period of 5 hours and 10 minutes. There was one operational delay due to a tailhold shift and one mechanical delay due to a blown hose on the grapple of the shovelling machine. The tailhold shift took 23.4 minutes, while the blown hose took 32.8 minutes to repair. 2.1 stems were shovelled per cycle on average throughout the study, leading to productivity of 35.0t/SMH or 132.7t/PMH.

Most of the delay stemmed from incomplete processing when the carriage returned with a new load, causing a subsequent wait for the shovelling machine. This problem was particularly pronounced at shorter extraction distances. Conversely, at longer distances, the carriage's return time increased, resulting in extended wait times. Figure 20 shows a breakdown of each cycle time by task.

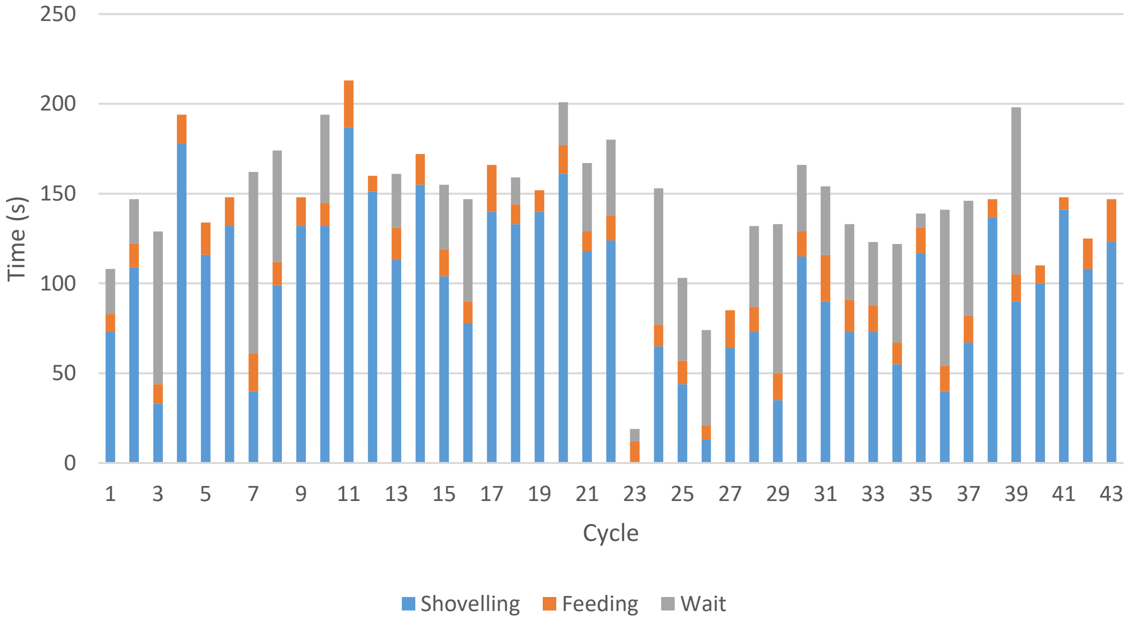

Figure 20: Breakdown of cycle times by task.

4.4. Cable Logging Geraldine

This study took place in Geraldine Forest in first rotation Radiata Pine forest with an average piece size of 3.5 tonnes. The setting was variable in slope, with the average being 27 degrees (51%). It is situated in a low ESC zone. The operation was harvesting from an area part of the way down a face, with the yarder located on a pad below the skid to gain deflection and an excavator feeding stems to the processor on the skid above as in Figure 21.

Figure 21: Yarder and processor layout.

The skyline runs from a Madill 171 tower to a tail spar on the slope below. A motorised grapple carriage (Falcon 1750) was used in a shotgun configuration. Stems were prepped and fed to the grapple by a Tigercat LS855E with a dangle-type felling head as in Figure 22. This machine was attached to a Waka Engineering winch assist machine on a Sumitomo SH300 base. Once the stems were extracted to the skid, they were processed and stored to be loaded as in Figure 23.

Figure 22: Tigercat LS855E feeding a stem to the Falcon 1750, with tail spar in the background.

Figure 23: Landing layout.

The study was undertaken over three days. The extraction distance varied from 80 to 172 metres, with up to 50 metres of shovelling distance before feeding the grapple. This shovelling distance is larger than crews such as NMH due to the use of the tail spar, which requires far more effort to conduct line shifts than a bulldozer/excavator. When moving to another tail spar, the skyline was pulled down the slope by the shovelling machine and was then attached to a strawline and pulled through a pulley block on the new spar. The shovelling machine was also used to tidy the cutover by bunching heads to be extracted.

The average cycle time over the two days of the study was 2 minutes and 2 seconds. This was broken down into components (Figure 24). Note that these cycle times exclude delays and other activities unrelated to the process of feeding the grapple.

Figure 25 shows the cycle time with increasing extraction distance. The extraction distance increased as the machine worked down the slope towards the tail spar. There is a clear increase in cycle time with distance, as given by cycle number. In this study, the shovelling machine would not return to the skid for breaks and would continue shovelling stems to the corridor for part of this time, meaning that the corridor was well laid out and the whole operation was more efficient when feeding the grapple. The peak of high cycle times on day three was due to stems having to be shovelled from 30 metres away. The low cycle times early in day three were due to stems being shovelled to the lines and the grapple only being fed sporadically.

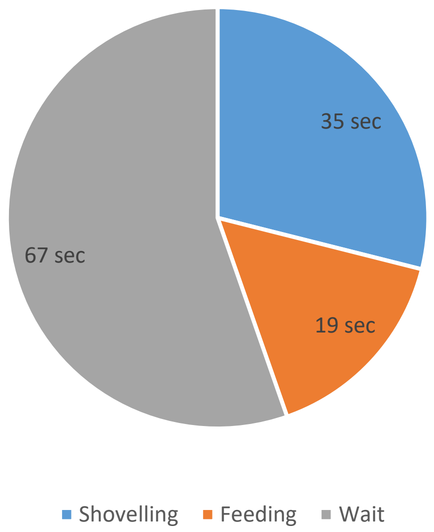

Figure 24: Breakdown of average cycle time by task.

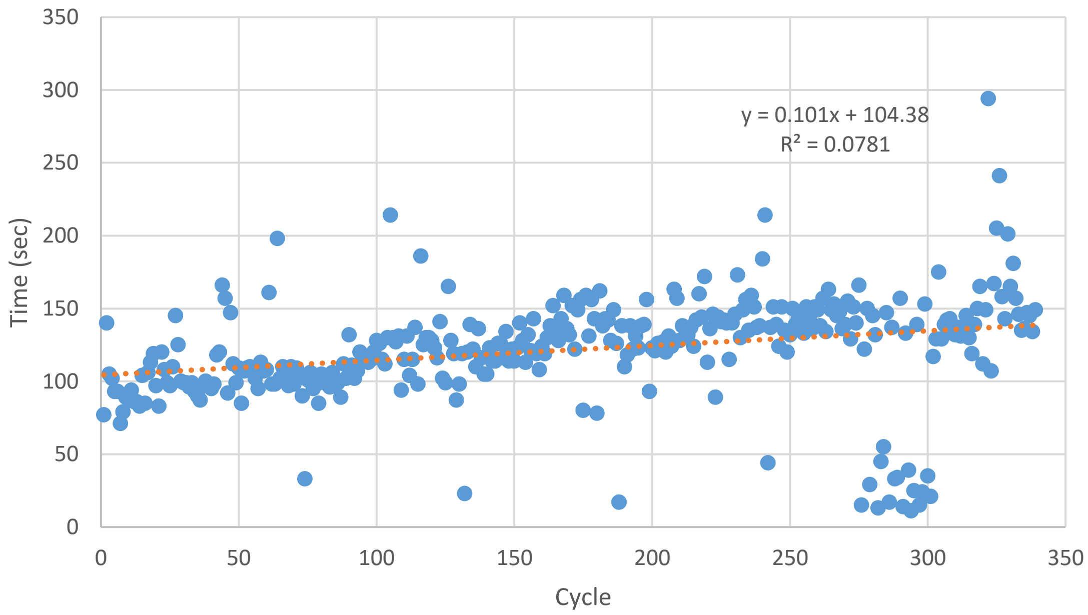

Figure 25: Cycle time with increasing extraction distance.

The utilisation of the machine shovelling was 29% when considering all delays and activities unrelated to feeding the grapple. On average, 1 stem was moved per cycle over the three days. This number is less than other crews because some cycles were extracting heads, which are only 15% of the total tree volume, and due to the large piece size, only one tree could be extracted by the yarder. This leads to a productivity value of 67t/SMH or 232t/PMH. This is higher than other crews as most stems had been shovelled into neat rows on either side of the corridor before feeding the grapple took place, making the process more efficient. To ensure that new area was still being felled, the shovelling/felling machine operator would often work Saturdays to keep up with the rest of the crew.

The majority of the wait time was a result of the chute not being cleared, causing the carriage to wait. As the yarder was on a small pad, the excavator must have control over the stems before the carriage can return, leading to longer turnaround times. These longer times caused a flow-on effect to the shovelling machine. This was more of an issue at shorter extraction distances, while at longer distances, the time taken for the carriage to return increased, leading to increased wait time. Figures 26-28 show a breakdown of cycle times by task.

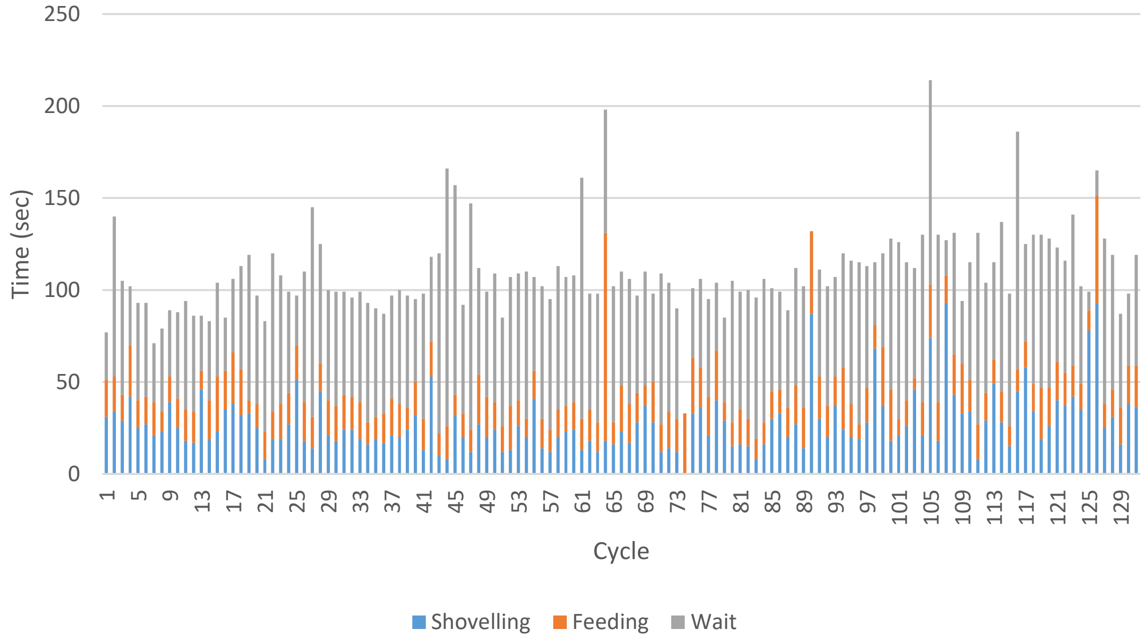

Figure 26: Breakdown of cycle time by task (Day 1).

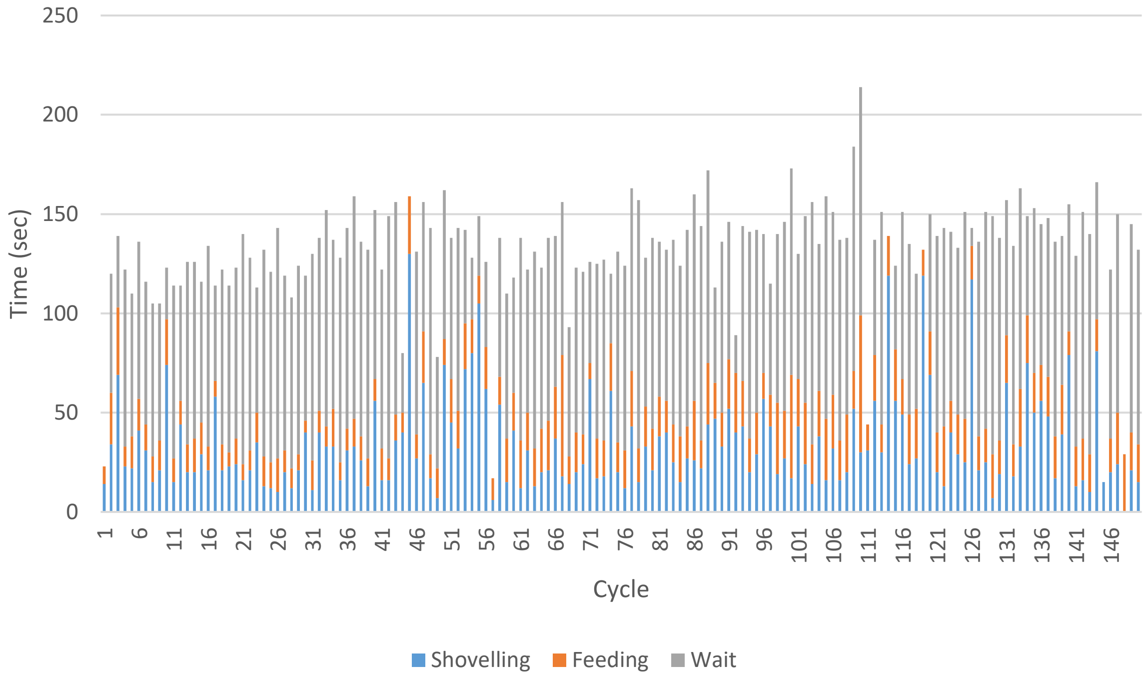

Figure 27: Breakdown of cycle time by task (Day 2).

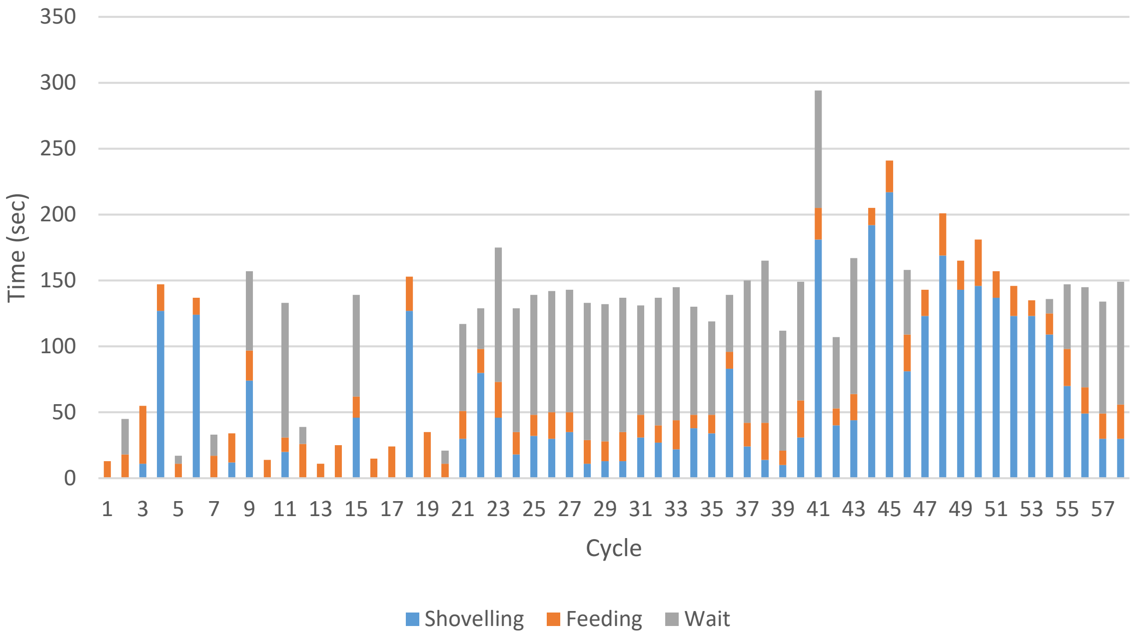

Figure 28: Breakdown of cycle time by task (Day 3).

4.5. Survey of Feeding the Grapple

The survey laid out in the methodology section was presented to all four crews. A full list of responses can be found in the appendix. The respondents were as follows:

- The foreman and shovelling machine operator of Gillion Logging.
- The foreman and shovelling machine operator of Nelson Marlborough Harvesting (NMH).
- The shovelling machine operator of Barns Grapple Yarding (BGY). Other crew members also helped in answering questions.
- One of the foremen and shovelling machine operator of Cable Logging Geraldine (CLG).

There were varying opinions on when to feed the grapple. Most crews fed the grapple in the following situations: on back faces, over/on ridges or lips, and in flat areas where deflection and/or access would have otherwise been an issue. When extraction distances were under 100 metres and a yarder was not already set up, shovelling stems to the landing with the shovelling machine was also an option. This shovelling-only system was limited by winch assist line speed. This shovelling-only system is not commonly used in NZ. CLG fed the grapple wherever possible, while BGY invested in a fixed felling head which they hope will achieve better bunching and less breakage than the original dangle head. This would allow them to feed the grapple less as fewer heads are left in the cutover. Back faces and areas with low deflection will still be extracted by feeding the grapple. NMH mentioned that feeding the grapple on a front face could be a concern at times as the stem could slip and hit the shovelling machine if it got dropped or slipped out of the grapple while being extracted.

All crews mentioned that the limitations of the system were the average slope limits of 30 degrees when unassisted and 45 degrees when using winch assist. Most crews would use winch-assist on lower slopes, especially in wet conditions, to increase their speed and make the operator's task easier.

The maximum extraction distance of the system was limited by the skyline length of the cable yarder, which for most was 600 metres. If winch-assist was used, this then governed the maximum distance as most winch-assist systems have 450-500 metres of rope. These distances are not desirable for any crew as the increased cycle time and general complications at this distance lead to low productivity.

Reduced road and landing construction can be seen in some scenarios, as a yarder operation can pull from back faces and flatter areas instead of front-face areas only, if using a shotgun system. In first rotation areas such as Geraldine Forest, roading and landing costs can be saved as the system allows timber to be extracted from areas that may have otherwise needed an additional skid or pad.

The reduction in environmental impact when feeding the grapple could be seen by all crews. This is due to heads and other debris being bunched and extracted while still being productive. The system was still productive as these smaller items could be bunched and fed to the grapple, which otherwise would have to be extracted in smaller bunches by the yarder operator, decreasing production. This has led to better environmental outcomes and saved costs as crews have not been called back to an area to tidy the cutover. If winch assist is used, the environmental impact further decreases as there is less ground disturbance, meaning less chance of erosion and sedimentation.

Fuel used by the shovelling machine decreased when using winch-assist, however, when considering the addition of the winch-assist machine, fuel burn was perceived to increase.

Other benefits of feeding the grapple and using winch-assist were crew members preferring not using breaker-outs, and everyone being in a machine, meaning it was safer. The winch assist machine has been used on slopes as low as 20 degrees (35%) by some crews when ground conditions are wet, due to the increased stability and travel speed.

All crews found the benefits of feeding the grapple outweighed the cost of the system. BGY would like to reduce the amount of feeding the grapple by bunching and using a fixed felling head, however, they will still feed the grapple when needed. This system works well for crews that produce over 300 tonnes per day as the cost can then be spread over a greater production. Some anecdotal evidence suggests that feeding the grapple can increase production by 100 tonnes per day when used as stems can be bunched and brought to the yarding corridor, leading to an increased number of stems extracted per yarder cycle. Some crews mentioned that it made their logging operation possible as they could access steep slopes and areas that would otherwise require breaker-outs when using winch assist.

All crews considered breaker-outs and chokers as an alternative extraction method, however, due to safety concerns, all decided against this system. CLG has used breaker-outs for four hours in the past three years as feeding the grapple could be done on the rest of the terrain they encounter. Other benefits of not using breaker-outs were that the crew was smaller, so staffing problems were minimised.

5. Conclusion

This project aimed to gain an understanding of logging contractors in NZ who utilise a shovelling machine to feed a mechanical or motorised grapple carriage to extract timber. A time study was conducted for nine days across four harvesting crews. It was found that utilisation averaged 35%, while production averaged 44.3t/SMH and 142.3t/PMH.

A survey was also conducted, with findings strongly indicating that while all crews considered using breaker-outs and chokers, safety and staffing concerns led to the use of a machine feeding the grapple. This aligns with the increasing mechanisation seen in NZ harvesting crews. The crews also liked that having the machine on the cutover enabled heads and harvest residues to be extracted while remaining productive. This is especially important now with changes to the NES-CF. The extraction of those items led to a tidier cutover and lower environmental impact. There was also anecdotal evidence that utilising a machine to feed the grapple could gain the crew 100 tonnes of production per day. The only limitations of the system were the slope of the terrain and the maximum extraction distance of the yarder or winch assist machine.

The system could be implemented in a variety of ways depending on the terrain and machinery available to a crew. Some crews were using their self-levelling felling machine to feed stems to the grapple while attached to a winch assist machine, others were not using winch assist and using a 24-tonne excavator with a grapple. Though an entirely separate system consisting of a winch assist machine and an excavator-based shovelling machine is an ideal solution, the additional cost would be over $3,000/day. The benefit to this system is it can be utilised with existing machinery when implemented correctly, minimising cost to the contractor. While this system adds cost, its use will continue as the NZ forest industry becomes increasingly mechanised and systems such as breaker-outs and chokers become less common.

References

Bombosch, F., Sohns, D., Nollan, R., & Kanzler, H. (2003). Are forest operations on steep terrain (average of 70% slope inclination) with wheel mounted forwarders without slippage possible? *Austro2003: High Tech Forest Operations for Mountainous Terrain*.

Cadei, A., Mologni, O., Roser, D., Cavalli, R., & Grigolato, S. (2020). Forwarder Productivity in Salvage Logging Operations in Difficult Terrain. *Forests*.

Cox Forestry Services. (2023). *Contact - Cox Forestry Services.* Retrieved from Cox Forestry Services: https://static1.squarespace.com/static/540d27bee4b0bb88c083ab2a/t/588a9cf6197aea204296260d/1485479190881/Cox+Forestry+Company+Profile_digital.pdf

DC Equipment. (2023). *Falcon Winch Assist*. Retrieved from Falcon Forestry Equipment: https://www.falconforestryequipment.com/products/falcon-winch-assist

Deans, M. (2013). *Shovel logging within New Zealand: time and motion study (SOF Final Year Dissertation, University of Canterbury).* Retrieved from Forest Engineering NZ: https://forestengineering.org/wp-content/uploads/2020/11/2013-ShovelYardingDeans.pdf

Donald, K., Boswell, B., Amishev, D., & Hunt, J. (2018). *Winch Assist Fowarder: Best Practice Manual.* Montreal: FP Innovations.

Dyson, P., & Strimbu, V. (2017). *Assessments of a Winch-Assisted John Deere Harvester and Forwarder.* FP Innovations, Canada.

EcoForst. (2023). *T-Winch 10.2*. Retrieved from EcoForst: https://www.ecoforst.at/t-winch-2/t-winch-10-2/#technical%20data

EcoForst. (2023). *T-Winch 30.2*. Retrieved from EcoForst: https://www.ecoforst.at/t-winch-2/t-winch-30-2/

Evanson, T., & Amishev, D. (2009). *A New Method for Bunching Treeson Steep Terrain* . Rotorua: Future Forests Research.

Forme. (2023). *Informe Harvesting 2023.* Forme Consulting, Tawa, Wellington, NZ.

Hancock, C. (2023). Email communications, Owner, EMS, Rotorua. (Howden, A; Visser, R).

Harrill, H., & Visser, R. (2018). *Survey of Yarders and Rigging Configurations: 2018.* Forest Growers Research, HTN 10-04.

Harrill, H., & Visser, R. (2019). *A Survey of Ground-based Harvesting Systems in New Zealand.* Forest Growers Research, HTN 12-04.

Harrill, H., Visser, R., & Raymond, K. (2019). New Zealand Cable Logging 2008–2018: a Period of Change. *Current Forestry Reports, Volume 5, Issue 3*, 1-10.

Holzfeind, T., Kanzian, C., Stampfer, K., & Holzleitner, F. (2019). Assessing Cable Tensile Forces and Machine Tilt of Winch-Assisted Forwarders on Steep Terrain under Real Working Conditions. *Croatian Journal of Forest Engineering*.

Holzfeind, T., Stampfer, K., & Holzleitner, F. (2018). Productivity, setup time and costs of a winch-assisted forwarder. *Journal of Forest Research*, pp. 196-203.

Leslie, C. (2019). *Productivity and Utilisation of Winch-Assist Harvesting Systems: Case Studies in New Zealand and Canada.* Christchurch: University of Canterbury.

MPI. (2023). *Forestry and Wood Processing Data*. Retrieved from Ministry for Primary Industries: https://www.mpi.govt.nz/forestry/forest-industry-and-workforce/forestry-wood-processing-data/#:~:text=Forestry%20contributes%3A,Zealand's%20GDP%20(Gross%20Domestic%20Product)

Parker, D., & Henare, P. (2023). *Updated forestry regulations increase council controls and require large slash removal*. Retrieved from Beehive.govt.nz: https://www.beehive.govt.nz/release/updated-forestry-regulations-increase-council-controls-and-require-large-slash-removal

Pedofsky, M., & Visser, R. (2019). *Assessment of Winch-Assist Skidder Case Study in Gisborne, New Zealand.* Christchurch: University of Canterbury.

Proto, A., Macri, G., Visser, R., Harrill, H., Russo, D., & Zimbalatti, G. (2018, January 30). Factors affecting forwarder productivity. *European Journal of Forest Research*.

Raymond, K. (1988). *Forwarder Operations in Australia.* Logging Industry Research Association (LIRA).

SafeTree. (2005). *Best Practice Guidelines for Ground-based Logging.* Retrieved from SafeTree: https://safetree.nz/wp-content/uploads/2022/08/Ground-Based-Logging.pdf

Strimbu, V., & Boswell, B. (2018). *Adverse Skidding Using a Tigercat 635E Assisted by a T-Winch 10.1.* FP Innovations.

Visser, R. (2019). *A Decade of Benchmarking Harvesting Cost and Productivity.* Forest Growers Research.

Visser, R. (2023, May 18). Personal communication. Prof, SOF, University of Canterbury. (A. Howden, Interviewer)

Visser, R., & Leslie, C. (2021). *Productivity of a winch-assist forwarder and processor: A case study in the Hawkes Bay Region.* Christchurch: University of Canterbury.

Visser, R., & Spinelli, R. (2023, February 3). Benefits and Limitations of Winch-Assist Technology for Skidding Operations. *Forests*.

Visser, R., & Stampfer, K. (2015). Expanding Ground-based Harvesting onto Steep Terrain: A Review. *Croatian Journal of Forest Engineering*, pp. 321-331.

Appendix

Survey Responses

Respondents:

- Tony, the foreman and shovelling machine operator of Gillion Logging.
- Hayden, the foreman and shovelling machine operator of Nelson Marlborough Harvesting (NMH).
- Eddie, shovelling machine operator of Barns Grapple Yarding (BGY). Other crew members also helped in answering questions.
- Glen, one of the foremen and shovelling machine operator of Cable Logging Geraldine (CLG).

For each question, the following answers were given:

- When do you decide to shovel and feed the grapple?
    - Areas where deflection cannot be gained when using a cable yarder – over lips, in corners of a block for example. Anywhere where it is not worth it to set up the cable yarder, pure shovelling can be done.
    - Feed flat areas, along ridges and back faces. Feeding on front faces can be dangerous if stems slip out of the grapple or break and fall towards the shovelling machine.
    - BGY have invested in a fixed felling head so higher quality bunching can be achieved and less shovelling/feeding the grapple is required in the future. Back faces and otherwise inaccessible areas will still be done via feeding the grapple.
    - CLG feed the grapple wherever possible.
- When do you reach the system's operating limit with or without winch assist?
    - At anything over 45 degrees average slope when using winch assist.
    - At anything over 30 degrees, we must use winch assist, the upper limit with a winch is 45 degrees.
    - 30 degrees average slope without winch assist.
    - We use winch assist wherever practical, even on lower slopes it reduces travel time and effort. Limits are 45 degrees average slope while using winch assist.
- What is your maximum extraction distance? Why are you limited to this distance?
    - When feeding the grapple on winch assist, 450 metres is the maximum amount of rope on the winch assist machine drum. While purely shovelling only 100 metres, if a faster winch assist line speed could be attained then this distance could increase.

- 600 metres on the Madill 124, however, we would not do that due to lack of productivity and general complications. If winch assist was used, 500 metres would be the limit due to winch assist rope limits.
- 600 metres of skyline on the Madill 124, however as with NMH, BGY would not go that far due to lack of productivity and general complications.
- The limiting factor would be the 600-metre skyline on the Madill 171.

- Has there been reduced trucking road construction/maintenance when utilising the shovelling system? If so, how much?
  - Not for this block.
  - Yes definitely, means fewer skids or pads as a yarder operation can pull from back faces and flatter areas instead of front-face areas only.
  - A lot of the area in Geraldine Forest is first rotation, meaning input can be given and roading/landing costs can be saved in the initial building.
- Do you see a reduced impact on the environment when using the shovelling machine and winch-assist machine (if used)? In what way(s)?
  - Yes, we see reduced slip and less ground disturbance. Due to the slope, we must use winch assist either way.
  - Yes, it leaves a far tidier cutover (than using the grapple carriage only) as any broken heads can be extracted efficiently and gullies or streambeds cleaned out.
  - Yes, it leaves a tidier cutover.
  - Yes, it leaves a tidier cutover, our environmental assessors are very happy, it also means we don't get told to move machines back into an area to clean up which is good.
- Is there a significant fuel saving when the shovelling machine is attached to the winch (if used)?
  - Yes, when only considering the shovelling machine, when considering both it is around the same.
  - Slight increase when considering both the shovelling machine and the winch assist machine.
- Have you found other benefits when using a shovelling machine attached to a winch-assist machine (if used)? If so, what are they?
  - The crew are happier as they don't have to use breaker outs, everyone is in a machine, and it is far safer. The winch assist machine is very helpful, we often use it on 20-

degree (35%) slopes when wet as the movement speed is far greater than the shovelling machine alone can do.

- Do the benefits outweigh the operating costs of the shovelling machine and winch assist machine (if used)?
    - Yes absolutely, it makes our logging operation possible. (Winch assist used)
    - Yes, especially if pulling 300t+/day. We would not use this machine if we were producing under 300t/day, the cost would not outweigh the benefits at that point. We have found the shovelling machine can allow us to produce 100t/day more than otherwise. (No winch assist)
    - Yes, however, the fixed felling head aims to reduce the use of the shovelling machine. (No winch assist)
    - Yes, the winch assist and shovelling machine have changed the game.
- Have you considered other extraction methods? If so, what are they and why was shovelling used?
    - Breaker-outs and chokers were considered, but due to safety concerns, the motorised grapple and shovelling machine was used.
    - Breaker-outs and chokers were considered, but due to safety it just isn't practical. It also means NMH does not have staff issues as the crew members are happy and committed, as well as being a smaller group.
    - As with the previous two crews, breaker-outs were considered but not used due to safety concerns.
    - Breaker-outs have been considered, but with the shovelling machine, everywhere is accessible in the terrain we work in. Breaker-outs have been used for four hours in the last three years.