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Assessment of Winch-Assist Skidder in Gisborne, New Zealand

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EXECUTIVE SUMMARY

Winch-assist systems are commonly used to expand ground-based operations onto steeper terrain. Skidders tethered to winch-assist machines are becoming popular in New Zealand as a method of extraction, however little is known about the productivity and soil disturbance effects from this system. The aim of this research was to improve the industry's knowledge of winch-assisted skidder systems. An investigation was carried out in Emerald Forest, about 30km south-west of Gisborne, of an operation using a Falcon Winch Assist machine and a six-wheeled Tigercat 635G grapple skidder over a period of three days. Objectives were to determine the productivity of the winch-assisted skidder operation, to carry out a soil disturbance assessment on the slopes, and to evaluate the benefits of utilising this system.

Productivity was assessed by measuring 121 skidder cycles over two different skidder paths using standard time study methods. The skidder paths followed the same main trail from the landing for 150m before diverging down different sides of a ridge. Bunches were extracted from different distances along the paths. Skidder Path 1 had a maximum slope of 33 degrees (65%) and was 300m long. Skidder Path 2 had a maximum slope of 30 degrees (58%) and was 315m long.

As expected, as the extraction distance increased, the cycle time of the skidder increased and productivity decreased. The average skidder productivity over the study period was 65.0 cubic metres per productive machine hour (m^3/PMH). The average productivity per scheduled machine hour (SMH) was 48.7 m^3/SMH. Machine utilisation was 75%. This was largely attributed to a significant mechanical delay which stopped the skidder from working for half of the second day of the study.

The soil disturbance assessment was carried out post-harvest using a line transect method collecting 902 data points over three different sites. The assessment combined the effect on site of the winch-assist skidder, the tracked felling machine and the shovel logger. The three sites resulted in deep disturbance across 17%, 11% and 10% of the sites measured, where deep disturbance was defined as exposure of subsoil. Shallow disturbance, defined as mixing of litter and topsoil, occurred in 27%, 20% and 21% of the three sites respectively.

In this particular setting, the use of the winch-assisted skidder contributed to saving the construction of 720m of road, a large culvert crossing and two skid sites that were originally planned. A forest area of 19.3 hectares which was planned to be harvested by cable yarder was scheduled for this winch-assisted skidder system, with significant savings in logging cost.

Other benefits of using this system included increasing the utilisation of the winch machine by tethering both the felling machine and skidder. By enabling more days logging due to the ability to work in poor weather conditions, overall system productivity was improved. The ability to extract stems away from waterways resulted in the riparian strips being left intact, reducing the impact of harvesting on the waterways. It was evident that maintaining a mix of extraction distances throughout the day was necessary to ensure that the processor on the landing had adequate buffer stock and was not waiting for wood throughout the day.

INTRODUCTION

It is necessary for the New Zealand forest industry to increase the number of steep slope harvesting operations in order to access plantation forests planted on steep and difficult terrain (Visser, Raymond and Harrill, 2015). This requires extending the operating limits of ground-based machinery (such as feller bunchers). Removing, minimising or mitigating the risks to operators and machinery is essential. Extending ground-based machinery onto steep slopes also requires consideration of the environmental impact risks, to ensure the industry maintains its social licence to operate (Raymond, 2015).

Mechanisation of tree felling (using feller bunchers) and breaking out (using grapples instead of choker-setters) has placed workers in machines removing them from the most dangerous parts of harvesting operations. Technological advancements are allowing ground-based operations to expand onto steeper slopes and become safer (Visser & Stampfer, 2015). Terms such as winch-assist, traction-assist, cable-assist and tethering all refer to winch-based cable technology that supports a machine to climb a steep slope safely (Cavalli & Amishev, 2017). These machines provide assistance to the machine's traction through a wire rope which is attached from the winch machine to a machine working down a slope. The winch is designed to give the tethered machine greater climbing ability and stability. This increase in traction allows machines to safely descend and climb steeper terrain and improves track or wheel slip in poor soil conditions, such as weak or saturated soils, or soils with high clay content. However, manufacturers of winch-assisted technology emphasise that the operator's safety should not be reliant on the winch (Koszman, 2018; Cavalli & Amishev, 2017).

While many studies have been conducted on winch-assist productivity with felling machines (Evanson *et al.* 2013, Chase *et al.* 2019, Leslie *et al.* 2019), there is limited information available on winch-assisted skidders being used. Grapple skidders are the most common form of ground-based stem extraction, being the lowest cost method of extraction from forests on easy country, and hence are a good candidate system to be extended on to steeper terrain using winch-assist (Figure 1).

Figure 1: Tigercat 635G skidder hauling logs to landing with traction assistance.

LITERATURE REVIEW

Recent literature shows that winch-assist operations have resulted in improved terrain access, increased the slope limit for ground-based operations, have lower impact on soil disturbance (when used correctly), have reduced the amount of roading necessary, and overall have higher productivity and lower cost than cable yarding systems (Visser & Stampfer, 2015; Chase *et al.* 2019; Holzfeind *et al.*, 2020).

Expanding ground-based operations onto steeper terrain increases the risk not only of loss of traction, affecting the ability of a machine to move up and down the slope, but also of machine rollover (Visser & Stampfer, 2015). Loss of traction occurs when the force pulling the machine down due to gravity is greater than that of the traction force. The benefit of a cable-assist system is to increase this traction force therefore increasing the slope limit on which a machine is able to operate. Expanding terrain access for ground-based machinery allows forests which were previously thought to be uneconomical to harvest, to become a viable operation through winch-assist extraction (Cavalli & Amishev, 2017).

Establishing slope limits for ground-based operations has proven difficult. A study by Berkett and Visser (2012) showed that harvesting machinery working on slopes commonly exceeded the recommended maximum slopes of 30% for wheeled machines and 40% for tracked machines that were in place at the time. Since then the Approved Code of Practice for Safety and Health in Forest Operations (ACOP) in New Zealand has removed slope limits stating that mobile plant shall not be operated on slopes that exceed the maximums in accordance with the manufacturer's specifications (ACOP, 2012). Few manufacturers actually specify operating limits for purpose-built machinery. The ACOP also states that when the stability of a mobile plant is compromised by slope, weather or ground conditions then a specific hazard management plan shall be developed, implemented and monitored. This places the responsibility on the operators to measuring slope gradient. At this site, the forest manager, Forest Enterprises Ltd, provided LiDAR slope maps and Speirs Logging Ltd staff monitored slope and assessed risk once daily at minimum.

It has been found that winch-assisted systems reduce the amount of soil disturbance (Holzfeind *et al.* 2020). In a report by Thompson & Hunt (2016) it was discussed how conventional ground-based systems on steep terrain involve more turning and repositioning of tracks to achieve better stability for operating, whereas a winch-assisted machine can move straight up and down the hill and still maintain contact with the ground, thus disturbing less soil area. Koszman (2018) and Cavalli & Amishev (2017) also indicated that the amount of soil disturbance may be decreased by the added traction assist creating less site damage such as rutting or compaction. Iarocci (2017) observed an operation in Chile where a Tigercat 635E skidder, tethered to an Ecoforst T-Winch with a load of approximately eight tonnes operating at a grade of 40-45%, showed little to no ground disturbance from wheel spin. This concept proves especially valuable when operations are required in areas with more sensitive soils or environmental constraints. In Europe the main use of winch-assisted systems is to reduce soil disturbance and allow operations in more sensitive environments (Thompson & Hunt, 2016; Holzfeind *et al.* 2020).

In an ongoing study by Oregon State University, investigating the effects of winch-assisted operations on reducing soil disturbance, it has been discovered that nutrient delivery to tree roots has been improved due to the mixing up of soil layers as machines moved across the soil (Green *et al.*, 2019). The study also revealed that the topsoil segment was able to better absorb moisture increasing the water holding capacity and potentially reduce water flows. However, it was noted that more research was needed to quantify these initial results.

Thompson & Hunt (2016) discussed how winch-assisted systems combined with appropriate road layout offer an opportunity for reducing large scale haul road construction and may provide more cost-effective forwarding distances. A contractor in the Monashee Mountains of British Columbia found that using winch-assisted skidder systems may provide cost savings by reducing the amount of skid trails requiring construction for accessing small pockets of volume associated with steep slopes (Koszman, 2018).

A study carried out by Strimbu & Boswell (2018) in Alberta, Canada, consisting of a Tigercat 635E skidder attached to a T-Winch 10.1 winch-assist, compared the productivity of a skidder with and without assistance from the T-Winch. The study confirmed that use of the T-Winch saved 1.1km of road construction, and overall determined that adequate block layout and road engineering with the use of winch-assisted extraction systems could reduce the road construction required by half compared to that required for a conventional cable yarding system.

Berkett (2012) stated that one of the benefits of the shift to using ground-based systems on steep terrain was the lower operating costs per tonne of ground-based systems over cable-based systems. Unlike cable yarding systems, they do not require deflection to be productive, and this has seen their use expand onto steeper slopes (Berkett & Visser, 2012). Cost is a major factor in deciding what type of harvesting system to use. It was noted that the minimum cost approach seemed to be the primary selection criteria for choosing a harvesting system in a study conducted in Europe (Enache *et al.* 2016).

Strimbu & Boswell (2018) found that when skidding uphill or in snowy conditions, the winch-assisted system productivity was double that of the conventional skidding system. They also determined that shutdown time due to weather disturbance was reduced, as the traction assistance provided by the winch enabled equipment to keep working while conventional equipment had to stop. This is aligned with results from Koszman (2018) who concluded that winch-assisted systems would have a great application when harvesting areas in Canada during winter months, when traction issues are created from heavy snow or when extracting heavy wood.

In the study using a T-Winch, Strimbu & Boswell (2018) indicated that the winch-assist system was more productive at longer haul distances (greater than 70m) due to a lower proportion of time spent shifting and setting up the T-Winch. At very short distances (less than 70m) productivity was lower due to the short cycle times of the skidder and the need to shift the winch-assist machine more often. It was also found that slope had a large influence on productivity, and on slopes above 18% gradient the winch-assisted method became more productive.

It is evident that winch-assist systems will be used increasingly in the future, if more information can be provided to the forest industry on winch-assist extraction productivity to prove that it is a viable method. There have been few studies which investigate winch-assisted skidders specifically, and at what distances and slopes on which they operate and how much this affects their cycle time.

PROJECT OBJECTIVES

The purpose of this study was to provide information to the New Zealand forest industry on the productivity of a winch-assisted skidder and the terrain, distances and slopes on which it operates, along with evaluating and outlining the benefits of the system.

The objectives of the study were to undertake a comprehensive case study of an existing winch-assist skidder operation in New Zealand, including:

- A productivity study to look at the effect of slope and extraction distance;
- A soil survey conducted to assess the ground disturbance made from the winch-assist skidder system;
- Identifying the advantages and disadvantages of a winch-assisted skidder system. These were identified by conducting a questionnaire survey of winch-assist skidder operators.

STUDY METHODOLOGY

Productivity Study

Cycle Time

A comprehensive time study was carried out on the winch-assist skidder to determine the average cycles per productive machine hour (PMH). Each cycle was detailed using the following time elements:

- **Travel Empty:** Skidder leaves landing empty to gather stems from hillside. Element starts the moment the skidder crosses the edge of the landing, and ends when the skidder stops to pick up a stem.
- **Load:** Skidder picks up or repositions logs in order to create an effective load. Element starts when the skidder stops travelling and moves to pick up or reposition a stem. Element ends when the skidder begins its return journey to the landing with a full payload.
- **Travel Loaded:** Skidder returns to the landing with payload. Element starts the moment the skidder has grabbed a full payload and begins to return to the landing. Element ends when the skidder crosses the edge of landing.
- **Unload:** Skidder unloads stems onto drop zone to be processed. Element starts when the loaded skidder crosses the edge of the landing, and ends when the skidder crosses the edge of the landing unloaded to start a new cycle. In the unloading element, the skidder typically included a fleeting element, which comprised picking up the top end of stems and hauling them towards the surge pile to align them with the other stems.

Productive Time

Productive machine hours (PMH) were determined by the hours the machine actually worked doing its primary task. This was calculated from the Scheduled Machine Hours (SMH = "on the job" hours) minus all the measured delays, as shown in the equation below:

PMH = SMH – Delays

Delays

Delays were recorded to determine the proportion of time the skidder was productive and to identify reasons the operation had stopped. Delays were categorised into four groups:

- **Mechanical Delay:** When the machine is held up due to maintenance or repairs required. For example; replacing a worn hydraulic hose or lubricating the machine.
- **Operational Delay:** When the machine is held up by another part of the system, for example the winch-assist machine needs shifting or setting up.
- **Social Delay:** This is any delay to the machine not working due to lunch break, operator personal delay.
- **Other Delay:** Any other delay that does not fall into the above categories. If reason is able to be clearly identified it will be noted down.

Productivity

Attempting to measure the volume of individual stems as they were unloaded at the landing would have been unsafe and also would have interfered with normal operations. The number of stems for each cycle was recorded, and they were further categorised as either a full stem, butt end or a top end. The volume of a full stem (average piece size) was provided by the forest management company for that stand. The volume of butt end and top end pieces was calculated by applying the proportion each takes up of the full stem. This was derived from the typical log outturn from pruned stands published by NZFOA, giving averages of 77.8% of a full stem for a butt end, and 21.3% for the top end (FOA, 2017). The trees were the same age, and were assumed to be of similar merchantable length and diameter.

The volume per cycle was calculated by multiplying the number of each stem type skidded per cycle by the calculated average volume of each stem type. Productivity was calculated by then multiplying the average volume (m^3) per cycle by the average number of cycles per productive machine hour (PMH) to determine m^3/PMH.

Machine Tracking

The extraction distance (m) was measured for each cycle using a range finder. A GPS receiver was fitted to the skidder and recorded one data point every five seconds, consisting of an X, Y and Z coordinate locating position and the real time. This was used to provide additional information on distance travelled (extraction distance), the slope negotiated, and the speed at which the skidder moved (Figure 2). The data was used to create maps of routes the skidder travelled and cross-sectional profiles of terrain negotiated.

Figure 2: Tigercat 635 skidder navigating a 30 degree (60%) slope, fitted with a GPS unit to track its location, speed and change in altitude.

Soil Survey

A soil survey was conducted to assess the ground disturbance from the winch-assist skidder, but would also include any disturbance from previous activities, primarily the mechanised harvester. A large sample was taken using randomly located line transects in order to be representative of the harvesting area as a whole. Visual classes were used to simplify and standardise the assessment of soil disturbance as the degree of change from natural conditions (Page-Dumroese *et al.*, 2009; McMahon 1995).

The sample process involves laying out transect lines perpendicular to the main skidding direction and spaced 20m apart. Survey points were taken at 3m intervals along the transect lines. The visual classes of soil disturbance were categorised according to the following classification (Table 1):

Table 1: Soil survey classification

Class	Classification	Description
1	Undisturbed	Soil remains intact and original litter still in place.
2	Shallow Disturbance	Litter removed and topsoil exposed, litter and topsoil have mixed.
3	Deep Disturbance	Subsoil is exposed.
4	Slash	The soil is covered by slash.
5	Non-soil	The soil is covered by objects such as tree stumps or rocks.

Questionnaire Survey

Perceived advantages and disadvantages of the winch-assist skidder system, as identified by the harvest planner, harvesting crew foreman and skidder operator were obtained using a structured questionnaire. The questions were based on the review of previous literature and as such focussed on reducing downtime in wet conditions, infrastructure costs, fuel costs, soil disturbance and any other adverse effects on the environment:

- At what point/slope/weather conditions do you decide to tether the skidder to the winch-assist? At what point/slope do you feel you've reached the system's maximum operating limit?

- Have you found there has been reduced road construction when using the winch-assist system?

- Do you see a reduced impact on the environment due to less compaction and wheel spinning with the added traction of the winch-assist machine?

- Is there a significant fuel saving when the skidder is attached to the winch?

- What are other benefits of using a skidder attached to a winch-assist machine?

- Does the added performance/productivity outweigh the initial cost of purchasing the winch-assist machine?

- What was the main driver in attaching the skidder to the winch-assist machine? Was it safety, access to more terrain or environmental benefits that provided the most influence in your decision?

SITE DESCRIPTION

Forest Site and Harvesting Crew

The case study was carried out in Emerald Forest, 30km south-west of Gisborne. The stand was pruned *Pinus radiata* at a stocking of approximately 306 stems/ha, with an average stem volume of 1.8 cubic metres.

Speirs Logging Ltd operates a fully mechanised road line harvest crew which utilises both tethered felling and tethered extraction. The logging operation involved 7 machines; a felling machine, an excavator used for bunching, the skidder and winch machine for extraction, a grapple processor, and 2 excavator loaders stacking the logs and loading the trucks. The skidder operator (Figure 3) was deemed to be experienced, although still learning the nuances of operating the winch-assist system.

Figure 3: The Tigercat 635G and Speirs Logging's skidder operator

Tigercat 635G Skidder: The six-wheeled three-axle skidder utilising chains on the front tyres and band tracks on the rear tyres (Figure 4).

Figure 4: Tigercat 635 Skidder with chains and belt drive

Figure 5 shows the attachment method used to connect the winch wire rope to the skidder. It can be seen that the chain goes through the skidder blade to attach onto the chassis of the skidder.

Figure 5: Attachment method of winch wire rope to skidder

Falcon Winch Assist

The Falcon Winch Assist used in Speirs Logging Ltd.'s operation is a single drum winch with 500m of winch rope, mounted on a hydraulic excavator base (Figure 6).

Figure 6: Falcon Winch Assist machine

Study Site Layout

Figure 7 shows part of the landing that was being used during the study. It shows the skidder dropping its payload into the surge pile, the Falcon Winch Assist machine, and the processor.

Figure 7: Landing featuring the location of Falcon Winch Assist (left), the Tigercat skidder (centre) and the grapple processor (top).

During the study two primary extraction paths were being used. Both paths followed the same trail for the first 150m then diverged down different sides of the slope. Initially the skidder travelled downhill from the landing for 40m and then a slight uphill portion out to a distance of 150m.

Path 1 – This path was 300m in length and was used for the first two and a half days of the study. It consisted of stops at 60m, 90m, 110m, 150m, 240m, and 280m. The profile of Path 1 is shown in Figure 8. From 150m its average slope was 25 degrees (47%). At that point the skidder travelled downhill to retrieve stems at the bottom of the hill. The slope had a convex steep segment from 180m – 250m and its maximum slope was 33 degrees (65%). A total of 86 skidder cycles were observed on Path 1.

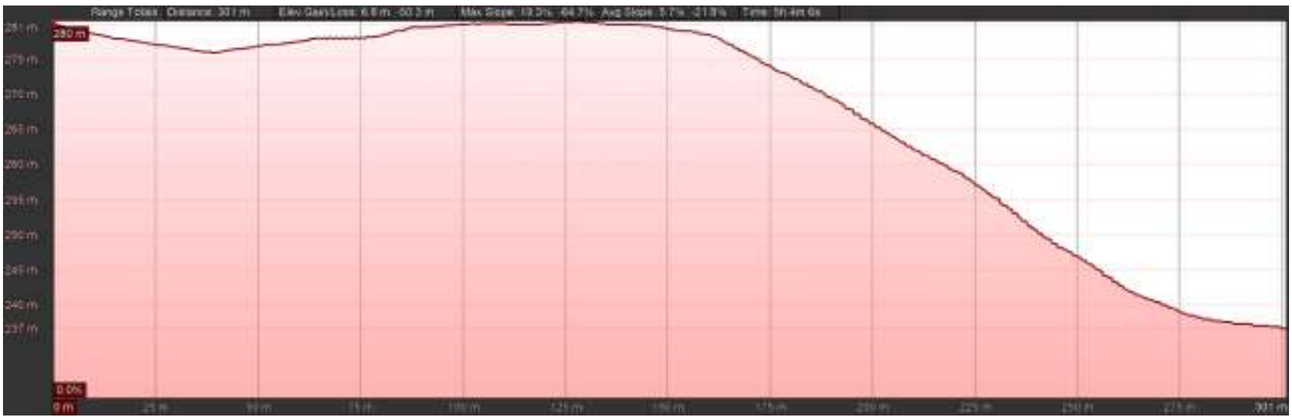

Figure 8: Profile of Path 1

Path 2 – This path was 315m in length and was used on Day Three of the study (Figure 9). It consisted of stops at 210m, 250m and 300m. Its steep slope from 150m out was more concave in shape than Path 1 and its maximum slope was 30 degrees (58%). From 150m its average slope was 22 degrees (40%). Skidder cycles extracted on Path 2 were observed for 35 cycles.

Figure 9: Profile of Path 2

RESULTS

Productivity

Productivity data were collected by observing 121 skidder cycles over 3 days. Table 2 and Table 3 show a breakdown of the cycles observed for both Paths 1 and 2. The tables detail the number of cycles that were completed at each extraction distance, the average time for each element in the cycle (in seconds), the average total cycle time, and the average volume skidded at each respective extraction distance. In total from both Paths 1 and 2, the majority of cycles were skidded from distances of 240m or greater, as this was where the majority of the wood was located. The shorter extraction distances were used to supplement the longer cycles to ensure there was an adequate buffer at the landing surge pile at all times.

Table 2: Breakdown of cycles for Path 1

Path 1						
Extraction Distance (m)	**60**	**90**	**110**	**150**	**240**	**280**
No. of Cycles	2	8	10	5	21	40
Travel Empty (s)	32	65	79	97	179	210
Loading (s)	12	12	29	13	28	27
Travel Loaded (s)	53	66	78	99	223	284
Unloading (s)	85	101	86	77	86	82
Delay (s)	0	15	0	0	10	16
Average Cycle Time (s)	181	258	272	286	527	619
Average Volume (m^3)	8.1	9.19	7.17	9.12	8.09	7.95

Table 3: Breakdown of cycles for Path 2

Path 2			
Extraction Distance (m)	**210**	**250**	**300**
No. of Cycles	7	18	10
Travel Empty (s)	150	180	205
Loading (s)	18	21	33
Travel Loaded (s)	200	232	259
Unloading (s)	97	96	93
Delay (s)	12	6	27
Average Cycle Time (s)	476	535	616
Average Volume (m^3)	8.07	8.87	7.65

Figure 10 displays the proportion of time each time element of the total cycle time at three different extraction distances: 60m, 150m and 280m. These distances represented the first stop, the point where the skidder paths diverged and the last stop along Path 1.

It clearly shows the effect that longer extraction distances had on the proportion of total cycle time of each element. At shorter extraction distances travel empty was only 18% of the total cycle time and travel loaded was only 29%, and there was a larger proportion of unloading time (47%). As the extraction distances increased to 280m, the proportion of travel empty increased to 34% and that of travel loaded increased to 46%, reducing the proportion of unloading time to 13% of total cycle time.

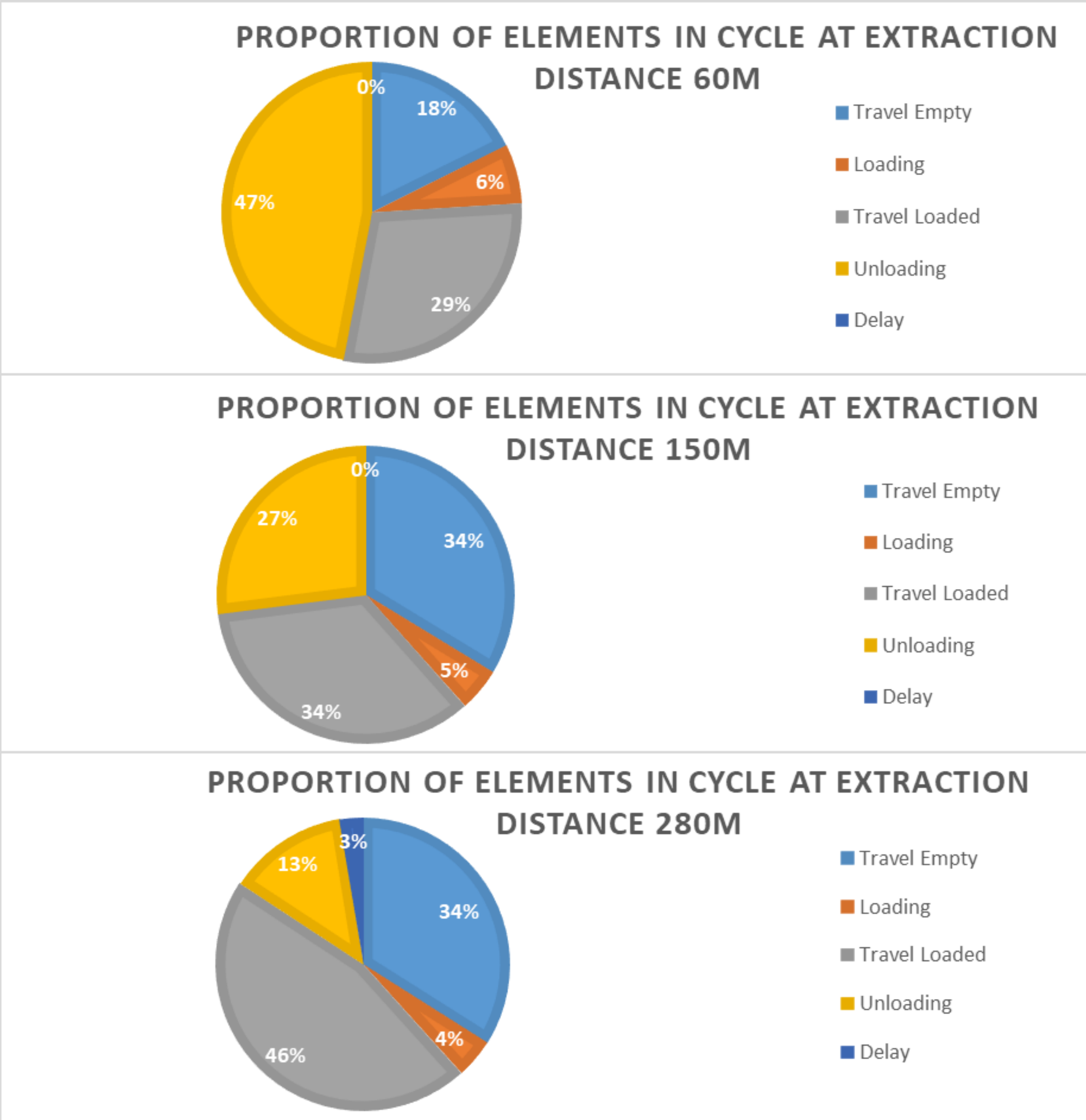

Figure 10: Proportion of total cycle time for each element extraction distances of 60m, 150m and 280m.

At distances over 150m, where the skidder had to navigate the steep segment of the path, the travel loaded element was significantly longer than travel empty due to the reduced speed when travelling uphill with a full payload.

The total cycle time of the skidder was ultimately dependent on the extraction distance that was travelled. Figure 11 shows the cycle time by distance for both paths, and also shows the effect of increasing slope beyond the 150m mark.

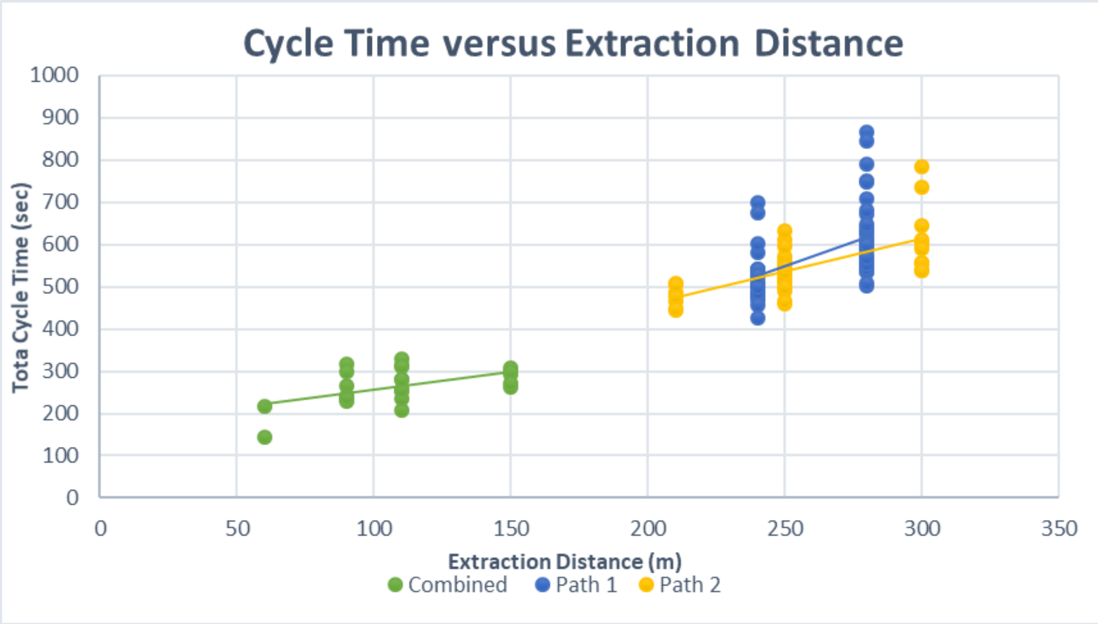

Figure 11: Cycle times recorded at varying measured extraction distances

Average productivity relative to extraction distance is shown in Figure 12. Logically the trend line clearly shows that productivity decreases with increasing extraction distance. It was evident that a small change in slope gradient affected the skidder's ability to haul a full payload up the slope as it became more reliant on the winch machine.

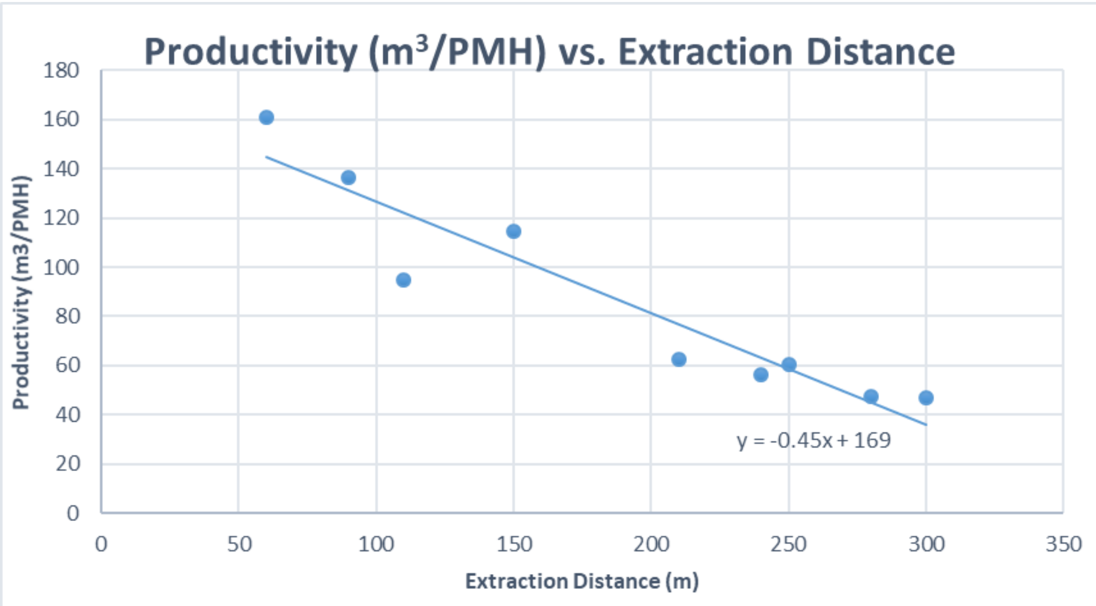

Figure 12: Productivity of average cycle times at each extraction distance

Using this regression, a basic productivity equation is shown below. Note that this only applies to extraction distances between 50m to 300m:

$$Productivity\left(\frac{m^3}{PMH}\right) = 169 - 0.45 \text{ x } Extraction\ Distance\ (m)$$

The overall productivity results for the three day study are shown in Table 4 below. The productivity for Day 1 and Day 3 were very similar (63.3 m^3/SMH vs. 61.8 m^3/SMH, and 65.5 m^3/PMH vs. 63.3 m^3/PMH respectively). Productivity in m^3/SMH on Day 2 was very low due to a mechanical delay of 4 hours 10 minutes, due to one of the band tracks on the skidder's rear tyres breaking and requiring fixing. This took up a large portion of the skidder's working day and reflects in the poor productivity per SMH. Once repaired productivity per PMH was very high, with Day 2 recording the highest productivity/PMH (67.2 m^3/PMH).

Table 4: Productivity results for the three day study

Productivity Results

	Volume (m3)	Scheduled Machine Hours	Productivity (m3/SMH)	Productive Machine Hours	Productivity (m3/PMH)
Day 1	349.5	5.52	63.3	5.34	65.5
Day 2	243.4	8.38	29.1	3.62	67.2
Day 3	394.3	6.38	61.8	6.23	63.3
TOTAL	987.3	20.28	48.7	15.19	65.0

As the skidder path was tracked using GPS, it is also possible to overlay the skidder path on a GoogleEarth map (Figure 13), from which the Path 1 (left) and Path 2 (right) can be displayed.

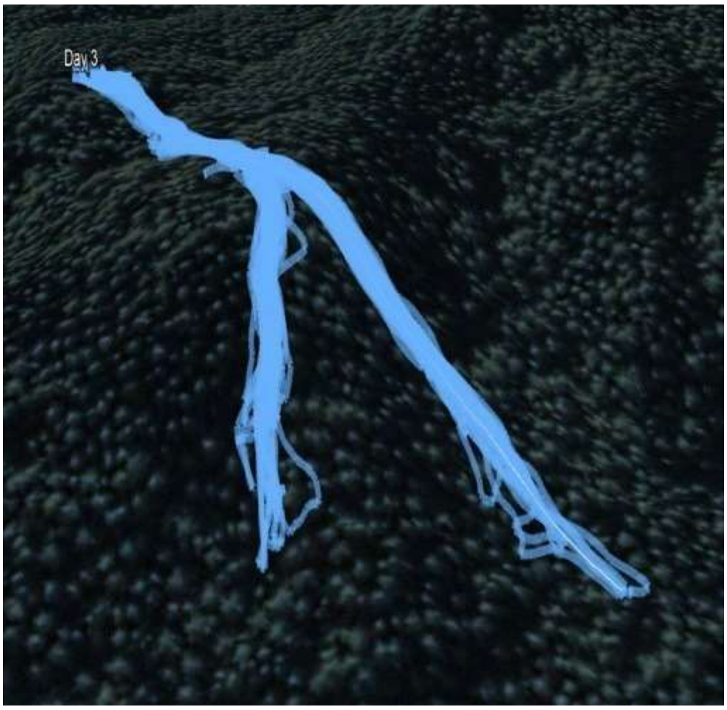

Figure 13: GPS data overlaid on GoogleEarth shows the two skidder paths. Path 1 is shorter (left) than Path 2 (right).

GPS data also allowed the elevation changes to be recorded (Figure 14). This figure represents part of Day Two of the study, showing each skidder cycle. The start of the cycle consisted of the skidder beginning its descent from the landing travelling downhill and stopping to pick up a bunch and then returning uphill back to the landing. A large drop reflects a long extraction distance to the bottom of the path, whereas a shallow drop reflects a short extraction distance not far from the landing elevation.

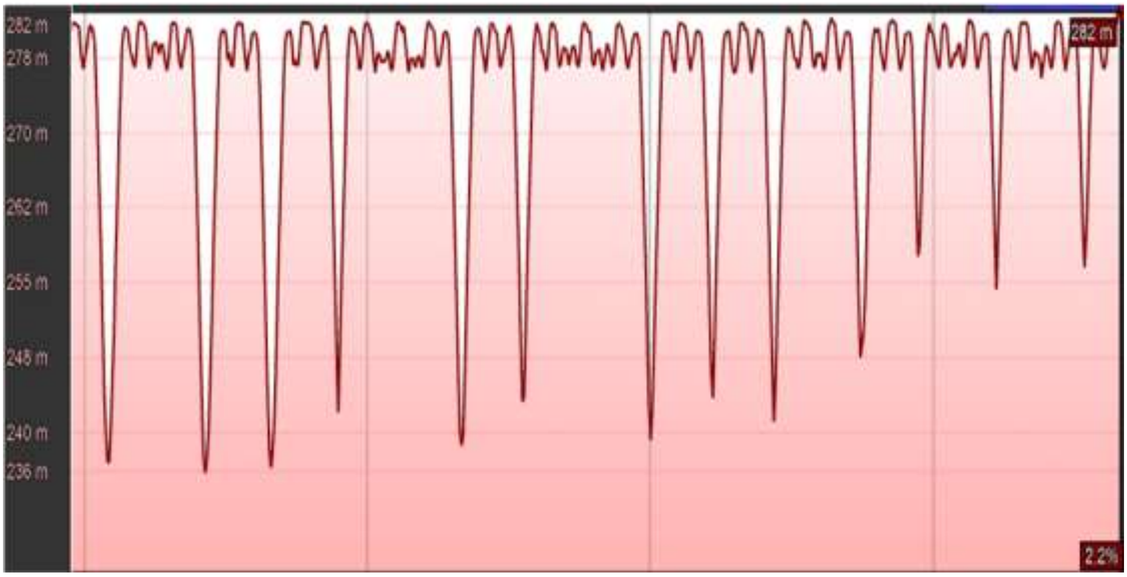

Figure 14: Skidder elevation changes from one period on Day 2. Each drop in elevation is one extraction cycle with the skidder travelling downhill to pick up the load.

From this figure it can be seen that there was a mixture of elevations which related to a mix of extraction distances. It also shows that the skidder operator utilised the short hauls to mix up the length of cycle times to ensure that there was an adequate buffer at the surge pile at all times for the processor.

By analysing the GPS data, the velocity of the skidder can also be derived. This is overlaid with the change in elevation in Figure 15. It can be seen that a typical operational velocity for the skidder was about 4.5 m/sec, which is 16.2 km/hr (ranging between 2.5 and 5.0m/sec).

Figure 15: Changes in elevation (red) and velocity of skidder (blue)

It can be seen from Figure 15 that as the skidder left the landing and travelled downhill the velocity was higher than when it travelled back uphill with a payload. This clearly shows the decreased velocity of uphill travel loaded compared to downhill travel empty. It also indicates that the number of cycles can be derived from both elevation and velocity data. The maximum skidder velocity of 5.5km/hr was limited by the PLC in the Falcon Winch Assist.

Figure 15 also shows delays where the velocity was zero (see note at the bottom of the graph). The delay that is highlighted shows a period where the skidder was stationary for 2 minutes and 20 seconds at the landing, which occurred when the processor was down and the skidder took the opportunity to rearrange the surge pile.

Delays

Figure 16 shows the breakdown of the total delays that were recorded over the three days of the study. Total delays amounted to 5.09 scheduled machine hours or 25.1% of total time. Machine utilisation was 74.9%, which is very close to the industry standard of 75% for conventional skidder operations (Visser, *pers comm*. 2019).

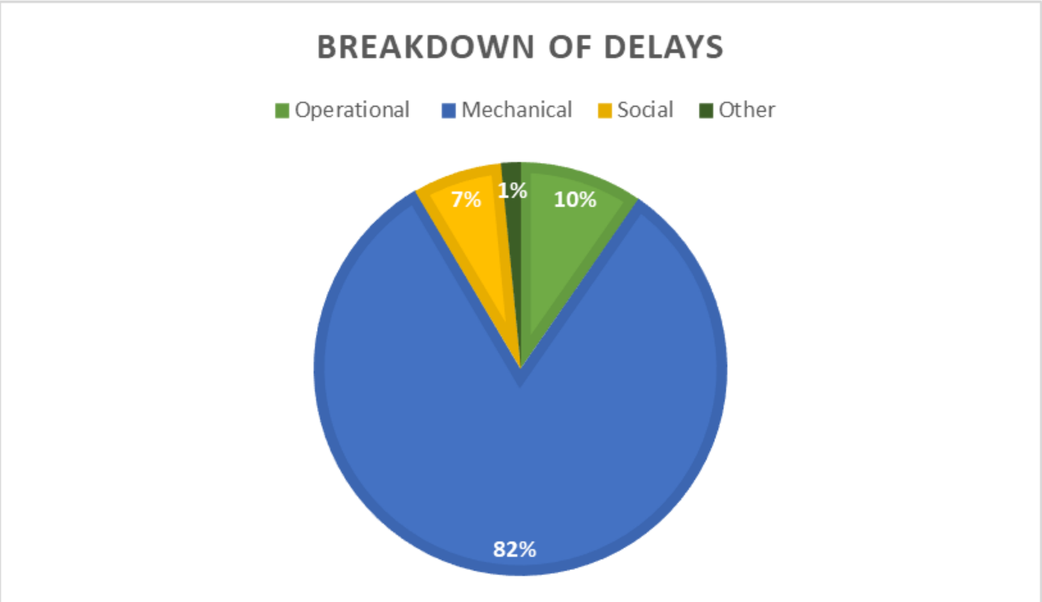

Figure 16: Breakdown of delays experienced over the study period

Of mechanical delay time, 82% was related to mechanical delays comprising one delay which occurred on Day Two when the band track on the skidder's rear tyres had broken and required fixing. This meant the skidder was immobile for 4 hours and 10 minutes until the mechanic had reached the forest and repaired the band track.

Of the operational delay time (10% of total delays) almost half (48%) was attributed to the skidder dropping and regathering stems or readjusting its payload. Other operational delays included a Falcon Forestry technician from DC Equipment Ltd installing new hardware into the Falcon Winch Assist Machine's PLC (35% of operational delay time); allowing for the winch-assist tension to build up; and waiting for other machinery to cross the cutover. Of the social delay time, most (97%) was attributed to FICA representatives visiting the operation on Day Two (21 minutes). Other social delays included stopping to communicate through radio. Other delays (1%) included the skidder moving or placing slash over the skid trail to improve traction.

Soil Disturbance Survey

The soil disturbance assessment was carried out using a line transect method and collected 902 data points over three different sites. At all three sites felling was mechanised and extraction via the winch-assisted skidder system. Table 5 below provides the area, maximum slope, average slope and the amount of data points taken for each respective site. Site 1 was an area that was being harvested and where the time study was completed. Site 2 and 3 were areas of the same forest which had been previously harvested by the same system.

Table 5: Description of soil disturbance assessment sites

	Area (ha)	Maximum Slope (degrees)	Average Slope (degrees)	Data Points Taken
Site 1	0.37	5	4	151
Site 2	3.50	40	25	542
Site 3	1.14	35	20	209
Total	5.01	36	22	902

It is important to note that the line transect soil survey measures soil disturbance, not soil impacts such as compaction or erosion. While overall it is a good goal to minimise the level of soil disturbance, it is recognised that many disturbed soils will quickly stabilise after revegetation.

Site 1

Site 1 was the area associated with the shorter extraction distances at the top of the crown before the path traversed down the steep segment. It was located off the main trail, was only 0.37 ha in area and had an average slope of 4 degrees. The majority of the trees had been bunched into the middle of the area for ease of extraction. There was a larger amount of deep disturbance associated with this site as the skidder did not come off the main trail at the same location every time, but exited at various intervals along the trail.

Table 6 shows that slash was the largest classification recorded at 35% out of the total data points surveyed at Site 1. Shallow disturbance accounted for 26% of the total data points and deep disturbance was 17%. It was noted however that the majority of the deep disturbance was attributed to the tracked felling machine and not the wheeled skidder.

Table 6: Soil disturbance results collected at Site 1

Site 1	Soil Disturbance Class				
	Undisturbed	Shallow Dist.	Deep Dist.	Slash	Non-soil
Total	21	40	26	53	11
Proportion (%)	14	26	17	35	7
Absolute Error (±)	3	4	3	4	2

Figure 17 shows a section of Site 1 that was surveyed, with tracks can be seen coming off the main trail by the binding stump.

Figure 17: Section of Site 1 showing tracks

Site 2

Site 2 was the largest of the sites assessed with an area of 3.50ha. It had the most surveyed points taken with 542 collected. This site involved extracting the timber via bunching towards skidder paths and then skidding uphill with the assistance of the winch system (Figure 18). Slopes were ranging from 10^o to a maximum of 40^o, with average slope 25^o. This site had a lot of slash placed in the cutover with 32% of the points surveyed accounting for that category (Table 7). There was a relatively large proportion of the area undisturbed (26%) and the site showed significant new grass growth.

Figure 18: Soil disturbance assessment Sites 2 and 3

Table 7: Table showing soil disturbance results collected at Site 2

Site 2	**Soil Disturbance Class**				
	Undisturbed	Shallow Dist.	Deep Dist.	Slash	Non-soil
Total	139	111	61	172	59
Proportion (%)	26	20	11	32	11
Absolute Error (±)	2	2	1	2	1

Shallow disturbance made up 20% of the area and was recognized as shallow rutting or where the subsoil had become exposed or mixed with topsoil. The deep disturbance accounted for 11% of the total area and was attributed to the skidder paths that had been used to extract stems or significant tracked machine ruts. The majority of the skidder paths had been closed out with slash placed over them to reduce the amount of soil exposed and slow the erosion process (Figure 19). The remaining 11% of the area surveyed were stumps, rocks or logs.

Figure 19: Cutover of Site 2

Figure 20 below shows an aerial view of Site 2, where the riparian strip can be seen to be still intact due to the ability of the winch-assisted skidder system to pull trees away from the waterway.

Figure 20: Site 2 showing retention of riparian vegetation along streamside

Figure 21 shows a skidder path that measured 30 degrees slope, and also the effect of closing it out with slash to reduce the risk of erosion.

Figure 21: Left, skidder path used at Site 2, and right, showing slash being used to close out the path.

Figure 22 shows as example of scouring that has occurred from a dragged stem on the weaker clay soils found in the Gisborne region.

Figure 22: Scouring disturbance at Site 2

Site 3

Site 3 consisted of an area of 1.14ha with an average slope of 20º (ranged from 15º to 35º). This site backed onto a previous landing and so there was a large pile of slash where off-cuts were deposited (Figure 23) and reflected the significant amount of slash recorded (38%). Most of the undisturbed data points were taken on the sides of this catchment area (Table 8).

Disturbed soil made up 31% of the area, of which 21% was in the shallow disturbance category. The deep disturbance made up only 10% and was attributed to the skidder paths, and deep rutting caused by the tracked machine.

Table 8: Soil disturbance results collected at Site 3

Site 3	Soil Disturbance Class				
	Undisturbed	Shallow Dist.	Deep Dist.	Slash	Non-soil
Total	51	44	20	80	14
Proportion (%)	24	21	10	38	7
Absolute Error (±)	3	3	2	3	2

Figure 23: Aerial view of Site 3, showing the slash pile next to the landing.

Questionnaire Responses

The following is a summary of responses to the survey questions from the Harvest Planner, Crew Owner and Skidder Operator:

- **At what point/slope/weather conditions do you decide to tether the skidder to the winch-assist? Or at what point/slope do you feel you've reached the system's maximum operating limit?**

The forest management company, Forest Enterprises Ltd, does not specify a maximum operating limit for the system. However, they provide Avenza Maps® of the slope of each setting with the prescription, so that slope class and other hazards are identified pre-operation. Forest Enterprises Ltd audits Speirs Logging Ltd.'s health & safety system, their equipment and their operational compliance with codes and best practice. Speirs Logging Ltd.'s manager and machine operators assess risk on a minimum daily basis and controls are implemented using a risk assessment tool. The risk assessment process helps to determine the slopes on which to use the winch assisted skidder system. Speirs Logging Ltd are conscious that this is a new system and they are still learning how to best utilise it. One person's risk assessment may be different to another, but the operator has to feel comfortable with the safety of the operation.

Blake Speirs, the crew owner, stated that once the terrain stretched more than 100m over 25 degrees, shovelling with an excavator no longer became productive and it is winch-assisted skidder territory. At the moment they limit the slope to 35 degrees, however it is very dependent on the type of soil, the condition it is in and the current weather conditions.

- **Have you found there has been reduced road construction when using the winch-assist system?**

In this setting alone, the use of the winch-assisted skidder system along with a new six- wheeled Tigercat skidder has helped to save building approximately 720m of road, a large culvert crossing, and two skid sites that were originally planned. By having the ability to continue logging in greasy conditions and poor weather, the tether system has enabled this infrastructure to be eliminated, which has resulted in reduced earthworks and reduced roading costs.

- **Do you see a reduced impact on the environment due to less compaction and wheel spinning with the added traction of the winch-assist machine?**

Using the winch-assisted skidder system has meant that work is able to be continued in wetter and poorer conditions. Originally the skidder would have been working harder in these conditions and could have made a mess of the cutover. By having the additional support of the winch, less wheel spinning occurs due to the added tension providing support to the skidder climbing up the hill.

- **Is there a significant fuel saving when the skidder is attached to the winch?**

Approximately 50% less fuel is used by the skidder when it is attached to the winch-assist due to the low speed and assistance provided from the winch. However when the winch-assist machine is being used, it too requires fuel. It is evident that when the skidder is not tethered to the winch and working in wet or greasy conditions, more fuel is used as the skidder works harder to cover the slippery terrain and travels at faster speeds.

- **What are other benefits of using a skidder attached to a winch-assist machine?**

Along with having increased days logging due to the capability to work in poor weather conditions, the main one is the ability to extract stems either side of the waterways. This essentially leaves the riparian strip intact as no machine is within 5m of the waterway. Yarder settings rarely achieve full suspension and may damage or sweep debris into waterways, so the opportunity to leave the riparian plantings untouched is favourable. 19.3 ha of planned cable yarder settings is set to be extracted via the winch-assisted skidder system and there is another 9.3 ha which is still planned to be extracted with the cable yarder as it is very steep. The forest manager is confident that the tethered skidder system will not make a mess, however for safety reasons deemed it to be extracted via cable yarder. The crew owner feels that it is achievable so a final decision will be made closer to the time. The capacity to ground base previously cable yarder territory reduces the cost of logging by approximately $6.50 – $8.50/tonne. The tether system also enables extracting very long distances (greater than 400m) in poor soil conditions.

- **Does the added performance/productivity outweigh the initial cost of purchasing the winch-assist machine?**

Yes, it increases the utilisation of the winch machine. Originally the utilisation of the winch machine was roughly 50% with just the felling machine being used. Now with the added skidder system being used utilisation this has increased by approximately 30% bringing the total utilisation of the winch machine to approximately 80%. The tethered skidder also allows for larger payloads to be hauled and less fuel to be used in the skidder.

- **What was the main driver in attaching the skidder to the winch-assist machine? Was it safety, access to more terrain or environmental benefits that provided the most influence in your decision?**

For Blake Speirs, the main driver in attaching the skidder to the winch-assist machine was utilisation of the winch machine. After that the environmental and safety benefits were clear. Having a reduced impact in wet conditions and leaving waterways and riparian strips untouched was important. Safety was also a big driver as it enables a 100% mechanised operation. With a cable yarder crew there is still time when workers are out of the cab, setting up ropes, line shifts or breaking out. With the winch-assisted skidder system there is less interaction between people and reduced safety risks.

- **What are the disadvantages of the winch-assisted skidder system?**

Disadvantages include:

- Speed at which the skidder travels when tethered to the winch machine. When the skidder reaches a flat section of terrain after negotiating a steep segment, its speed is limited to 5.5km/hr which can decrease cycle time. This works out to roughly 3 drags with the skidder attached to the winch-assist machine being equivalent to 4 drags without the winch-assist (25% reduction).

- Winch tension not increasing on demand, if the speed of the skidder is greater than the rope which can occur on downhill sections when heading towards the landing, the skidder must wait for the winch-assist tension to build up which can take 2-3 seconds.

- Having to run another machine provides an added cost, which has to be offset by additional production.

DISCUSSION

Efficient Operation

There had been significant planning into how the system was going to be used and appropriate routes were laid out to ensure optimum extraction distances and effective bunching locations were implemented. The bottleneck of the operation was identified to be the processor and the goal was to optimise this part of the process. Always ensuring that there were stems for the processor to process at the surge pile and maintaining a sufficient buffer at all times was key, so if any other part of the supply chain halted the operation, the processor could continue to work. A mix of extraction distances for the skidder was implemented to achieve this. If all timber close to the landing was pulled first then when stems were extracted further from the landing, the buffer at the surge pile would be depleted and the processor would be waiting for wood.

Designing the correct landing layout was important in order to arrange the different machinery and log stacks in a way that created smooth flow and best suited each machines task minimising down time. As the terrain in Gisborne was very broken, having a long narrow landing with the winch-assist machine at one end enabled the skidder to move around freely in the cutover within the 30 degree arc of the winch, binding around stumps to negotiate the best possible route to retrieve stems. At no point was the winch system hindering processes carried out on the landing. This particular design of a long narrow landing is ideal for road lining crews and the system works with the crew having access to small areas of clearfell to keep the logging costs down.

The broken terrain meant that the skidder was limited to certain areas and so bunching stems by the excavator to selected areas along the skidder path was crucial to improve the productivity of the skidding operation. This ensured that once the skidder had reached its required haul distance there were ready-made bunches for it to haul back to the landing immediately. This reduced loading time and also reduced the amount of skidder trails necessary. The bunching machine was able to shovel log and bunch stems to the skidder trail that would have been difficult for the skidder to reach.

With regard to slope, the results show that Path 2, the more concave slope with maximum gradient of 30 degrees (average 22 degrees) resulted in higher productivity than Path 1 with extraction distances over 150m. Path 1 with a more convex slope (maximum gradient of 33 degrees and average 25 degrees) resulted in lower productivity at extraction distances over 150m. The difference however was small.

Limitations of the study included time being a limiting factor and the data collection was only carried out for a short period, three days. Assessing one operation only provides an insight into the winch-assist skidding operation occurring at that one site. The data retrieved only reflects the topography of the area the system was working. Only one type of winch machine was used, a Falcon Winch Assist Machine and only one type of skidder was used, a Tigercat 635G and so the results reflect these machines working at this site in these conditions.

Environmental Impact

Placing slash onto the skidder trail provided more traction and reduced the rutting impact from the skidder moving down the one haul trail the whole time. Rutting is soil disturbance that might lead to riling and gully erosion, because Gisborne is a landslide prone area there is a need to minimize this as much as possible. After use, trails were filled in with slash and stumps to close them out. This also acts as a barrier absorbing and reducing the velocity at which the water will run down the track, therefore reducing erosion from potential scouring.

The soil disturbance assessment for combined shallow and deep disturbed soil categories returned values of 44%, 31% and 31% for sites 1, 2 and 3 respectively. From this deep disturbance results were 17%, 11% and 10% for the three sites. A study carried out in Alberta, Canada, consisting of a Tigercat 635E skidder attached to a T-Winch 10.1, also carried out a soil disturbance assessment (Strimbu & Boswell, 2018). The study returned values of 33.3% for the conventional skidder system and 24.9% for the winch-assisted skidder system. The technique used accounted for all classes of soil disturbance no matter how deep or shallow. However, the average slope of the surveyed area was 26% (14.5 degrees) so significantly less steep than this study.

There was a large emphasis placed on the ability to pull stems either side of the waterway, keeping the riparian strip untouched and sediment out of the waterway. A goal of using this system was to result in all riparian zones still being intact and none damaged or felled, once all road lining and harvesting was completed. This is not only aesthetically pleasing but also provides a vegetation filter similar to a slash collection fence for debris to collect in the event of a landslide. Cable yarding settings in areas where adequate deflection cannot be achieved usually results in riparian vegetation such as willows and poplars being removed. The opportunity for some cable yarder settings to be accessed by ground-based extraction methods, using a winch-assisted skidder, also reduces the incidence of hauler drags (rutting) which create routes for water to accumulate and travel down, creating rill and gully erosion.

Harvest planning with the use of winch-assist skidder systems in mind will result in less infrastructure costs as the need for short spur roads is reduced. For fragile subgrades, maintaining road infrastructure over long periods of time costs money. Moving in crews after road lining and walking cable yarders in for small settings damages roads and costs money in transport and maintenance. The opportunity to build one road and harvest the area with one crew reduces logging cost.

Operational Learnings

Since first using the winch-assist skidder system there have been many learnings that have occurred. When the skidder trails are established, typically the first six cycles are run with the skidders payload at 70% capacity. This allows the track to get set up and prevents skidding and rutting occurring early on. When it comes to binding around stumps to change direction, the stumps need to be placed 10m back from the edge of the knoll of a hill to allow the skidder to drop the tension and drive around the binding stump once they have reached the top. The binding stumps themselves need to be higher than usual (3m) to ensure the wire rope does not flick off the stump when the skidder traverses down a slope (Figure 24). It can be seen that it is positioned back from the edge of the knoll.

Figure 24: Tall binding stump used to redirect the rope.

Figure 25 below shows uphill road line logging to the skid and on the left the same site after road construction, skidder and cutover rehabilitation. It can be seen that the road has been constructed along what was previously a winch-assisted skidder trail, negating the effect of the disturbance.

Figure 25: Left, during logging, and right after the road has been constructed.

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REFERENCES

ACOP (2012). Approved Code of Practice for Safety and Health in Forest Operations. MBIE, Wellington, New Zealand.

Berkett, H. (2012). An examination of the current slope gradients being experienced by ground-based forest machines in New Zealand plantation forests. Dissertation, School of Forestry, University of Canterbury, Christchurch, New Zealand.

Berkett, H. and Visser, R. (2012). Measuring Slope of Forestry Machines on Steep Terrain. Harvesting Technical Note HTN05-02. Future Forests Research Ltd, Rotorua, New Zealand.

Cavalli, R., & Amishev, D. (2017). Steep Terrain Forest Operations - Challenges, Technology Development, Current Implementation and Future Opportunities. University of Padova, Italy.

Chase, C.W., Reiter, M., Homyack, J.A., Jones, J.E., Sucre, E.B. (2019). Soil disturbance and stream-adjacent disturbance from tethered logging in Oregon and Washington. Forest Ecology and Management, Volume 454 (December 2019) 117672.

Enache, A., Visser, R., Kuhmaier, M., & Stampfer, K. (2016). Current Practices and Efficiency Gaps in Logging Operations from European Mountain Forests. Scandinavian Journal of Forest Research, 2016 Vol. 31 (4): 412-427.

Evanson, T., Amishev, D., Parker, R., & Harrill, H. (2013). An Evaluation of a ClimbMAX Steep Slope Harvester in Maungataniwha Forest, Hawkes Bay. FFR Report H013, Future Forests Research Ltd, Rotorua, New Zealand.

FOA. (2018). Facts and Figures 2017/18. Typical Log Outturn, page 20. NZ Forest Owners Association, Wellington, NZ.

Green, P., Chung, W., Leshchinsky, B., Sessions, J., Fitzgerald, S., Wimer, J., Cushing, T., and Garland, J. 2019. Insight into the Productivity, Cost and Soil Impacts of Cable-assisted Harvester-forwarder Thinning in Western Oregon. Accepted *in* Forest Science, 2019.

Holzfeind, T., Visser, R., Chung, W., Holzleitner, F., Erber, G. (2020). Development and benefits of winch-assist harvesting. Current Forestry Reports. Vol 6 (2).

Iarocci, P. (2017). Steep Slope Logging in Chile: Between the Branches No. 47. Tigercat November 2017.

Koszman, C. (2018). Timbermax “Traction-Winch T10” Steep Slope Operation in British Columbia's Monashee Mountains. Info Note No. 15. July 2018. FPInnovations, Canada.

Leslie, C., Visser, R., Roeser, D., Koszman, C., Hunt, J. and Harrill, H. (2019). Factors that Affect Productivity and Utilisation of Winch-Assist machines: Six Case Studies in New Zealand and Canada. In: FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future, 6-9 October, 2019. Sopron, Hungary.

McMahon, S. (1995) Survey method for assessing site disturbance: A procedure for estimating site disturbance caused by production thinning, harvesting, or mechanical site preparation. Project Report, No. 54. New Zealand Logging Industry Research Organisation: Rotorua, New Zealand.

Najafi, A., & Solgi, A. (2010). Assessing Site Disturbance Using Two Ground Survey Methods in a Mountain Forest. Croatian J. For. Eng. Vol 31 (1) 2010.

Page-Dumroese, D.S., Abbott, A.M., & Rice, T.M. (2009). Forest Soil Disturbance Monitoring Protocol. Volume II: Supplementary methods, statistics, and data collection. Gen. Tech. Rep. WO-GTR-82b. Washington D.C. United States Department of Agriculture Forest Service.

Raymond, K. (2015). Crisis. What crisis? Maintaining our social licence to harvest steepland forests. NZ Journal of Forestry, August 2015, Vol. 60, No. 2.

Strimbu, V., & Boswell, B. (2018). Adverse Skidding Using a Tigercat 635E Assisted by a T-Winch 10.1. Technical Report No. 23. FPInnovations, Canada. May 2018.

Thompson, S., & Hunt, J. (2016). Environmental Impacts of Steep Slope Harvesting in B.C: Discussion Paper. Technical Report No. 24. FPInnovations, Canada. July 2016.

Visser, R., & Stampfer, K. (2015). Expanding Ground-based Harvesting onto Steep Terrain: A Review. Croatian. J. For. Eng. 36 (2):321-331.

Visser, R., Raymond, K. & Harrill, H. (2014). Mechanising steep terrain harvesting operations. NZ Journal of Forestry, Vol. 59, No. 3 (November 2014).