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Productivity and utilisation of winch-assist machines: case studies in New Zealand and Canada

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EXECUTIVE SUMMARY

Winch-assist technology, where the felling machine is assisted by a winch rope tethered to another machine to improve felling machine traction, is a well-established system used with harvesting on steep slopes. However, these systems are more expensive than stand-alone feller bunchers, due to the cost of the winch machine, and little is known about their productivity and utilisation rates, or the factors that affect these. The aim of this project was to improve knowledge of the utilisation and productivity of winch-assisted harvesting, through six case studies in New Zealand and Canada.

Three to five days of continuous utilisation and productivity data were collected at each site. Utilisation was defined as the ratio of the time the machine was working on its primary tasks as a percentage of the total scheduled time. For winch-assist, working time was defined as; falling, bunching, moving between trees and brushing (cutting multiple stems). The time not included in productive time was time used for other activities not related to felling, such as shovelling (extracting felled tree stems by repeated swinging towards the road edge) or delays, defined as operational, mechanical, or personal.

Operational delays included moving the anchor machine, and setting up each line for the feller buncher, or where the winch machine was idle (waiting for work). Mechanical delays involved repairs and maintenance to the winch machine. Personal delays were recorded when the winch machine was available for work but the feller buncher operator was taking a break.

The average winch-assist productivity, recorded as volume harvested per productive machine hour (m^3/PMH), from the six case studies was 60 m^3/PMH, ranging from 34 m^3/PMH to 88 m^3/PMH. It is important that machine productivity (m^3/PMH) is considered in relation to overall machine utilisation, which is affected by the terrain and set up requirements for winch-assist systems. The volume per scheduled machine hour (m^3/SMH) was then calculated from the product of the utilisation rate and the volume harvested per PMH. The average productivity per scheduled hour through the six case studies was 30 m^3/SMH, ranging from 20m^3/SMH to 43m^3/SMH.

Delays were common in the six winch-assist operations studied, accounting for 45% of the total recorded time. Operational delays, where the winch machine was idle while the felling machine was involved in other tasks, accounted for 79% of all delays. Mechanical delays contributed 12% of total delays, and personal delays involving the operator taking a break were 9% of total delays.

The average utilisation recorded in these six case studies was 50%, which was similar to previous studies in New Zealand. The range of utilisation rates recorded over the six case studies was very wide, ranging from 22% to 60%. The relatively high amount of operational delay time for the winch machine, where it was available to work but the feller buncher was doing other tasks, results in higher costs of operation. If this utilisation rate could be increased, the cost of winch-assist harvesting would reduce significantly.

INTRODUCTION

Winch-assisted harvesting allows conventional felling machines to be supported on steep slopes with the security of a winch from an anchor machine. The anchor machine is generally located at the top of the slope. Winch-assist has become a well-established system to support harvesting on steep slopes. The reported benefits of winch-assisted harvesting for the forest industry have included improved safety performance with less manual falling and more efficient harvesting operations (Visser, Raymond and Harrill, 2014). However, these systems are more expensive in terms of operating cost than stand-alone feller bunchers, due to the cost of the winch machine, and little is known about their productivity, utilisation or the factors that affect them (Visser & Stampfer, 2015).
Previous studies on winch-assist productivity and utilisation studies provided widely differing outcomes. Amishev & Dyson; (2018) recorded a productivity of 42.8 m^3/PMH, while Malietoa (2016) recorded productivities of 79.6 m^3/PMH, 99.5 m^3/PMH and 109 m^3/PMH from three different winch-assist operations. Results from a five-month utilisation study in New Zealand indicated winch-assist utilisation at 57%. In the same report, a survey of 12 winch-assist machine owners found a mean utilisation of 45% (Harrill, Reriti, & Visser, 2018).

With an increasing demand for winch-assisted harvesting systems throughout New Zealand and Canada, an assessment of six winch-assist operations was conducted. The six case studies took place in New Zealand and Canada, and were undertaken between August 2018 and May 2019. The purpose of this research was to improve knowledge of winch-assist, through establishing the productivity and utilisation of winch-assisted harvesting systems, as well as identifying site and stand variables affecting these factors. These studies were also the basis of a Master of Forestry thesis by Cameron Leslie, a graduate student at the School of Forestry, University of Canterbury in Christchurch, New Zealand.

The winch-assist machines assessed were those manufactured by Waka Welding Ltd of Waikouaiti, Otago; the Remote Operated Bulldozer (ROB) manufactured by Rosewarne & May Ltd of Whangarei; the Tractionline manufactured by Electrical and Machinery Services Ltd (EMS) of Rotorua; and the Falcon Winch Assist manufactured by DC Equipment Ltd of Brightwater, Nelson.

The six case studies were:

- Button Logging Ltd, Okuku, North Canterbury, New Zealand
    - Waka Winch Assist on Hitachi Zaxis excavator
- Gamble Forest Harvesting Ltd, Ferny Hill, Otago, New Zealand
    - Remote Operated Bulldozer (ROB) / John Deere 850J tractor
- Mold Logging Ltd, Kaitaia, Northland, New Zealand
    - ROB / John Deere 850J tractor
- Wadlegger Logging & Construction Ltd, Clearwater, British Columbia, Canada
    - Tractionline on Cat 330DL excavator
- Lime Creek Logging Ltd, Carmi, British Columbia, Canada
    - Falcon Winch Assist on Volvo FC3329C excavator
- Gorge Creek Logging Ltd, Armstrong, British Columbia, Canada
    - ROB / John Deere 850J tractor

METHOD

The stand characteristics of each case study harvest area were recorded from the harvest plan. The typical operating slope was measured by inclinometer. The crew characteristics of each case study were recorded from observation by the author.

The total amount of time of the study was recorded by stopwatch, as scheduled machine hours (SMH). Total study time was classified into productive tasks (such as tree falling and moving the feller buncher, and extracting felled stems by shovel logging (commonly called shovelling), and delays. Shovelling describes the task where the felling machine swings felled stems towards the landing or road edge. Tree falling included bunching (collecting several felled stems into a bunch for extraction) and brushing (cutting multiple tree stems sequentially).

Delays were further classified as either operational, mechanical or personal. Operational delays included moving the anchor machine, and setting up each line for the feller buncher, or where the winch machine was idle (waiting for work). Mechanical delays involved repairs and maintenance to the winch machine. Personal delays were recorded when the winch machine was available for work but the feller buncher operator was taking a break (such as lunch).

Productive time, measured as productive machine hours (PMH), was recorded as the time the winch machine was attached to the felling machine while the felling machine was undertaking felling tasks (tree falling and moving only).

The utilisation of the winch machine was calculated as the ratio of productive felling time (total time excluding delays and shovelling) to scheduled time and expressed as a percentage.

Productivity was calculated by recording the total number of tree stems felled, and then multiplying this by the average tree size to calculate the total volume of wood produced (in cubic metres, or m^3). The total volume of trees felled was divided by the total productive time, in PMH, to calculate the average productivity in cubic metres per productive machine hour (m^3/PMH). The average productivity in m^3/PMH was multiplied by the utilisation to calculate the average productivity per scheduled machine hour (m^3/SMH).

CASE STUDY 1: BUTTON LOGGING LTD

Study Site: Okuku, North Canterbury, New Zealand

The study site was located in Okuku forest near Rangiora in North Canterbury, New Zealand. The study took place over the period of one week from the 6th – 10th August, 2018.

The harvesting contractor was Button Logging Ltd, a local contractor in the region, and having two crews contracting to Rayonier Matariki Forests. The winch was mounted on a Hitachi Zaxis excavator, and was one of six machines constructed by Waka Welding Ltd of Waikouaiti, Otago. The felling machine was a Tigercat LS855D tracked feller buncher with a Tigercat 5195 directional felling saw (Figure 1).

Figure 1. Waka Welding Ltd winch-assist and Tigercat LS855D: Case Study 1

The harvest setting was 5.8 hectares of douglas-fir *(Pseudotsuga menziesii*) with a stocking of 757 stems per hectare. The high stocking and relatively exposed site resulted in a relatively small piece size of 0.88m^3 per tree. The average slope throughout the setting was 50% although in places where the study was carried out, slopes of up to 70% were recorded with an inclinometer.

The forest site was predominantly rocky and in some cases, time was required to shift rocks and boulders out of the way when falling and manoeuvring between trees. Table 1 details the characteristics of the study site and crew.

Table 1. Stand and crew characteristics: Case Study 1

Crew	Button Logging Ltd.
Anchor machine	Waka Winch Assist on Hitachi Zaxis excavator
Felling machine	Tigercat LS855D
Felling head	Tigercat 5195 directional felling saw
Region	North Canterbury
Forest	Okuku
Harvest setting (ha)	5.8
Volume (m^3/ha)	662
Average stem volume (m^3)	0.88
Stocking (SPH)	757
Average slope (°)	29
Average slope (%)	50
Species	Douglas-fir

Results: Case Study 1

Figure 2 shows the amount of time spent in each category of work. Most of the operating time was spent falling (47%), and 32% of time was classified as delay.

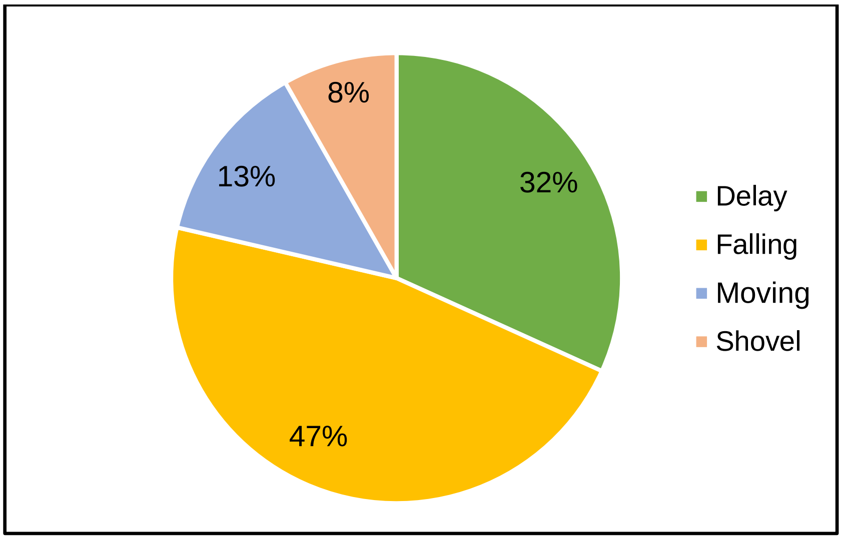

Figure 2. Proportion of operating time: Case Study 1

The large amount of time spent falling (47%) was a result of the high stocking per hectare, meaning less time was required moving (13%) between trees. Shovelling was required to clear stems that had been manually felled above a skid trail (refer to Figure 3). Shovelling was also required to open access to the end of a skid trail where the next setting for the swing yarder was to be located. Shovelling occurred for a significant amount of time during one of the days of the study (31%), and averaged 8% of total study time.

Figure 3. Shovelling along a skid trail
(Note: feller-buncher not attached to anchor machine).

Delays are common in winch-assist operations, for example moving the anchor machine and setting up each line (operational delays). Figure 4 below shows that almost half of the delays were operational (45%), followed by personal (36%) and mechanical (19%).

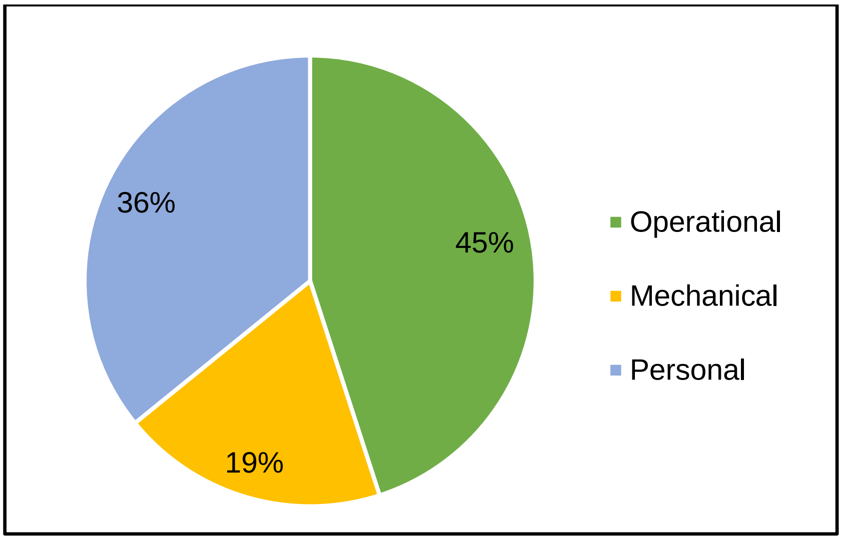

Figure 4. Breakdown of delays recorded by time study: Case Study 1

During Case Study 1, a total of 1,104 stems were felled, equating to a volume of 971.5 m^3. The total amount of time recorded during the study was 1,964.6 minutes (or 32.7 hours), resulting in an average productivity of 29.7 m^3/SMH. Excluding delays and shovelling, the productivity was 49.5 m^3/PMH. The winch-assist utilisation rate was 60%. This is the time the winch-assist machine was attached to the falling machine while it was working (falling and moving).

Observations: Case Study 1

The winch-assist operator at study site 1 was experienced, having operated a felling machine over the past five years. Although the operator had spent a lot of time working in felling machines, operating with winch-assist was a relatively new task. The operator had only seven months' experience operating winch-assist.

A commonly raised topic within the crew was the method of falling when 'winch-assisted'. The operator and other crew members noted that there was no set method, as it depends entirely on site and stand conditions. The winch-assist operator was safety conscious at study site 1, filling out two safety forms each day; a daily checklist ensuring both machines (anchor and felling machine) were inspected before operating and a mechanised falling plan. The mechanised falling plan helped identify any hazards in the felling area for the day, and how to control them.

One impact on productivity was the length of each felling corridor and the number of anchor shifts. When the corridor was short, more operational delays occurred moving the anchor machine. It was observed that each time the anchor machine was shifted, it was moved up to 100 metres along the trail to minimise the number of anchor machine shifts. A long shifting distance allows standing trees to redirect the rope when starting a new falling corridor.

The operator stated that having a second track above the tree face or having the ability to position the anchor machine well above the tree face would decrease operational delay. A second track increases the area able to be harvested before moving the anchor machine. An example of a second track can be seen in Figure 4. It was noted that the main purpose of this track was for access to provide access for the swing yarder tail hold machine (Figure 5).

Figure 5. Second track that could be used for the anchor machine (Case Study 1)

Winch-assist felling machines are higher cost than a manual falling system, although using a machine to fall and bunch trees increases the productivity of the next process in the harvesting system. For example, the felling machine in this operation laid stems across the slope in bunches of two or three, providing a significant improvement to the productivity of the cable yarder.

CASE STUDY 2: GAMBLE FOREST HARVESTING LTD

Study Site: Ferny Hill, Otago, New Zealand

The study site was located in Ferny Hill forest near Mosgiel in Otago, New Zealand. The study took place over a one-week period from 20th – 24th August, 2018.

The harvest setting was 16.2 hectares of radiata pine (*Pinus radiata*) and a tree stocking of 278 stems per hectare. The low stocking and longer rotation (32 years) of this stand resulted in trees with a relatively large piece size of 2.23m^3 in comparison to the other 5 studies. The average slope was 48% although it varied across the site with 22% of the area being less than 32% slope, 37% of the area was between 32 and 50% slope and 41% of the area was greater than 50% slope. The typical operating slope measured by inclinometer, during the study was 47%.

The ground was solid with strong and dry soil, providing good traction for ground-based machinery on days 1 2 and 3. On day 4, operations took place near the stream where soil was wet and soft. There was very little undergrowth throughout the study meaning limited brushing was required when falling trees and manoeuvring between trees.

The harvesting contractor was a resident in the area, with a long-term family relationship of at least 30 years with City Forests Ltd, the forest management company. The winch-assist machine was a Remote Operated Bulldozer (ROB) manufactured by Rosewarne & May Ltd in Whangarei, based on a John Deere 850 bulldozer. The felling machine was a John Deere 909MH feller buncher with a Woodsman Pro FH1350 directional felling saw (Figure 6).

Figure 6. ROB winch-assist and John Deere 909MH: Case Study 2

Table 2. Stand and crew characteristics: Case Study 2

Crew	Gamble Forest Harvesting Ltd
Anchor machine	Remote Operated Bulldozer (ROB)
Felling machine	John Deere 909MH
Felling head	Woodsman Pro FH1350 directional felling saw
Region	Otago
Forest	Ferny Hill
Harvest setting (ha)	16.2
Volume (m^3/ha)	621
Average stem volume (m^3)	2.23
Stocking (SPH)	278
Average slope (°)	26
Average slope (%)	48
Species	Radiata pine

Results: Case Study 2

As can be seen in Figure 7, 29% of time was spent falling and 20% of time moving between trees. The similarity in falling and moving time is a result of the relatively low stocking, requiring more time moving between trees.

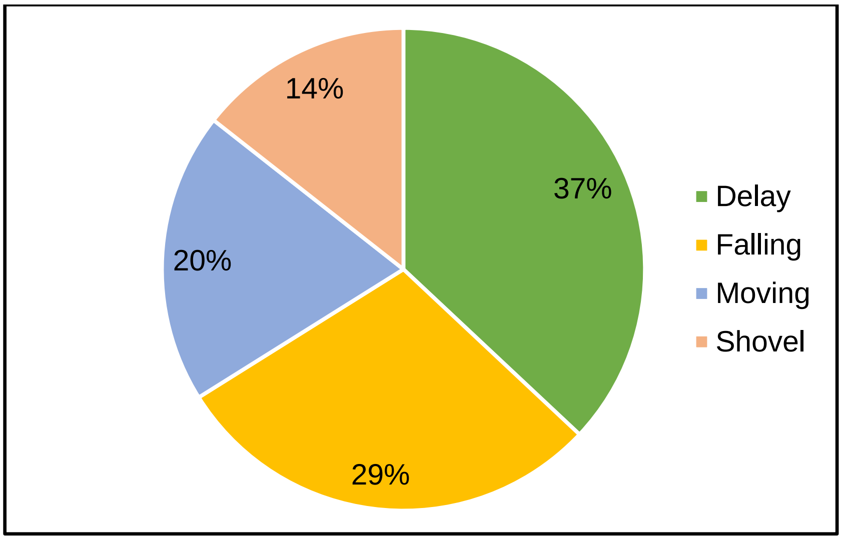

Figure 7. Proportion of operating time: Case Study 2

Shovelling (14%) took place when the harvested area was not visible to the swing yarder operator and when falling beside the stream. When falling and shovelling flat areas beside the stream, the falling machine detached from the anchor machine allowing easier manoeuvring (Figure 8).

Figure 8. John Deere 909MH beside a surge pile of trees shovelled to road: Case Study 2

The largest proportion of operating time during the study was classified as delay (37%). The main components within delay is described in Figure 9 with the majority of delays being operational (76%). Operational delays are defined as the felling part of the system being available to 'work', but was being held up by other parts of the operation. In this case, moving the anchor machine was the most significant operational delay. Anchor shifts occurred more frequently when the area of harvest changed, and corridor lengths were shorter.

Most mechanical delays (21%) occurred because of bar and chain problems, that is changing blunt chains. Only 3% of delays were personal, meaning that the operator either did not take long breaks and/or was good at multi-tasking, (for example, taking phone calls while operating and eating food during other delay periods).

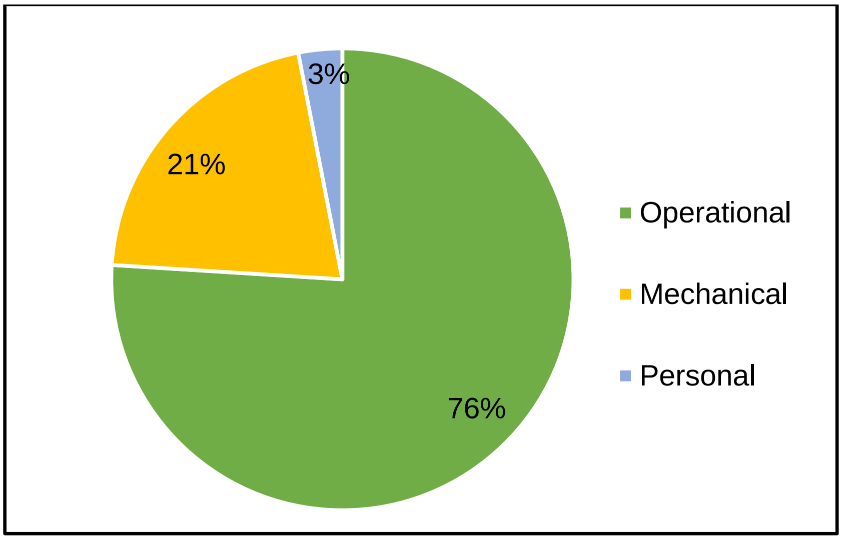

Figure 9. Breakdown of delays recorded by time study: Case Study 2

In Case Study 2, 669 trees were felled, equating to a volume of 1,493 m^3. The total amount of time recorded was 2,083 minutes (or 34.7 hours), resulting in a productivity of 43 m^3/SMH. Excluding delays, productivity was 88m^3/PMH. On one day, the productivity was 114m^3/PMH as a result of suitable falling conditions such as long even slopes and large piece size (Figure 10). The winch-assist utilisation rate in Case Study 2 was 49%. This is the time the winch-assist machine was attached to the falling machine while it was working (falling and moving).

Figure 10. Site conditions that yielded the highest productivity at Case Study 2

Observations: Case Study 2

As the week progressed, the difficulty of falling increase. The terrain changed from long even slopes to short slopes directly leading into a stream. Harvesting near streams requires significant care to protect riparian zones and watercourses. The solution for this area, was to pull stems away from the river and fall back into the cutover, adding time. Shortly after beginning this process, the operation was halted, and the remaining area was to be left standing as there was a high risk of stems sliding into the stream. Due to several rocky bluffs in the middle of the slope the terrain was difficult and dangerous for the winch-assist machine. The shovelling process would have been slow and added significant cost if this had continued.

Where slopes were not visible to the swing yarder operator or sufficient yarder deflection was poor, shovelling to a visible destination took place creating a stockpile of cut trees ready for yarder extraction. This slowed the productivity of the winch-assist machine, although it helped to increase the overall productivity of the operation. The large piece size on this site meant there was no need to bunch in preparation for extraction.

The setting can be seen in Figure 11.

Figure 11. ROB winch machine and John Deere 909MH felling machine: Case Study 2

CASE STUDY 3: MOLD LOGGING LTD.

Study Site: Herekino, Northland, New Zealand

The study site was located in Herekino forest near Kaitaia in Northland, New Zealand. The study took place over a week from the 29th of April until the 23rd of May, 2019.

The harvest setting was 25.2 hectares of radiata pine (*Pinus radiata*) with a stocking of 320 stems per hectare. The relatively low stocking had enabled the trees to grow to a large piece size of 1.9m^3 per tree. The average slope was 28 degrees and varied across the site with slopes of up to 46 degrees measured on site with an inclinometer. The soil was clay and shallow in places, large rocks were present in the soil. The soil was not favourable for winch-assist, causing traction issues on steeper slopes. The undergrowth was abundant at an average recorded height of 5 metres.

The harvesting contractor was Mold Logging Ltd and the forest management company was Summit Forests New Zealand Ltd. The winch-assist machine operating was a Remote Operated Bulldozer (ROB) manufactured by Rosewarne & May Ltd in Whangarei, based on a John Deere 850J bulldozer. The felling machine was a Tigercat LS855C with a Tigercat directional felling head (Figure 12).

Figure 12. Rob winch-assist and Tigercat LS855C: Case Study 3

Table 3. Stand and crew characteristics: Case Study 3

Crew	Mold Logging Ltd.
Anchor machine	Remote Operated Bulldozer (ROB) / JD 850J
Felling machine	Tigercat LS855C
Felling head	Tigercat Directional felling head
Region	Northland
Forest	Herekino
Harvest setting (ha)	25.2
Volume (m^3/ha)	608
Average stem volume (m^3)	1.9
Stocking (SPH)	320
Average slope (°)	28
Average slope (%)	53
Species	*Pinus radiata*

Results: Case Study 3

At study site 3, 15% of time was spent falling, 7% moving and 31% was due to delays. Shovelling (47%) was the largest proportion of operating time (Figure 13).

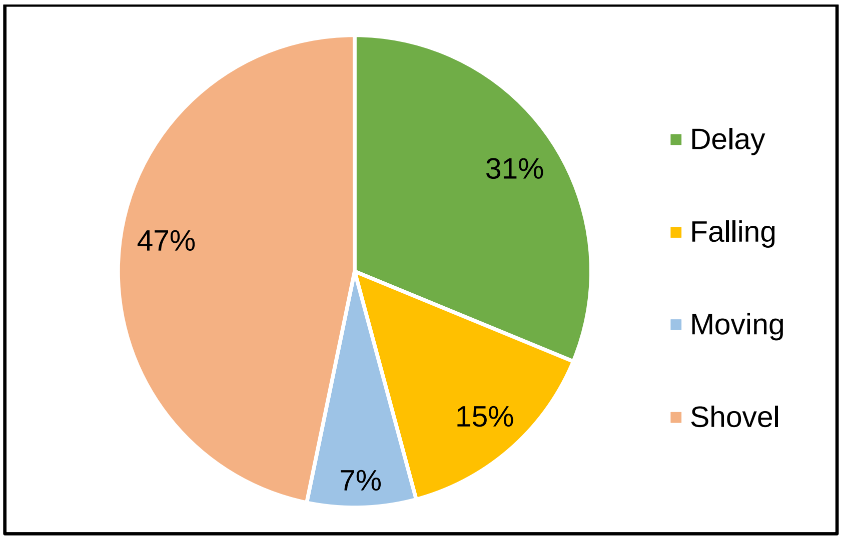

Figure 13. Proportion of operating time: Case Study 3

Stems were felled into gullies where shovelling up the slope was easier and the other excavators on site helped with the extraction (refer to figure 14). When slope was less than 20 degrees, the felling machine detached from the anchor machine to fall and shovel.

Some (31%) of time was classified as delay. A breakdown of what made up delay can be seen in Figure15 below. The majority of those delays were operational (49%). Operational delays are defined as the system being available to 'work' but are being held up by other parts of the operation. In this case, moving the anchor machine was the most significant operational delay. Mechanical delays (38%) occurred due to bar, chain and wire rope problems; specifically putting chain on the bar after slipping off. Personal delay (13%) was due to lunch breaks.

Figure 14. Komatsu PC270 assisting Tigercat LS855C with shovel extraction (winch wire rope highlighted in red).

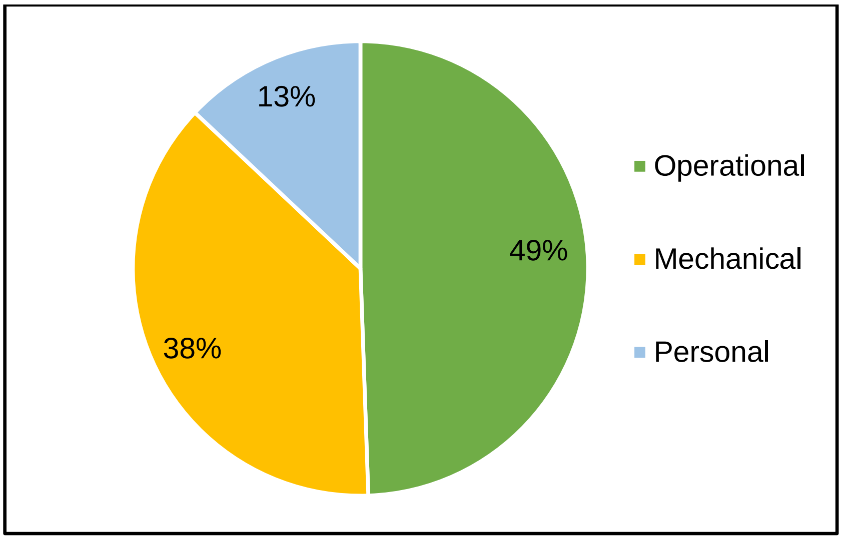

Figure 15. Breakdown of delays recorded by time study: Case Study 3

During the study period 117 trees were felled, equating to a volume of 222m^3. The total amount of time recording took place was 1,246 minutes (or) 20.8 hours, resulting in a productivity of 10.7m^3/SMH. Excluding delays, productivity was 48.5m^3/PMH.

The winch-assist utilisation rate was 22% which is the time the winch-assisted machine was working (falling and moving) and attached to the anchor machine

Observations: Case Study 3

The system involved winch-assist falling and shovelling on a steep hauler setting. The system would normally use a swing yarder for extraction however a number of factors prevented this; for example; the swing yarder was under maintenance, the setting had poor deflection, the nature of the block was dangerous and unsafe for manual breaking out or the undergrowth was thick and unsafe for manual falling.

The undergrowth on site 6 was brushed and relocated away from the shovelling path. Stems being shovelled up a slope are more likely to slide down the slope if woody debris are on the ground (Figure 16).

Figure 16. Tigercat LS855C next to undergrowth with an average height of 5m.

This site was a difficult setting often requiring three excavators working together on the slope (Figure 17). The winch-assisted felling machine shovelled stems to an area safe for a conventional excavator. The excavator closest to the winch-assist machine commonly cut a bench into the slope, allowing easier and safer shovelling.

Figure 17. Site conditions at Case Study 3 showing three excavators working together.

The steep slopes and rocky outcrops lead to wire rope fatigue (figure 18). The wire rope damage was a large mechanical delay, halting operations for the day requiring a mechanic to be called out and repair the wire rope.

Figure 18. Wire rope fatigue at Case Study 3 caused from repetitive use on steep slopes and rocky outcrops.

CASE STUDY 4: WADLEGGER LOGGING & CONSTRUCTIN LTD.

Study Site: Clearwater, British Columbia, Canada

The site for this case study was located 2 hours north of Kamloops near Clearwater, British Columbia. The study took place over three days between the 8th - 13th November, 2018.

The harvesting contractor Wadlegger Logging & Construction Ltd was currently harvesting under contract for Canfor. The winch-assist machine was an EMS Tractionline on a Cat 330DL excavator base. The felling machine was a Tigercat L870C with a Tigercat 5702 continuous rotation bunching saw (Figure 13).

The harvest setting was 12.3 hectares with a stocking of 423 stems/ha; 78% spruce (*Picea engelmannii*), 14% balsam fir (*Abies balsamea*), 4% douglas-fir (*Pseudotsuga menziesii*) and 4% lodgepole pine (*Pinus contorta*).

The study site was located between 1210 and 1630 m elevation. During the study, the soil was frozen and firm. Large rocky outcrops were common in the forest and required blasting for road access. Dense undergrowth required brushing of small stems to gain access to the larger diameter commercial trees. The bunching saw is efficient at brushing, being able to grab multiple trees in a single cycle.

Figure 19. Tractionline winch-assist and Tigercat L870C feller buncher: Case Study 4

Table 3. Stand and crew characteristics: Case Study 4

Crew	Wadlegger Logging and Construction Ltd.
Anchor machine	EMS Tractionline on Cat 330DL
Felling machine	Tigercat L870C
Felling head	Tigercat 5702 bunching saw
Region	Clearwater, B.C, Canada
Forest	Block D219
Harvest setting (ha)	12.3
Volume (m^3/ha)	296
Average stem volume (m^3)	0.7
Stocking (SPH)	423
Average slope (°)	29
Average slope (%)	51
Species	Spruce, Balsam, Douglas-fir, Lodgepole pine

Results: Case Study 4

At study site 4. 38% was spent falling, 19% of time was spent moving and 43% was due to delays (Figure 20).

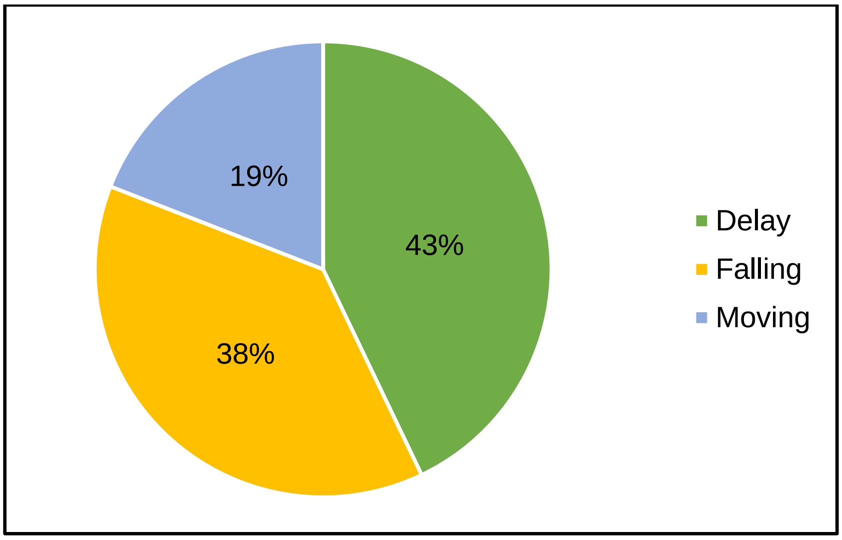

Figure 20. Proportion of operating time: Case Study 4

The largest proportion of operating time throughout the week was delay (43%). Delay was influenced by the short corridor lengths, which required frequent anchor machine shifts and line handling. A breakdown of delays is shown in Figure 21. The majority of delays were operational (86%), defined as the system being available to 'work', but held up by other parts of the operation. Moving the anchor machine was the most significant operational delay, followed by walking the machines to the block entrance to refuel. Anchor shifts occurred more frequently when the corridor lengths decreased in narrow areas of the setting. Mechanical delays (13%) occurred because of hydraulic hose issues. The operator rarely stopped working, resulting in only 1% of personal delay.

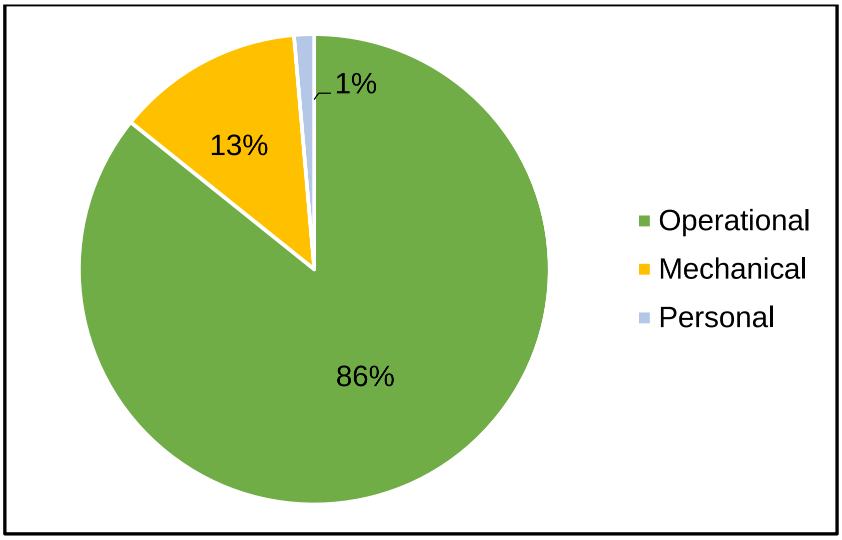

Figure 21. Breakdown of delays recorded by time study at Case Study 4

Figure 22 shows the falling machine at the end of the corridor, in this instance the corridor length is 45 metres.

Figure 22. Tigercat L870C felling a stem at the end of a 45 metre corridor at Case Study 4

During the study period, 706 trees were felled. The piece size was 0.7 m^3 equating to a volume of 494.2 m^3. The total study period was 870 minutes (or) 14.5 hours, resulting in a productivity of 34 m^3/SMH. The productivity was 60 m^3/PMH when taking into account only the moving and falling elements.

During this short-term study, the utilisation rate was 57% when the felling machine was working and tethered to the Tractionline machine (i.e. both machines working together).

Observations: Case Study 4

Winch-assist has recently been integrated into this system to allow more forest area to be accessed by machines. The felling machine was winched up and down the slope falling and bunching trees while travelling both uphill and downhill. The extraction phase will use a self-levelling excavator winched down the same slope, shovelling to a skid trail at the bottom of the block where a skidder can gain access (Figure 23).

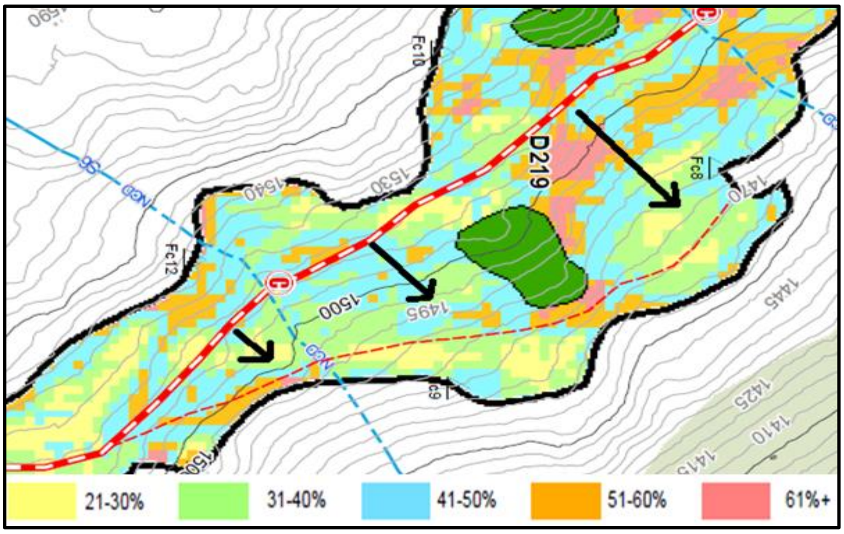

Figure 23. Slope map displaying the main access road, skid trail and direction of shovelling: Case Study 4

Productivity was most significantly impacted by the amount of anchor machine shifts. On the third day of the study, 46% of time was delay. A second person operating the anchor machine could speed up this task when working in short corridors. Other delays were; slashing wet areas, line handling, radio communication, refuelling, replacing a hose and poor visibility from snowfall when falling trees, requiring the operator to stop and wait (Figure 24).


Figure 24. Tigercat L870C and EMS traction line working at Case Study 4 (note snow fall above Tigercat L870C)

The stand had four tree species and varied age classes, with DBH ranging from 15cm to 83cm. The continuous rotating bunching saw appeared to suit these conditions well; being able to brush and having the ability to fall multiple stems in a single cycle. More than 1 tree was felled in 26% of cycles. Double cuts were required on larger trees; one cut below, and a second from above. Mechanical delays were not common, having new equipment and with regular servicing. Bunching saws require less maintenance than feller directors as they do not have a bar and chain (Figure 25).

Figure 25. Tigercat 5702 continuous rotating hot saw

Slashing was required in multiple areas at this site 4 where the soil was wet and excessive machine disturbance was frequent.

CASE STUDY 5: LIME CREEK LOGGING LTD.

Study Site: Carmi, British Columbia, Canada

The study site was located 1-hour south-east of Kelowna near Carmi, British Columbia. The study took place over a week from the 26th – 30th November 2018.

The harvesting contractor was Lime Creek Logging Ltd. currently harvesting under contract for Interfor Corporation. The anchor machine was a Falcon Winch Assist mounted to a Volvo FC3329C. The felling machine was a Tigercat LX870D with a Tigercat 5702-26 continuous rotation bunching hot saw (Figure 26).

Figure 26. Falcon winch-assist and Tigercat LX870D: Case Study 5

Harvesting took place in three settings within the same forest. The first setting was 5.1 hectares with a stocking of 575 stems/ha. The second setting was 16.5 ha with a stocking of 368 stems/ha.The third setting was 23.7 ha with a stocking of 450 stems/ha. The species present were engelmann spruce (*Picea engelmannii*), balsam fir (*Abies balsamea*), douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), western larch *(Larix occidentalis*).

There was rock on the three sites but not enough to impede the operations. The terrain was broken within the areas viewed during the study (along with landscape in general). Therefore a mix of conventional untethered falling and winch-assist falling was needed. In areas of the forest, regeneration was thick, especially in areas where tracks and landings were located during first growth harvest. Throughout the stand, dense undergrowth required brushing of small stems to gain access to the larger diameter commercial trees.

Extraction was done by a method the operator referred to as “packing” given steep slopes observed didn’t exceed 100m in length. “Packing” was defined as walking the machine while carrying the cut tree stems. In this way stems are extracted to either the top or bottom of the slope where a skidder can reach them. This meant that extraction using a yarder or other machine was not required.

Table 5. Stand and crew characteristics: Case Study 5

Anchor machine	FFE Falcon on Volvo FC3329C		
Felling machine	Tigercat LX870D		
Felling head	Tigercat 5702-26 bunching saw		
Region	Carmi, B.C, Canada		
Forest	Block 10L-88, 10L-79 and 10L-78		
Details	Setting 1 (Day 1)	Setting 2 (Day 2)	Setting 3 (Day 3)
Harvest setting (ha)	5.1	16.5	23.7
Volume (m^3/ha)	290	274	353
Average stem volume (m^3)	0.50	0.74	0.79
Stocking (SPH)	575	368	450
Average slope (°)	36	33	32
Average slope (%)	73	67	65
Species	Spruce, Balsam, Douglas-fir, Lodgepole pine, Larch		

Results: Case Study 5

The largest proportion of operating time throughout the week was delay (48%). During this study, delay was a result of the natural terrain, leading to more frequent anchor shifts and areas where untethered falling took place (flat benches).

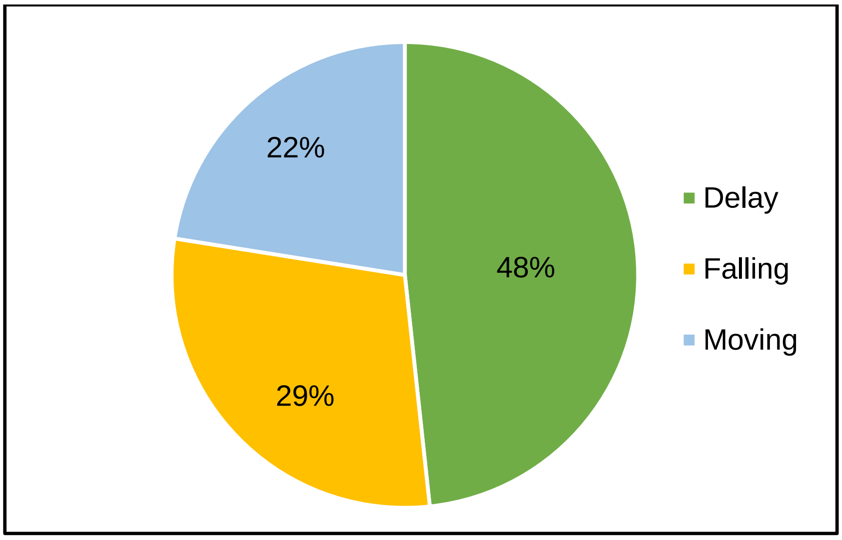

Figure 27. Proportion of operating time: Case Study 5

A breakdown of delays is shown in Figure 28. Delays are defined as the system being available to ‘work’, but held up by other parts of the operation. Delays observed were; moving setting, felling without winch-assist, relocating the anchor machine, refuelling, line handling, mechanical breakdowns, and personal delay.

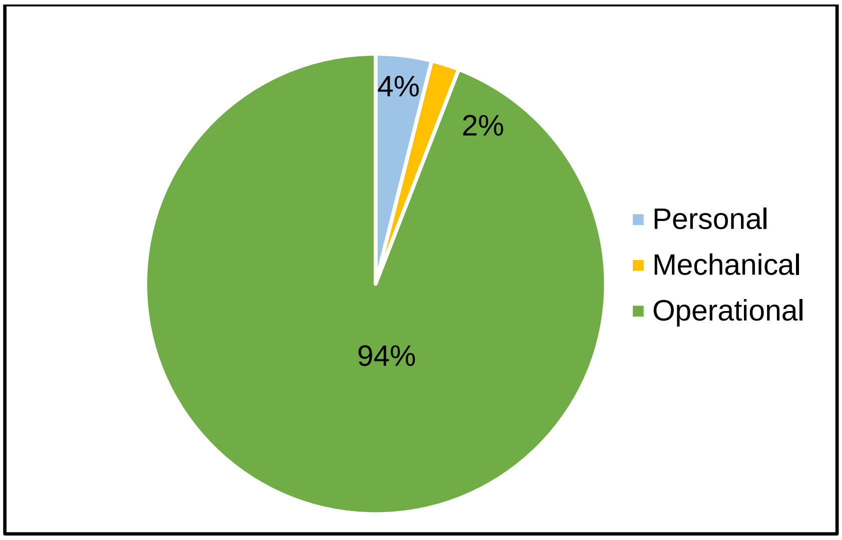

Figure 28. Breakdown of delays recorded by time study: Case Study 5

During the four-day study period, 819 trees were felled. The average piece size throughout the three sites was 0.71 m^3 equating to a volume of 581m^3. The total study time was 17.3 hours, giving a productivity of 34 m^3/SMH. The productivity was 65 m^3/PMH when only considering Moving and Falling.

The utilisation rate when the falling machine was working and tethered to the FFE anchor machine (both machines working together) was 52%. During the time study the operator mentioned that the winch-assist machine is often being utilised less than 50%. This is due to the nature of the terrain in the cut-blocks and some slopes being less than 50%.

Observations: Case Study 5

The harvest system at this site was a steep slope ground based operation. Winch-assist has recently been integrated into this system to allow more forest area to be accessed by machines with reduced hand falling and improved safety. The felling machine was working both up and down the hill with winch-assist falling and bunching trees.

The operator at this site prefers falling when moving up the slope, producing a shorter stump and hence more merchantable volume produced. The centre of gravity is at optimum position for cutting when the falling head is uphill. The average slope on day 1 was 73% with rocky outcrops present and a corridor length no greater than 100 metres. Slope at setting 2 was 67% with slightly longer corridor lengths. When falling landings, roadside, benches or gullies, the winch-assist machine would shut down and falling would take place untethered (which for the purpose of this study is defined as a delay).

On the second day 3 ½ hours was required to move both machines to a new setting. Figure 29 shows the Falcon Winch Assist ready to shift setting. The new setting required untethered harvesting to take place; clearing skid roads and falling of trees close to the road.

Figure 29. Falcon Winch Assist moving setting: Case Study 5

To avoid the risk of damage to the winch line when moving the line over stumps or obstacles, the operator stopped the hot saw quickly turning off the hydraulic flow and cutting part way into a larger stump.

A task by the name of ‘Packing’ was carried out at this study site. This is where full stems were ‘packed’ to the bottom or top of the slope (Figure 30). In this operation “packing” occurred when corridor lengths were less than 100m.

The extraction phase at this site was carried out by a Tigercat 632E skidder from either the top or the bottom of the slope where lower gradient slopes allow safe access. If a pre-existing road was not located on the slope, a skid road would be constructed for stem extraction.

Figure 30. Tigercat LX870D packing a stem to the bottom of the corridor at Case Study 5

CASE STUDY 6: GORGE CREEK LOGGING LTD.

Study Site: Armstrong, British Columbia, Canada

The study site was located in the Thompson Okanagan Region near Armstrong, a small town 1 hour north of Vernon, British Columbia. The study took place over two days from the 19th – 20th December 2018.

The harvesting contractor was Gorge Creek Logging Ltd. currently harvesting under contract for Tolko Industries Ltd. The anchor machine was a Remote Operated Bulldozer (ROB) mounted on a John Deere 850J base machine. The felling machine was a levelling Cat 552 with a Satco feller director head and heel (Figure 31).

Figure 31. ROB winch-assist and Cat 552: Case Study 6

The forest setting was 36.3 hectares with a stocking of 890 SPH. The forest was second growth and the average piece size 0.41m^3. There were few rocks and soil did not impede productivity although snow was present at a depth of 1 – 1.5 m. The terrain was relatively easy-going throughout although very steep pitches occurred in some places. Throughout the stand, dense undergrowth required brushing of small stems to gain access to the larger diameter commercial trees. Extraction was carried out during the falling phase whereby the operator would hoe-chuck stems down the slope while falling.

Table 6 below presents the stand characteristics as provided by Tolko Industries Ltd.

Table 6. Stand and crew characteristics: Case Study 6

Crew	Gorge Creek Logging Ltd.
Anchor machine	ROB on John Deere 850J
Felling machine	Self-levelling Cat 552
Felling head	Satco feller director
Region	Armstrong, B.C, Canada
Forest	Block 183
Harvest setting (ha)	36.3
Volume (m^3/ha)	361
Average stem volume (m^3)	0.41
Stocking (SPH)	890
Average slope (°)	24
Average slope (%)	45
Species	Douglas-fir, Western Red Cedar, Western Hemlock, Balsam, hybrid Spruce

Results: Case Study 6

As shown in Figure 32, the largest proportion of operating time throughout the week was falling (37%) followed by delay (27%).

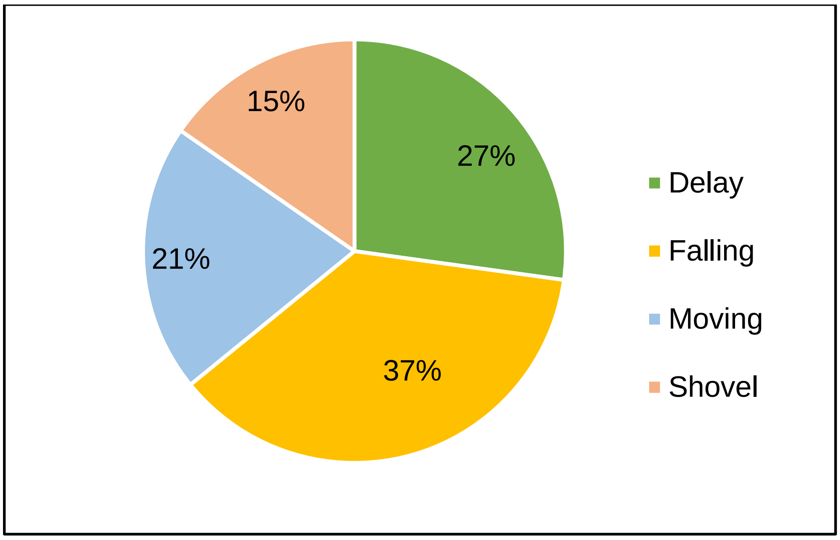

Figure 32. Proportion of operating time: Case Study 6

During this study, delay was found to be a result of moving site, relocating the anchor machine, refuelling, line handling, mechanical and personal delay. A breakdown of delays is shown in Figure 33.

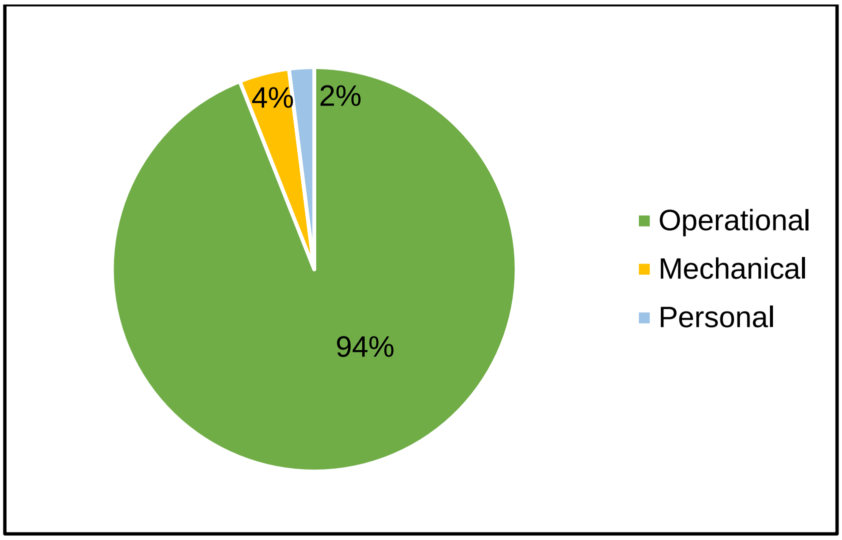

Figure 33. Breakdown of delays recorded by time study at Case Study 6

During the study period, 638 trees were felled. The piece size was 0.41m^3 equating to a volume of 262m^3. The total amount of time recording took place was 13.3 hours, giving a productivity of 20m^3/SMH. The productivity was 34m^3/PMH when only taking into account the moving and falling elements.

The utilisation rate when the falling machine was falling, moving and tethered to the ROB anchor machine (both machines working together) was 58%.

Observations: Case Study 6

The harvest system observed was a steep slope ground-based operation. This system has a high utilisation as it is solely a winch-assist crew with two machines whereby it works only in winch-assist required terrain. The slope lengths observed were between 80 and 120 metres (Figure 34) and the method of extraction involved falling and shovelling in the same process. This took place as the machine made its way down the slope, falling up to 10 trees before shovelling these stems 20 m to the next heap and then repeating the operation.

Figure 34. Operating conditions at Case Study 6

The falling machine was equipped with a heel, which improved the shovelling phase (Figure 35). At the end of the corridor, a large surge pile awaits extraction or processing by another logging company.

Figure 35. Cat 552 applying the heel while shovelling

The average slope was 35% and did not always require winch-assist however sharp pitches of up to 80% were common requiring winch-assist. Snow was also measured at 1-1.5 m which created another variable to deal with on the slope. In response to the snow, the falling machine tracks have had aftermarket spikes welded to the track grousers and the ROB anchor machine had four spikes attached to the bottom side of the blade to ensure anchor machine stability (Figure 36).

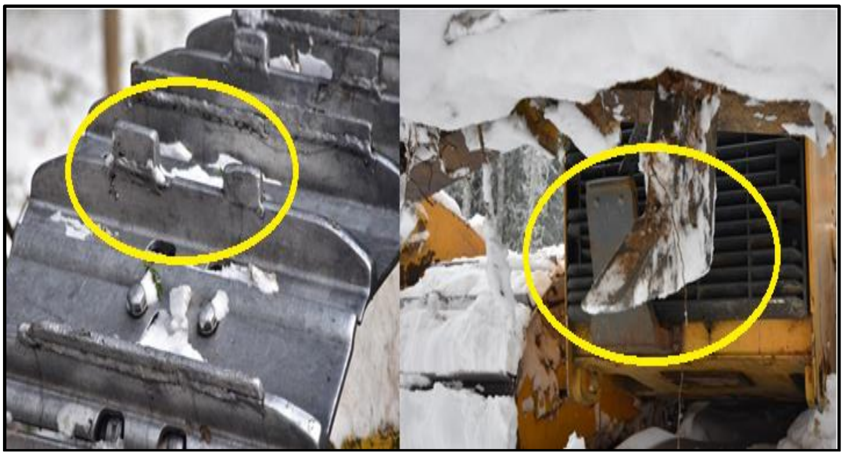

Figure 36. Traction and stability solutions at Case Study 6

The operator noted that snow not only decreases traction capability, it also causes ice to build-up within the falling head. This snow/ice build-up reduces flexibility for the hydraulic hoses and therefore leading to mechanical issues within the falling head.

A high utilisation of 90% was achieved on the first day as the machine was already setup ready to operate, did not require refuelling, no mechanical delay occurred and only one anchor shift took place. Note that this utilisation did not include the first hour of operating before arriving on site. The first hour often involves warming up the machine, ensuring everything is mechanically sound and the operator preparing any paperwork required for the day.

From the researcher's point of view, the high utilisation was a result of frequently using catch trees to limit the number of anchor shifts (Figure 37).

Figure 37. Example of a catch tree being used at Case Study 6

The operator advised that three or four corridors are commonly achieved per anchor shift. This depends entirely on the nature of the block used and the existence of suitable catch trees.

CONCLUSION

Table 7 below displays the results of the six case studies, showing utilisation and productivity by productive machine hour (PMH) and scheduled machine hour (SMH).

Table 7. Case Study Results

	New Zealand			Canada			
Case Study	**1**	**2**	**3**	**4**	**5**	**6**	**Avg.**
Utilisation (%)	60	49	22	57	52	58	**50**
Productivity (m^3/PMH)	50	88	48	60	65	34	**58**
Productivity (m^3/SMH)	30	43	11	34	34	20	**29**

Winch-assist falling and extraction operations differ considerably to traditional falling and yarding on steep slopes. It is important that harvest planners and forest managers understand winch-assist requirements to maximise the value from this new approach to falling and extraction. It should not be considered as the same operation, from a planning and layout perspective. Given costs of both field layout and winch-assist operations, it would be financially beneficial to all parties to ensure harvest planners are provided feedback from contractors as to how layout impacts logging. This will ensure the harvest plan meets the contractor's needs and maximises the benefit of winch-assist operations.

Installing aftermarket backup cameras to ensure that the operator has a clear view of the rear of the machine during moves is recommended. This would help reduce the time required to move the anchor machine, minimise the risk of damage to winches (and equipment) during moves in tight locations, and may improve safety.

When the falling machine is untethered to fall and extract flat areas, the anchor machine should be shut down (remotely) during such times (provided the remote start is reliable). Not shutting down leads to unnecessary hours added to the machines operating time, impacting warranty hours and increased machine servicing (based on non-productive time). Reducing machine hours also promotes fuel efficiency and reduces carbon footprint.

To maximise winch-assist machine utilisation, the contractor should consider using standing trees or high stumps as catch trees. This technique could allow the anchor machine to face along the track while the falling machine can redirect the line by moving it to a stump suitable for the next corridor, refer to Figure 38. When this approach is used, it will; minimise machine moves, keep the anchor machine further away from falling operations, and can help when ridges or tracks are narrow. To take advantage of large high stumps on road right of ways, harvest planners and road construction crews should identify the need for high stumps and leave them to provide options for the winch-assist operation. Reducing anchor moves can increase productivity and improve overall utilisation.

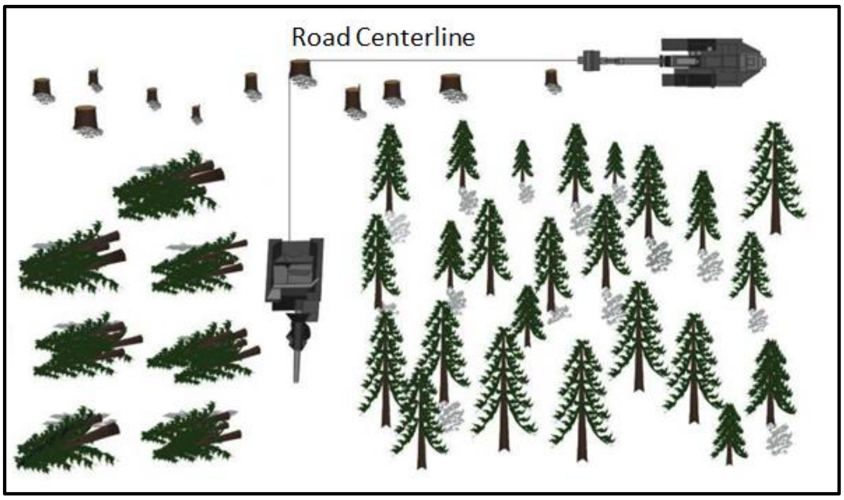

Figure 38. Illustration of operation of a catch tree

Winch-assist felling machines are higher cost than a manual falling operation, although using a machine to fall and bunch trees increases the productivity of the extraction element of the harvest cycle.

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