Assessment of Winch-Assist Skidder Case Study in Gisborne, New Zealand

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CONTENTS

1. ABSTRACT

Winch-assist systems are commonly used to expand ground based operations onto steeper terrain. Skidders tethered to winch-assist machines are becoming popular 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 our knowledge of winch-assisted skidder systems. An investigation was carried out in Emerald Forest 30km South West of Gisborne over a period of four days to determine the productivity of a winch-assisted skidder operation, to carry out a soil disturbance assessment on slopes where the winch-assisted skidder system was used and to evaluate the benefits of utilising this system.

Productivity was assessed by observing 121 skidder cycles over two different skidder paths. The paths followed the same main trail from the landing for 150m before diverging down different sides of the ridge. Bunches were extracted at different lengths along the paths. Path 1 had a maximum slope of 33 degrees (65%) and was 300m long. Path 2 had a maximum slope of 30 degrees (58%) and was 315m long. It was clear that as the extraction distance increased, the cycle time of the skidder increased and the productivity decreased. It was evident that a mixture of extraction distances throughout the day was vital to ensure that the processor had an adequate buffer and remained productive throughout the day. The average productivity over the study period was found to be 65.35 t/PMH. The average productivity per scheduled machine hour was 51.40 t/SMH. This was largely attributed to a significant mechanical delay which stopped the skidder from working for half of day 2. As the two paths were similar in terms of slope and distance the productivity results were similar for both paths.

The soil disturbance assessment was carried out using a line transect method collecting 902 data points over three different sites. The first site returned 17% deep disturbance and 27% shallow disturbance. The second site returned soil disturbance results of 11% deep disturbance and 20% shallow disturbance. The third site returned 10% deep disturbance and 21% shallow disturbance. It was noted that some of the deep disturbance was attributed to tracked machines such as the felling machine and bunching machine.

Clear benefits of using this system included increasing the utilization of the winch machine by tethering both the felling machine and skidder off the winch machine. By having more days logging due to the ability to work in poor weather conditions productivity is improved. The ability to pull stems either way from the waterways allows for the riparian strips to be left intact, leaving the waterways untouched. The use of this system combined with a six-wheeled Tigercat 635G skidder attributed to saving the construction of 720m of road, a large culvert crossing and two skid sites which were originally planned. 19.3 Ha of forest planned to be harvested by cable yarder is now set to be harvested using this winch-assisted skidder system with the potential for more planned forested area to change reducing the logging cost.

2. INTRODUCTION

The forest industry in New Zealand is the country's third largest export earner and provides jobs to many New Zealanders throughout the country. Along with clear economic benefits, forests also provide significant environmental and social values. By sequestering carbon, improving water quality, harbouring native species and protecting biodiversity to providing recreational areas and national parks for the public to enjoy it is no surprise the government is looking to invest further into the forestry industry and increase the forested area in New Zealand. Working in the forestry industry has relatively high rates of injuries and fatalities compared to other industries (Forest Owners Association, 2017/18). As the industry is progressing further into steep slope harvesting, the difficulty of the operations increase significantly and hence the safety risks associated with it, pushing machinery and operators to their limits. The importance to remove, minimise or mitigate this risk is essential to ensure the safety of the workers in their environment. Technological advancements however, have allowed for ground based operations to expand onto steeper slopes and become safer (Visser & Stampfer, 2015). The added process of mechanisation has placed workers in machines removing them from the most dangerous parts of harvesting operations.

Winch-assist technology has further expanded the terrain machines are able to access and do it safely. Terms such as winch assist, traction assist, cable assist and tethering all refer to technology that supports a machine to climb a steep slope (Cavalli & Amishev, 2017). These machines provide traction assist through a wire rope which is attached from a winch to a machine working down a slope. The winch is designed to hold a set tension giving the tethered machine greater stability. This increase in traction allows machines to safely climb and descend steeper terrain and is perceived to improve work in poor conditions such as areas with high rainfall or snow. It is made clear that tethered machines are not suspended from the cables and they must be able to stabilize themselves without reliance on the cable. Manufacturers of winch assisted technology emphasize that the operator's safety should not be reliant on the winch (Koszman, 2018, Cavalli & Amishev, 2017).

Although many studies have been conducted on winch-assist productivity with felling machines, there is limited information available on winch-assisted skidders being used. Skidders are very popular and are seen as an excellent method of extraction and hence are being used extensively to extract timber from the forest to the landing.

Figure 1: Tigercat 635G skidder hauling logs to landing with assistance from Falcon Winch Assist Machine

3. LITERATURE REVIEW

Literature shows that through the use of winch-assisted systems terrain access has expanded changing the slope limit guidelines, removed the amount of haul roads necessary and is thought to have a reduced effect on soil disturbance.

Establishing actual slope limits for ground-based operations is hard. Slope gradients of 30% for wheeled machines and 40% for tracked machines related to machine traction and soil erosion are common in many reports (Visser & Stampfer, 2015; Berkett & Visser, 2012). However the New Zealand Approved Code of Practice has removed slope limits stating that mobile plants shall not be operated on slopes that exceed the maximums in accordance with the manufacturer's specifications (ACOP, 2017). It 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 workers and the occurrence of them actually measuring the slope gradient they operate on is rare. Visser & Stampfer (2015) found that few manufacturers actually specify operating limits for purpose-built machinery.

Expanding ground-based operations onto steeper terrain increases the risk of not only loss of traction, affecting the ability of a machine to move up and down the slope but also that of machine rollover (Visser & Stampfer, 2015). Visser and Stampfer showed that loss of traction occurs when the weight force pulling the machine down due to gravity is greater than that of the traction force. They outlined that the benefits of a cable assist system increase this traction force therefore increasing the slope limit a machine is able to operate on.

It is perceived that winch-assisted systems reduce the amount of soil disturbance. 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 with fewer turns and still establish contact with the ground thus disturbing less soil area. Koszman (2018) and Cavalli & Amishev (2017) also shared 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 this in an operation in Chile where a Tigercat 635E Skidder tethered to an Ecoforst T –Winch with approximately an eight tonne load operating at a grade of 40-45% showed little to no ground disturbance from wheel spin. This concept proves especially valuable when operating is required in areas with more sensitive soils or environmental constraints and supports the statement that in Europe the main use of-winch assisted systems is to reduce soil disturbance and allow operations in more sensitive environments (Thompson & Hunt, 2016).

In an ongoing study by Oregon State University, which is 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 (Chung, Woodham, 2018). Woodham 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 more research was needed to quantify the results.

Berkett (2012) states the shift to using ground-based systems on steep terrain is due to the lower operating costs per tonne of ground-based systems over cable-based systems. This combined with the fact that they, unlike cable yarding systems, do not demand terrain which provides adequate deflection, has seen them expand onto steeper slopes often exceeding their manufacturers slope limit guidelines (Berkett & Visser, 2012). Cost can be a large factor in deciding what type of harvesting system to use and it was noted that the minimum cost approach seemed to have been the primary selection criteria of choosing a harvesting system in a study conducted in Europe by Enache, Visser, Kuhmaier, & Stampfer (2016) and could prove a large deciding factor in other operations. 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 who was part of a winch-assisted skidding operation in the Monashee Mountains in British Columbia, also commented 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). The decreased cost of operating ground-based methods and the ability to reduce infrastructure costs could increase the popularity of winch-assisted extraction methods.

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

Strimbu & Boswell (2018) also 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 shutdown time due to weather disturbance was reduced, as the traction assistance provided by the winch helped keep equipment working while conventional equipment had to stop. This is aligned with Koszman (2018) who felt winch assisted-systems would have a great application when harvesting areas during winter months, when traction issues are created from heavy snow or when extracting heavy wood.

The results from Strimbu & Boswell (2018) showed that for shorter distances, less than 70m, using the winch-assist was less productive due to the short rotation times of the cycle and the need to shift the T-Winch more often. This resulted in a larger proportion of time allocated to shifting and resetting the T-Winch. At longer distances, greater than 70m, the winch-assisted system was more productive. This was due to longer cycle times resulting in a lower proportion of time shifting and setting up the T-Winch. It was also found that the severity of slope had a large influence on the productivity of both skidding systems. On a slope above 18% gradient, the winch-assisted method became more productive.

These studies show that ground-based operations are expanding onto steeper terrain and through the use of winch-assisted systems, these operations can become safer by increasing traction, reduce effects on the environment through less soil disturbance, reduce costs through less infrastructure construction and improve productivity in difficult terrain. Expanding terrain access for ground-based machinery allows stands which were previously thought to be uneconomical, to be a feasible harvest operation through winch-assist extraction (Cavalli & Amishev, 2017).

It is evident that winch-assist systems will be increasingly used in the future, however the problem lies within providing more information 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 slope they operate and how much this affects their cycle time. The purpose of this study is to provide information on the productivity of a winch-assisted skidder and the terrain, distances and slopes it operates on along with evaluating and outlining benefits of the system.

Figure 2: Winch-assisted Tigercat 635 skidder navigating 33 degree (65%) slope

4. PROBLEM STATEMENT & OBJECTIVES

Harvesting operations are progressing further into steeper terrain and the need for safe extraction methods while also minimising adverse effects on the environment has led to the use of winch-assisted skidder systems being used. Although this is becoming a popular option to expand ground-based extraction, there is very limited knowledge available regarding the productivity of skidders when tethered to winch-assist machines, what slopes they can operate on and the impact they can have on soil disturbance.

Undertake a comprehensive case study of an existing winch-assist skidder operation to improve our knowledge of the system, including:

- A productivity study to look at the effect of slope and extraction distance.
- Soil survey to assess ground disturbance.
- Identifying Advantages and Disadvantages of a winch-assisted skidder system.

5. METHODOLOGY

An elemental time study will be carried out to determine the cycle times of a winch-assisted skidder operating down a slope. The site where the skidder is working will be assessed to describe the terrain it is working in. Delays will be recorded to determine the proportion of time the skidder was actually working per cycle. A GPS will be fitted to the skidder and record a data point every 5 seconds which will consist of an X, Y and Z coordinate locating a position and a time. This will be used to provide additional data and can determine distance travelled, slope negotiated and the speed at which the skidder moved. The data will be used to create maps of routes the skidder travelled and cross-sectional profiles of terrain negotiated.

5.1 Elemental Time study

The elemental time study cycle will consist of detailing the time of each element within the cycle and total cycle time, the length and type of any delays that occur and the number of stems extracted. This will provide information on the proportion of time each element and delay takes compared to that of the overall cycle time. The number of stems will be used to estimate the volume skidded in each cycle.

The elements in the time study will be broken into four clear categories to ensure that there is no confusion when differentiating between elements. The four categories are outlined below:

Skidder travel empty:

Skidder leaves landing empty to gather stems from hillside. Starts the moment the skidder crosses the edge of the landing. Ends when the skidder stops to pick up stem.

Loading:

Skidder picks up or repositions logs in order to create an effective bunch. Starts the moment the skidder stops travelling and picks up or repositions a stem in order to create an effective bunch. Ends when the skidder begins its return journey to the landing with a full payload.

Skidder travel loaded:

Skidder returns with payload. Starts the moment the skidder has a full payload and begins its return journey to the landing. Ends when the skidder crosses the edge of landing.

Unloading:

Skidder unloads stems onto drop zone to be processed. Starts the moment the skidder reaches and crosses the edge of the landing. Ends when the skidder crosses the edge of the landing unloaded to start a new cycle.

In the loading element, the number of stems will be recorded along with whether they were a full stem, butt end or a top end. This will provide data on how many of each log type was skidded to the landing. The volume will be taken from the average piece size. The volume of butt end and top end is calculated by the portion each takes up of the total volume of the stem. This was determined to be 77% for butt end and 21% for top end (New Zealand Forest Owners Association, 2016).

The skidded volume per cycle can then be calculated by multiplying the number of skidded stems by the average stem volume. As the harvesting is occurring in a plantation forest, the trees will be of similar age, length and DBH.

5.2 Delay Breakdown

Delays will be recorded to identify reasons the operation has stopped. A delay will consist of any period where the machine is not working. Even if it is a small amount of time it will be recorded as the same delay may happen every cycle and the accumulation of these delays may result in a large proportion of time at the end of the day. They will be categorised into 4 groups: Mechanical, Operational, Social and Other.

Mechanical:

This is where the machine is held up due to maintenance or repairs required. For example; replacing a fatigued hydraulic hose or greasing the machine.

Operational:

This is where the machine is held up by another part of the system, for example the winch-assist machine needs shifting or setting up.

Social:

This is any delay to the machine not working due to lunch break, toilet break or personal phone call.

Other:

Any other delay that does not fall into the above categories. If reason is able to be clearly identified it will be noted down.

6. SOIL SURVEY

A soil survey will be conducted to assess the ground disturbance made from the winch-assist skidder system. This will allow for quantitative data to be collected to show the disturbance effect a tethered skidder has on the soil on steep slopes. As it is impossible to monitor every section of soil due to time and budget constraints, a sample must be taken. When large samples are taken randomly it can be considered representative of the activity area as a whole. Visual classes are used to simplify and standardize soil disturbance assessments to describe the degree of change from natural conditions (Page-Dumroese, Abbott, & Rice, 2009). The investigation was carried out using a line transect method. Transect lines were established perpendicular to the main skidding direction and spaced 20m apart. Survey points were taken at 3m intervals along the transect lines. The description of the visual classes of soil disturbance were categorised into the following categories (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.

7. QUESTIONNAIRE SURVEY

Identifying the advantages and disadvantages of a winch-assisted system will be determined by reading relevant literature on previous winch-assist skidder operations and conducting a review. The Harvest Planner, Crew Boss and Skidder Operator of the visited operation will be asked a series of questions to gather their thoughts and opinions on how and why they use this system and what the benefits are. When researching how to effectively assess a new system that is being used, it was found that Key Performance Indicators were used to provide a measurable value that a company can use to gauge its progress towards achieving its goals. In a forest operation a goal may be to decrease downtime in wet conditions, reduce infrastructure costs, reduce fuel costs and reduce soil disturbance or any adverse effects on the environment. Questions were developed to determine if this system had any effects on these issues or any other added benefits.

- 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?

8. ANALYSIS APPROACH

Productivity will be determined by finding the average volume per cycle by multiplying the average stem volume by average number of stems per cycle. This divided by the average cycles per PMH will determine m^3/PMH. Productive man hours (PMH) is determined by the hours a machine actually works doing its primary task. This is shown in the equation below.

$$\boldsymbol{PMH = SMH - RM - Delays}$$

SMH = Scheduled machine hours

RM = Repair and maintenance time

Delays = Time taken for any delay that occurred.

9. SITE DESCRIPTION

The case study was carried out in Emerald Forest 30km South West of Gisborne. The forest consisted of pruned *pinus radiata* planted at 306 stems/ha. The average stem volume was 1.8t. Speirs Logging are a fully mechanised road line harvest crew which utilises both tethered felling and tethered extraction.

Figure 3: Speirs Logging Skidder Operator Whana and the Tigercat 635G

Machines Used

Tigercat 635G Skidder. Six-wheeled triple axle skidder utilising chains and belts on front and rear axles.

Figure 4: Tigercat 635 Skidder

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

Figure 5: Attachment method of winch wire rope to skidder

Falcon Winch Assist Machine

Single drum single rope hydraulic winch-assist system with 500m of winch rope on a multi-purpose excavator machine.

Figure 6: Falcon Winch Assist Machine

Figure 7 below shows the layout of a landing used in a previous winch-assisted skidding logging operation with the same crew in the same forest.

Figure 7: Layout of a previous landing

10.RESULTS

10.1 Overview

Productivity data was collected by observing 121 skidder cycles over 3 days. Cycles were broken down into key elements and the length of time was recorded for each element.

The skidder cycle consisted of the skidder leaving the landing and travelling to a location to pick up a payload of bunched stems. It then returned to the landing to unload. The total cycle time was ultimately dependent on the extraction distance that was travelled. In the unloading element, the skidder typically hauled the logs towards the surge pile then dropped its load, it then proceeded to drive to the top end of the stems and pick them up and drive them into the surge pile to align them with the other stems. If the skidder was able to drop the stems into the surge pile in one movement without having to double handle them it was significantly quicker, however in order to keep the surge pile tidy some additional moving of stems was required. The whole logging operation involved 7 machines; 2 excavators stacking the logs and loading the trucks, a processor, a felling machine, an excavator used for bunching and the skidder and winch machine for extraction.

The below figure shows a portion of the landing that was being used. It shows the processor and surge pile, Falcon Winch Assist machine and the skidder dropping its payload into the surge pile for the processor.

Figure 8: Current landing site featuring location of Falcon Winch Assist Machine and Processor along with skidder

Figure 9: Elevation changes of skidder showing mixture of cycle distances from period on Day 2

Figure 9 shows elevation changes as recorded by the GPS on the skidder. This represents a portion of day two and 22 skidder cycles can be seen. A cycle consists of a period of 3 peaks. The start shows 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. The different extraction distances are indicated by the drops in elevation. 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. From this figure it can be seen that there is a mixture of drops in elevations which relates to a mixture of extraction distances. This shows the skidder mixing up the length of cycles and hence cycle times to ensure that there is an adequate buffer at the surge pile at all times for the processor.

There were two different paths the skidder travelled. These are shown in figure 10 and 11 below. Both trails followed the same path once leaving the landing for 150m then diverge down different sides of the slope. 86 cycles were observed on Path 1 and 35 were observed on Path 2.

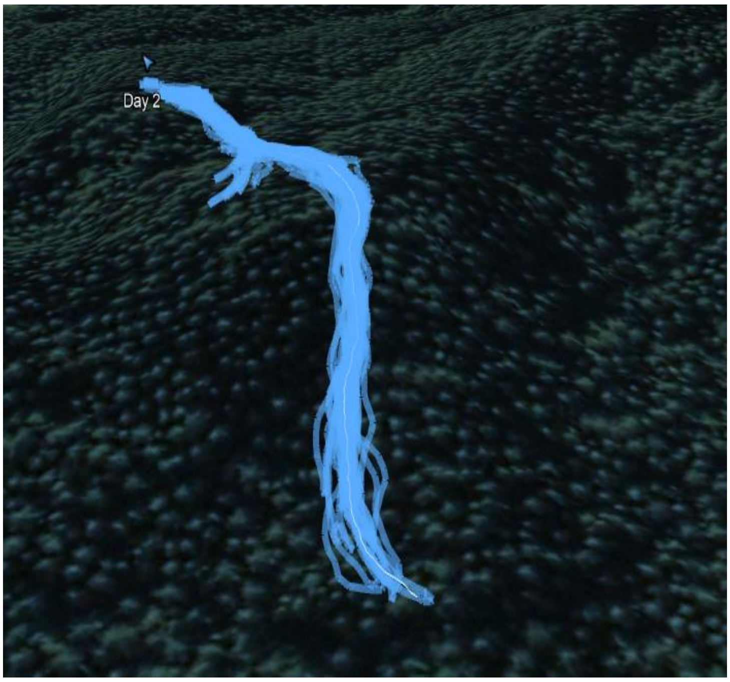

Figure 10: Path 1 travelled by the skidder on Day 1 and Day 2

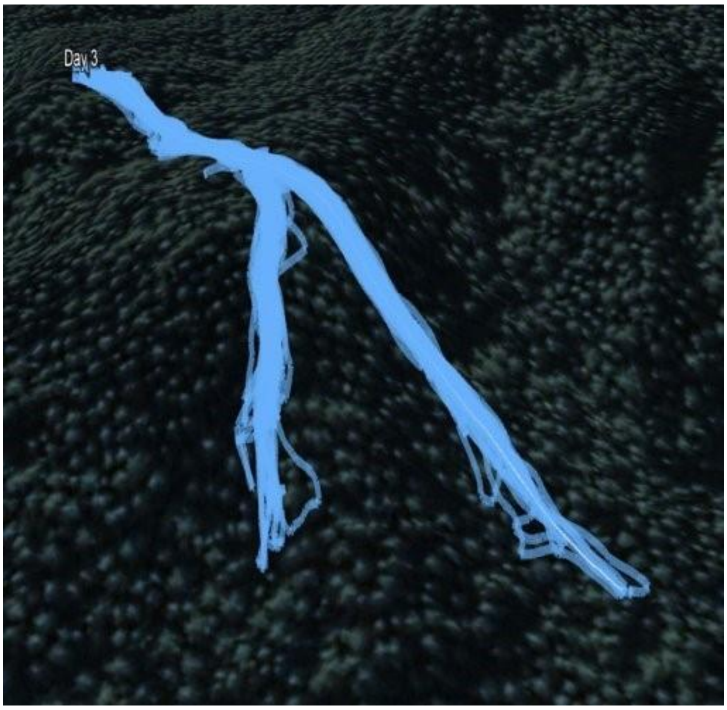

Figure 11: Path 2 (right route) travelled by the skidder on Day 3

Path 1

Path 1 was used for the first two and a half days and was a length of 300m. It consisted of stops at 60m, 90m, 110m, 150m, 240m, and 280m. It had more of a convex steep segment from 180m – 250m and its maximum slope was 33 degrees (65%). From 150m its average slope was 25 degrees (47%). The side profile of Path 1 is shown below. Initially the skidder travels downhill from the landing for 40m and then back uphill until a distance of 150m is reached. Here it travelled downhill to retrieve stems at the bottom of the hill.

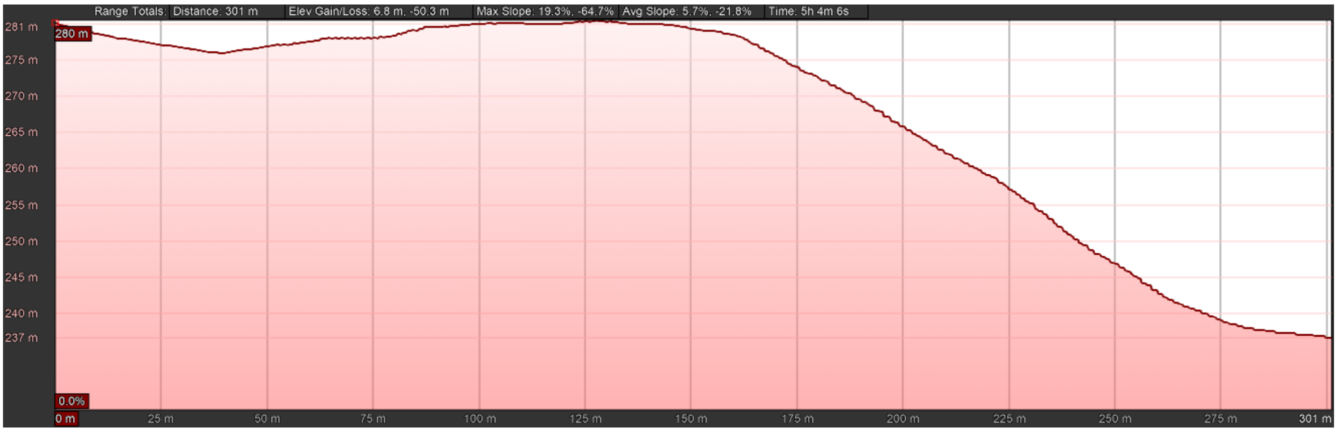

Figure 12: Side profile of Path 1

Path 2

Path 2 was used on day three and was a length of 315m. It consisted of stops at 210m, 250m and 300m. Its steep slope was more concave in shape and so its maximum slope was 30 degrees (58%). From 150m its average slope was 22 degrees (40%). The side profiles of Path 2 is shown below.

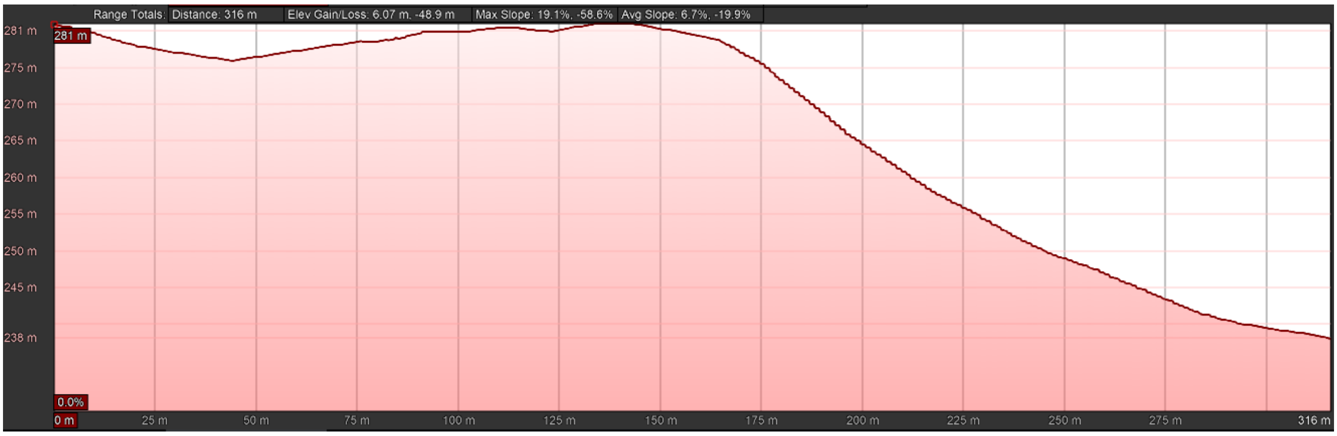

Figure 13: Side profile of Path 2

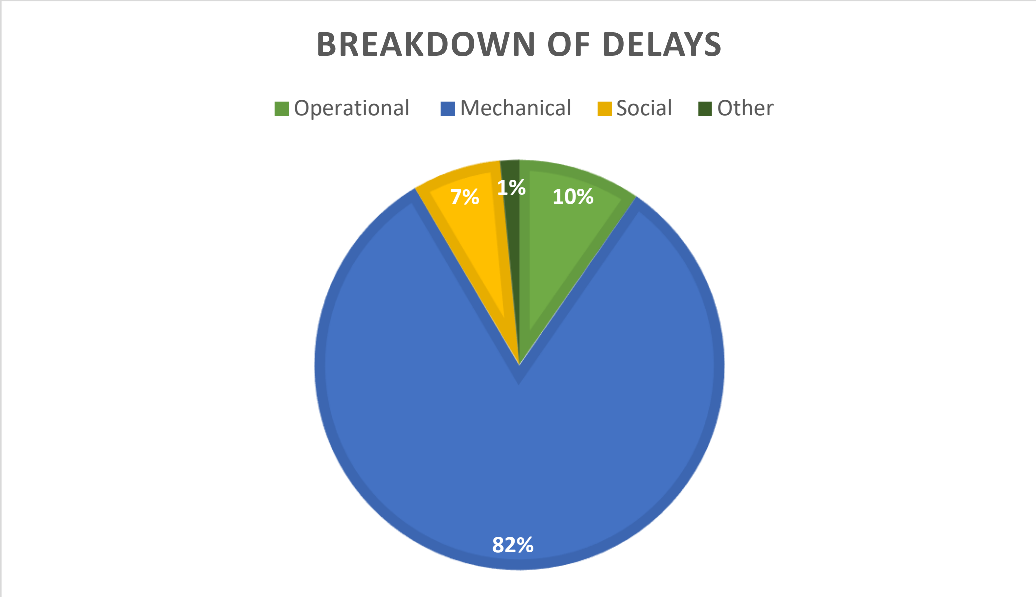

Figure 14: Breakdown of delays experienced over the study period

Figure 14 shows the breakdown of the total delays that were recorded over the three days. 82% of the time was related to a mechanical delay which occurred on day two where the belt chain on the skidders 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 mended the belt chain. 48% of the operational delay time was attributed to dropping and regathering a stem or readjusting its payload. 35% of the operational time was due to a Falcon Forestry technician from DC Equipment installing new hardware into the Falcon Winch Assist Machine's PLC. Other operational delays included allowing for the winch-assist tension to build up, and waiting for other machinery to cross the cutover. 97% of the social delay was attributed to FICA representatives visiting the operation on day two which totalled 20 minutes and 47 seconds. Other social delays included stopping to communicate through radio. The main reason for any other delays that occurred was due to the skidder moving or placing slash over the trail to improve its traction.

10.2 Productivity Study Results

Table 1 and table 2 show a breakdown of the cycles observed for both Paths 1 and 2. It details the number of cycles which were completed at each extraction distance, the average time for each element in the cycle at the respective distance, the total average cycle time and average volume skidded per extraction distance. It can be seen that the majority of cycles were at a distance of 240m or greater where the majority of the wood was. The shorter extraction distances were used to supplement the longer cycles to ensure there was an adequate buffer at the surge pile at all times.

Table 2: Breakdown of cycles for Path 1

Path 1	**Extraction Distance (m)**					
Element	**60**	**90**	**110**	**150**	**240**	**280**
n	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)**		
Element	**210**	**250**	**300**
n	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

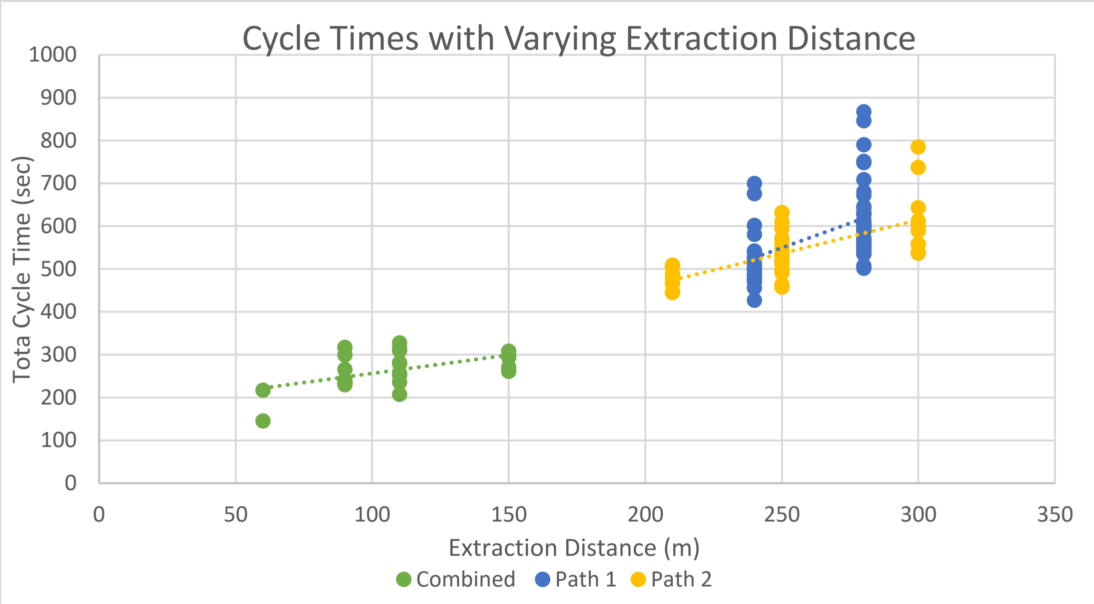

Figure 15: Cycle times recorded at measured extraction distances

Figure 15 above displays all observed cycles and the time taken to complete them along with the extraction distance each one travelled. It can be seen from the trend lines of Path 1 and Path 2 that they both have a similar average cycle time. This figure shows there is a clear relationship between the length of extraction distance and time of cycle completion.

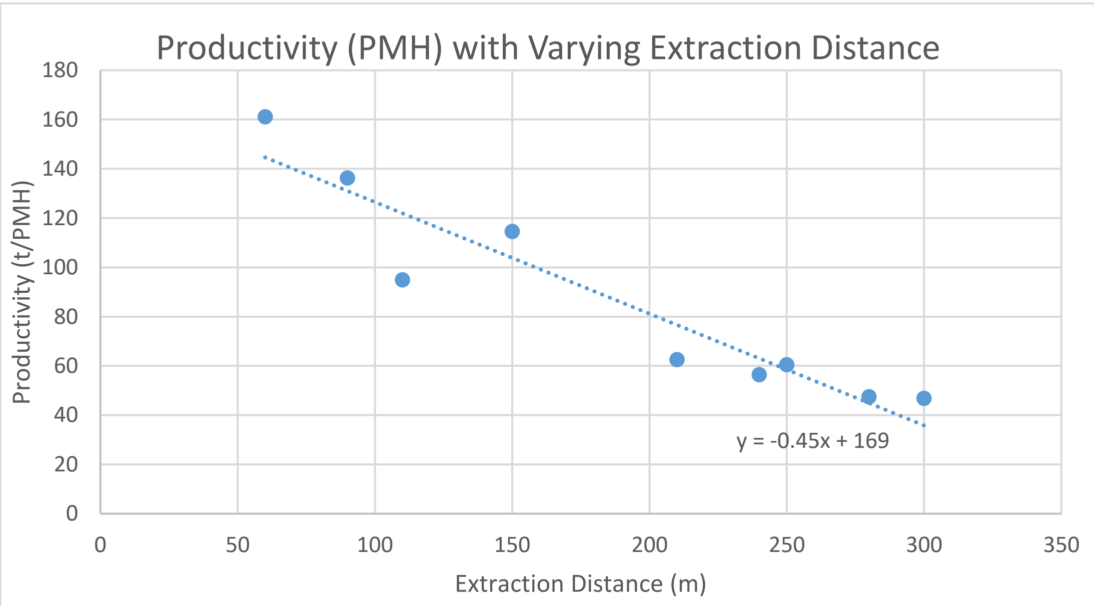

Figure 16: Productivity of average cycle times at each extraction distance

The productivity is shown above in Figure 16. The trend line here clearly shows that productivity decreases with length of extraction distance. It was evident that a small change in gradient affected the skidders ability to haul a full payload up the slope. It became more reliant on the winch machine. The ground was also dryer on day 3 when Path 2 was being used as rainfall had occurred 5 days prior to the investigation which may have had an effect on the skidders traction. The productivity equation is shown below.

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

The volume (t) skidded to the landing, scheduled machine hours (SMH), productive machine hours (PMH) and productivity per SMH and PMH for each day is shown in Table 3 below.

Table 4: Productivity results for Day 1, Day 2 and Day 3

Productivity Results					
	Volume (t)	SMH	Prod (t/SMH)	PMH	Prod (t/PMH)
Day 1	349.54	5.52	63.34	5.34	65.43
Day 2	243.40	8.38	29.04	3.62	67.28
Day 3	394.34	6.38	61.83	6.23	63.33

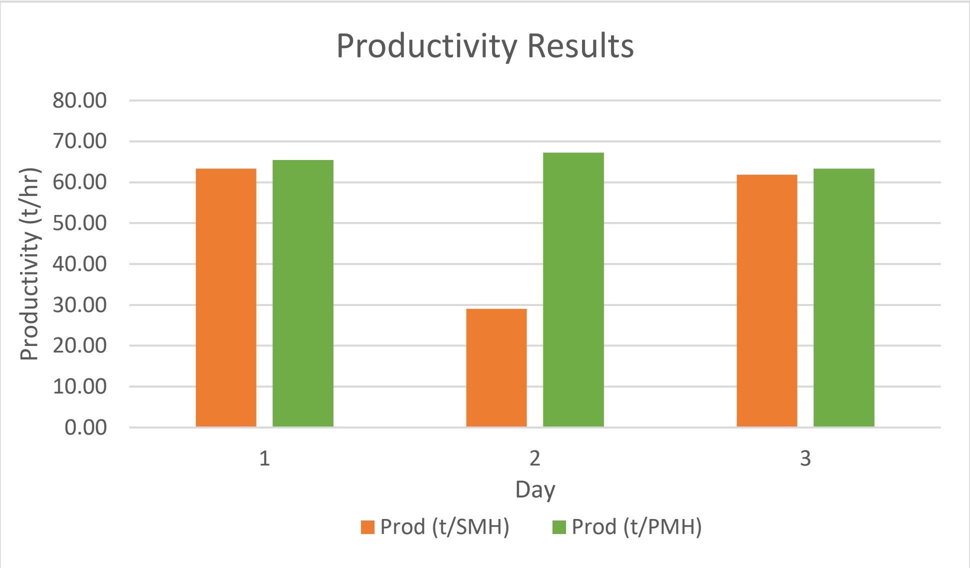

Figure 17: Productivity results from Day 1, Day 2 and Day 3

The results shown in Table 3 and Figure 17 above show that the productivity for days 1 and 3 were very similar, 63.34 t/SMH, 65.43 t/PMH and 61.83 t/SMH, 63.33 t/PMH respectively. Day 2 had a significant difference between its SMH and PMH as there was a 4 hour and 10 minute mechanical delay due to one of the skidders belt chains breaking and requiring fixing. This took up a large portion of the skidders working day and reflects the poor productivity/SMH. Day 2 also recorded the highest productivity/PMH of 67.28 t/PMH.

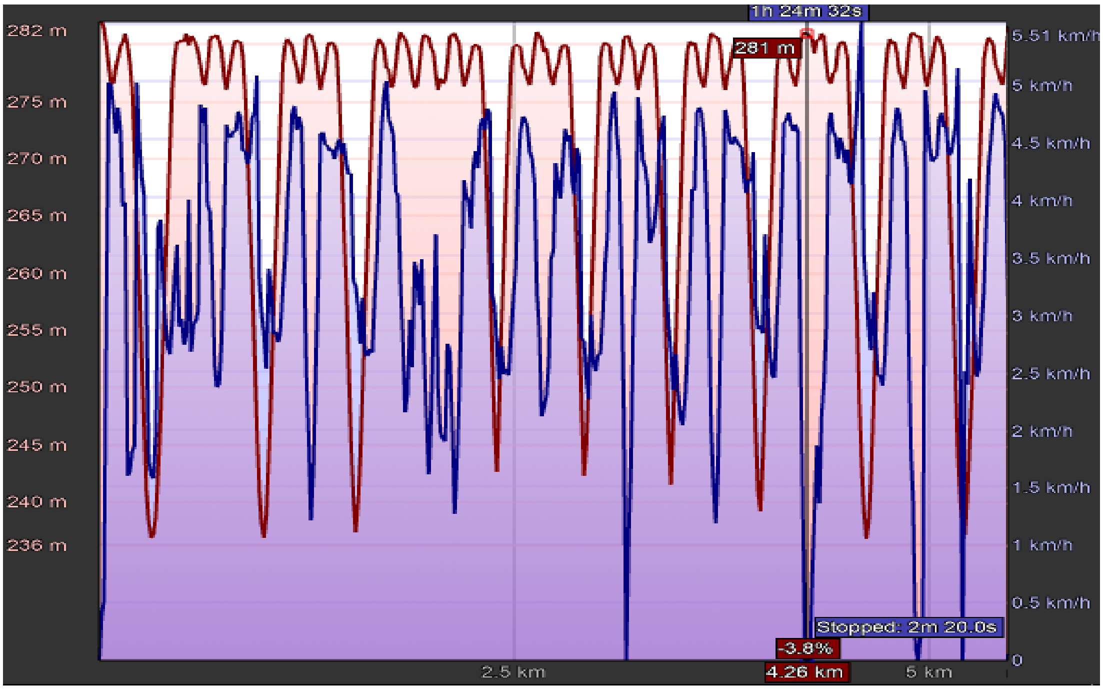

Figure 18: Changes in elevation and velocity of skidder overlaid on each other

Figure 18 shows the change in elevation overlaid with the velocity data from the GPS. It shows a breakdown of the velocity changes as the skidder travels throughout its cycles. The velocity is shown in blue and measured on the right hand side of the graph. 5.5km/hr is the speed the skidder is limited to by the Falcon Winch Assist PLC. It can be seen from this figure that as the skidder leaves the landing and travels downhill the velocity is higher than it is when it is travelling back uphill with a payload. It also shows delays which appear as zero velocity 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.

Figure 19: Skidder traversing up Path 1 with a full payload

Figure 20 displays the portion of time each element took in the cycle for 60m, 150m and 280m extraction distances. These distances represent the first stop, point where the skidder paths diverge and the last stop along Path 1. This clearly shows the effect longer extraction distances have on the portion of each element in the overall cycle time. At shorter extraction distances there is a larger proportion of unloading time. This is due to less time spent travelling empty and loaded to and from the landing. As the extraction distances increased, the portion of travelling empty and loaded increase resulting in the cycle time increasing and reducing the portion of unloading time. At distances over 150m, where the skidder has to navigate the steep segment of the path, the travelling loaded element is significantly larger than that of travelling empty. This is due to the skidders reduced speed when travelling uphill with a full payload. This is also displayed in Figure 18 earlier which showed the decreased velocity of uphill travel compared to downhill travel speed.

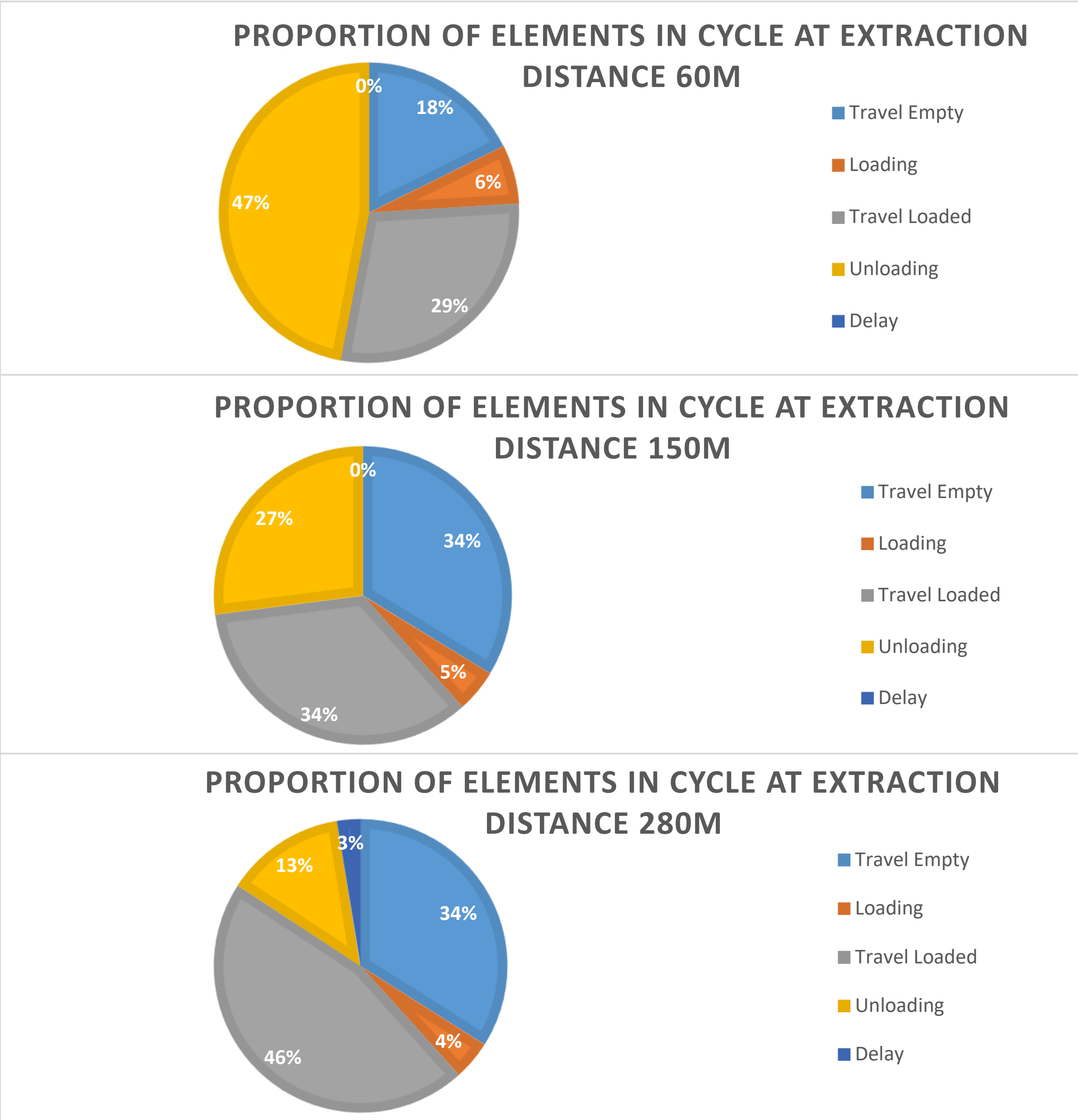

Figure 20: Portion of each element in overall cycle time for extraction distances of 60m, 150m and 280m along Path 1

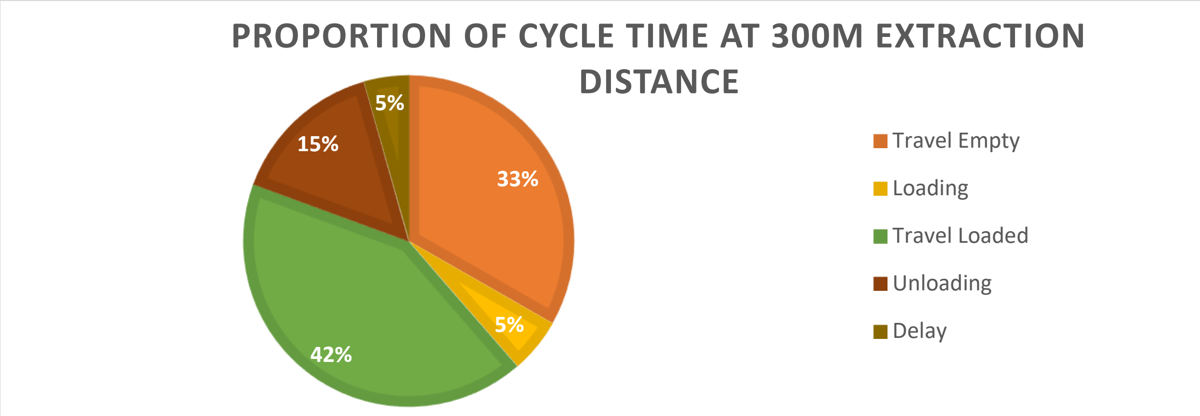

Figure 21: Portion of each element in overall cycle time for 300m extraction distance along Path 2

Figure 21 above shows the portion of time each element took in the cycle for an extraction distance of 300m along Path 2. Once again the unloading time represents a small portion compared to overall cycle time. This figure also shows the time difference between travelling empty and travelling loaded attributed to traversing the steep segment from 150m along Path 2. As there were only 35 cycles observed on this path with only 3 extraction distances there is limited data to show relationships.

10.3 Soil Disturbance Survey Results

A soil disturbance assessment was carried out using a line transect method and collecting 902 data points assessed over three different sites. At all three sites, felling was carried out by mechanised felling 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 still inside the harvest area. Site 2 and 3 were areas of the same forest which had been previously harvested.

Table 5: Description of soil disturbance assessment sites

	Area (ha)	Max 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

Site 1

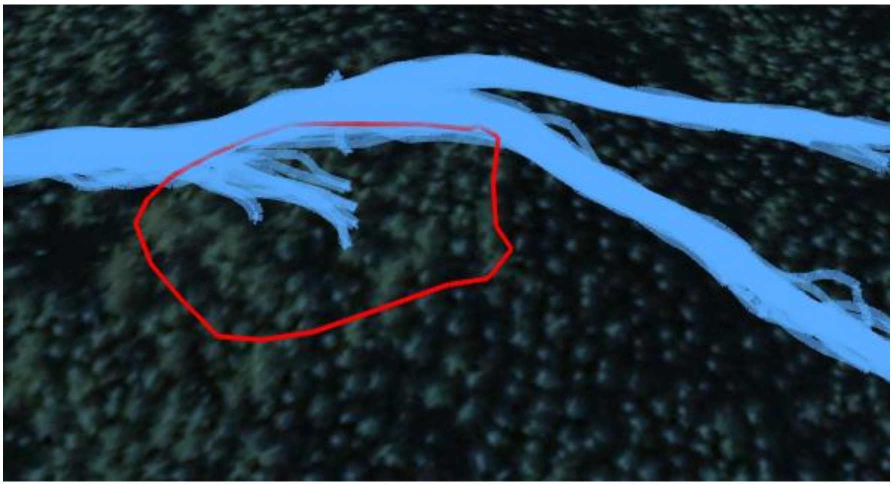

Figure 22: Soil disturbance assessment Site 1

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 as shown in figure 22. This area was 0.37ha and had an average slope of 4 degrees. The majority of the wood 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, it was at various intervals. Also the limited amount of transect lines measured and data points collected reflect this. Table 6 below shows the data collected from Site 1. It can be seen that slash was the largest classification recorded at 35% out of the total data points surveyed. Shallow disturbance accounted for 26% and deep disturbance 17%. It was noted however that a large majority of the deep disturbance was attributed to tracked machines and not the wheeled skidder. Table 6 and Figure 23 below show the results from the soil disturbance assessment.

Table 6: Table showing soil disturbance results collected at Site 1

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

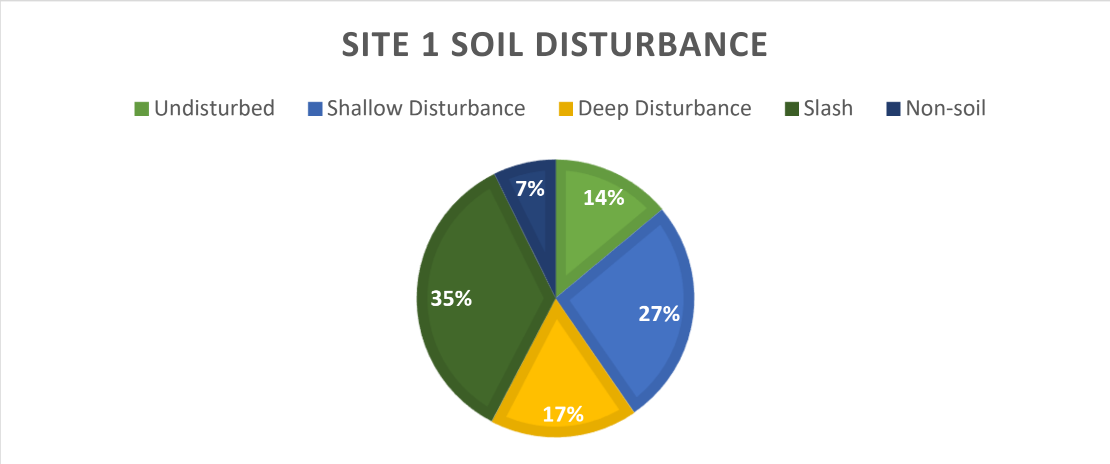

Figure 23: Percentage of each soil disturbance category at Site 1

Figure 24 below shows a section of Site 1 which was surveyed. Tracks can be seen coming off the main trail by the binding stump.

Figure 24: Photo of section of Site 1

Site 2

Figure 25: Soil disturbance assessment Sites 2 and 3

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. Slopes were ranging from 10 degrees to a maximum of 40 degrees. This site had a lot of slash placed in the cutover with 32% of the points surveyed accounting for that category. There was a relatively large portion of the area undisturbed (26%) and the site showed significant new grass growth which can be seen in figure 27. The shallow disturbance category 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. The remaining 11% of the area was attributed to points that were surveyed such as stumps, rocks or logs. Table 7 and figure 26 below show the results of the soil disturbance assessment for Site 3.

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

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

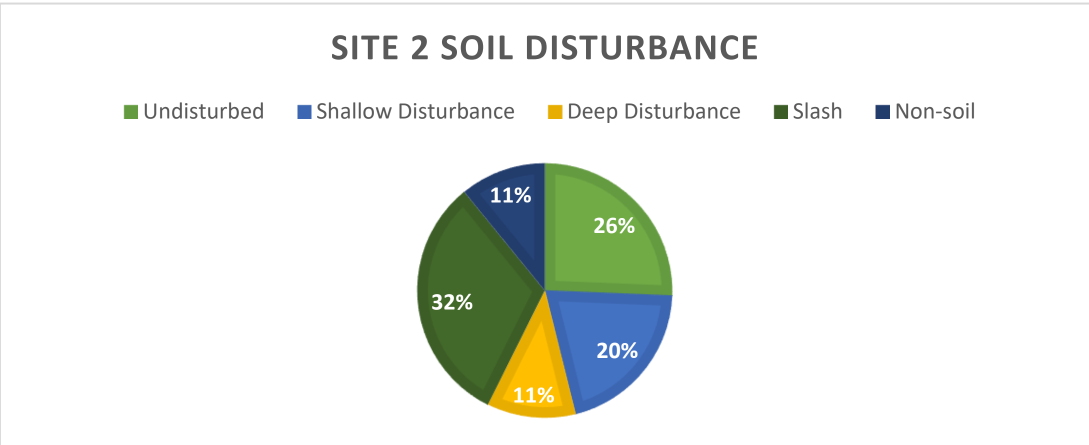

Figure 26: Percentage of each soil disturbance category at Site 2

Figure 27: Photo of cutover of Site 2

Figure 27 above shows a picture of the cutover of Site 2. Figure 28 below shows a photo of the area of Site 2. The riparian strip can be seen to still be intact due to the ability of the winch-assisted skidder system to pull away from the waterway.

Figure 28: Photo of Site 2 with riparian strip along streamside

Figure 29: Skidder path used at Site 2

Figure 29 shows a skidder path that was used at site 2 which measured 30 degrees.

Figure 30: Skidder path used at Site 2 which has been closed out

Figure 30 above shows a skidder path that has had slash placed over it to close it out. This path was on a slope of 35 degrees.

Figure 31: Scouring disturbance at Site 2

The above figure shows scouring that has occurred from a dragged stem on the top section of Site 2.

Site 3

Site 3 consisted of an area of 1.14ha. It ranged from slopes of 15 degrees to a max of 35 degrees with an average slope of 20 degrees. This site backed onto a previous landing and so there was a large pile of slash where off cuts were deposited which can be seen in figures 33 and 34. This reflects the significant amount of slash recorded (38%). Most of the undisturbed data points were taken on the sides of this catchment area. Disturbed soil made up 31% of the area with 21% in the shallow disturbance category. Once again this was attributed to exposed subgrade or shallow rutting. The deep disturbance made up 10% and was attributed to the skidder paths and deep rutting caused by tracked machines. Table 8 and figure 32 below show the results from the soil disturbance assessment from Site 3.

Table 8: Table showing soil disturbance results collected at Site 3

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

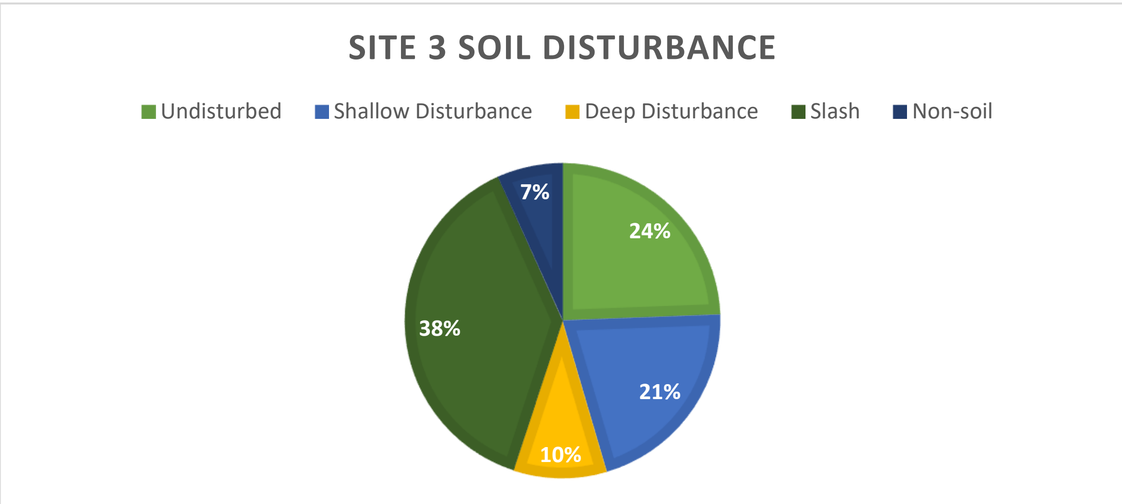

Figure 32: Percentage of each soil disturbance category at Site 3

Figure 33 and 34 both show the cutover of site 3. The landing site can be seen along with the slash pile used.

Figure 33: Photo of Site 3

Figure 34: Photo of cutover of Site 3

10.4 Survey Question Responses

The following are responses to the survey questions from the Harvest Planner, Crew Boss and Skidder Operator.

- 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?

The forest management company, Forest Enterprises Limited, don't employ a policy in regard to the systems maximum operating limit. They trust in the contractor's capability and feel that Speirs Logging manage risk extremely well. They therefore use Speirs Logging's risk assessment to decide what slopes to use the winch assisted skidder system on. They are conscious this is a new system and they are still learning how to best utilise it. One man's risk assessment may be different to another, the operator has to feel comfortable.

Blake Speirs, the crew boss stated that once the terrain stretches more than 100m over 25 degrees shovelling with an excavator no longer becomes productive and it becomes 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 present weather conditions.

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

The use of the winch-assisted skidder system along with a new six-wheeled Tigercat skidder has helped saved building 720m of road, a large culvert crossing and two skid sites which were originally planned. By having the ability to continue logging in greasy weather the tether system has enabled these to be eliminated which has resulted in reduced earthworks and reduced road infrastructure 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/poorer conditions. Originally the skidder would have been working harder in these conditions and 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?

Less fuel in the skidder is consumed when it is attached to the winch-assist, approximately 50% less 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. When attached to the winch machine, the skidder does not have to work as hard as it is being supported by the winch.

- 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. There is another further 9.3 ha which is still planned to be extracted with the cable yarder as it is very steep. 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 boss feels that it is achievable so will be decided closer to the time. The capacity to ground base the previously cable yarder territory reduces the cost of logging by approximately $6.50 -$8.50/t. The tether system also enables hauling 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 has increased by approximately 30% bringing the total utilisation of the winch machine to approximately 80%.

The ability to carry on working in wet or greasy conditions has enabled more days logging. Typically if it was wet logging hours would be reduced which decreases productivity. 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 crew boss, it 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 a big driver as it enables a 100% mechanised operation. With a cable yarder crew there is still time men are out of the cab setting up ropes, line shifts or breaking out. With the winch-assisted skidder system there is less people interaction and reduced safety risks.

Disadvantages of the winch-assisted skidder system include the speed the skidder travels at 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. 3 drags with the skidder attached to the winch-assist machine is equivalent to 4 drags without the winch-assist.

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.

11.DISCUSSION

From observing the operation throughout the case study it was clear that the whole winch-assisted skidder system had to operate efficiently in order to be productive. The focus must be on keeping the flow of the operation steady. A clear strategy was seen to be implemented in the action of achievable plans and goals. 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. Ensuring that there were always stems for the processor to process at the surge pile and maintaining enough of a buffer at all times was key so if a process further down the supply chain halted the operation, the processor could continue to work. A mix of extraction distances was required to achieve this. If all timber close to the landing was pulled first then there would be a large buffer at the surge pile which would keep the processor busy. However, when it comes time to extract the stems further from the landing, the buffer at the surge pile would be depleted and the processor would be kept waiting due to the longer extraction distance and hence longer cycle time of the skidder.

Having the correct design to lay out the landing 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 and thin landing with the winch-assist machine at one end enabled the skidder to move around freely in the cutover within the 30 degree v of the winch, binding around stumps to negotiate the best possible route to retrieve stems. At no point was the winch system in the way of any processes being carried out at the landing. This particular design of a long and thin landing is ideal for road lining crews and the system works with the crew having the chance to have 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 of stems by an excavator to selected areas along the skidder path was crucial to improve the productivity of the operation. This ensured that once the skidder had reached its required destination there were ready made bunches for it to haul back to the landing. This reduced loading time and also reduced the amount of skidder trails necessary. The bunching machine was able to bunch/shovel stems to the trail that would have been difficult for the skidder to reach.

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 productivity of this extraction system over the three days was averaged to be 65.35 t/PMH. At distances as long as 300m over terrain as steep as 33 degrees this is very productive for a ground-based crew. The average productivity per SMH over the three days was found to be 51.40 t/SMH. This is largely attributed to a significant mechanical delay which stopped the skidder from working for half of day 2. The results showed that as the extraction distance increased, cycle time increased and productivity decreased. With regard to slope, the results show that Path 2, the more concave slope with max value of 30 degrees and average of 22 degrees had a higher productivity with extraction distances over 150m. Path 1 with a more convex slope, maximum gradient of 33 degrees and average of 25 degrees had a lower productivity at extraction distances over 150m. The difference is small however and it must be known that this productivity data is only a small sample and representative of the terrain where the operation was carried out.

The soil disturbance assessment returned values of 44%, 31% and 31% for sites 1, 2 and 3 respectively for combined shallow and disturbed soil categories. From this 17%, 11% and 10% was classified as deep disturbance for the three sites. A study carried out by (Strimbu & Boswell, May 2018) in Alberta, Canada consisting of a Tigercat 635E skidder attached to a T-Winch 10.1 which compared the productivity of a skidder with and without assistance from the T-Winch also carried out a soil disturbance assessment and returned values of 33.3% for the conventional skidder system and 24.9% for the winch-assisted skidder system. The technique that was used accounted for all soil disturbance no matter how big or small. However, the average slope of the surveyed area was 26% or 14.5 degrees so significantly flatter.

Figure 35: Tigercat 635G skidder assisted by Falcon Winch Assist Machine hauling stems to landing

The main benefits of using this system included increased utilization of the winch-assist machine. This allows for the winch-assist machine to be used more often. The capability to log in greasy conditions increases the amount of days able to be logged, which in turn increases productivity.

There is a large emphasis on the ability to pull stems either side of waterways keeping the riparian strip untouched and sediment out of the waterways. A goal of using this system is to finish logging/roadlining at the bottom of the gully and look up to see all riparian zones still intact and none damaged or fallen. This is aesthetically pleasing to look at. It also provides a slash collection fence for debris to fall into in the event of a landslide. When landslides occur, more and more slash is accumulated the further they go and so leaving standing trees such as riparian strips as far up a gully as possible provides a safety net to catch slash. Cable yarding settings in areas where adequate deflection cannot be achieved requires riparian trees, willows and poplars, to be removed. The opportunity for some cable yarder settings to be accessed by ground-based extraction methods also reduces the overall logging cost. With winch-assisted ground-based extraction, there are less drags from hauler settings which create routes for water to travel down enhancing rill erosion where water accumulates and increases in velocity.

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 quickly saves money.

Figure 36: Main trail back towards landing

There have been learnings that have occurred since first using the system. 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. The figure below shows a tall binding stump that was used. It can be seen that it is positioned back from the edge of the knoll.

Figure 37: Divergence of tracks 150m from landing, tall binding stump positioned back from edge of hill.

Figure 38 below shows uphill road line logging to the skid. The second figure, figure 39 shows 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.

Figure 38: Uphill road line logging

Figure 39: Site after road construction, skidder and cutover rehabilitation

Limitations included time being a limited factor and the data collection was only carried out for a short period, 4 days. Assessing one operation only provides an insight into the winch-assist skidding operation occurring at 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.

12. ACKNOWLEDGEMENTS

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