Winch-Assisted Feller-Buncher Equipped with a Continuous-Rotation Disc Saw: Short-Term Productivity Assessment

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1. INTRODUCTION

Until recently hand falling has been the only method for felling trees on slopes that are too steep to be accessed by conventional mechanized felling machines. However, the recent ability to equip a conventional felling machine with a winch-assist system means that mechanized felling is now possible on steeper slopes. In some winch-assist systems, an anchor machine, which is often a modified excavator, is positioned above a steep slope and tethers the felling machine working below with a tension-controlled cable. The winch-assist system provides the felling machine with added traction.

Because mechanized felling is much safer than hand felling, the forest industry is adopting winch-assist technology for steep-slope timber harvesting. The technology also offers potential for improving the productivity and efficiency of a harvesting operation. A felling machine equipped with winch-assist technology may have a higher cost ($/m^3) than manual falling, but it may allow the extraction phase to be more productive, potentially leading to lower overall costs.

A winch-assisted felling machine is typically equipped with a directional felling head or harvester head. However, harvesting contractors in Washington and Oregon have recently started using feller-bunchers equipped with continuous-rotation disc saws (hot saws) because this type of saw offers the potential for higher productivity. Continuous-rotation disc saws are especially efficient in small-diameter stands and in stands containing a high percentage of non-merchantable stems. In May 2016, FPInnovations conducted a short-term productivity evaluation of a winch assisted feller-buncher equipped with a continuous-rotation disc saw that was operating on a steep site in northwestern Washington State.

2. OBJECTIVES

The objectives of the study were to:

- Describe the winch-assisted harvesting system and its operation on a steep slope.
- Measure the productivity of the system.
- Calculate the cost per m^3 of the system.
- Document the advantages and disadvantages of using a winch-assisted feller-buncher equipped with a continuous-rotation saw (hot saw).

3. STUDY SITE

The study took place in May 2016 on a steep portion of private forestland in the foothills of the Cascade Mountains, near the town of Enumclaw in northwestern Washington. The 40 years old second-growth stand had been precommercially thinned (Figure 1), and contained scattered old-growth stumps. FPInnovations estimated the species mix was 75% western hemlock (*Tsuga heterophylla),* 10% Douglas-fir (*Pseudotsuga menziesii*), and 15% red cedar (*Thuja plicata*) and red alder (*Alnus rubra*). Slope ranged from 35 to 45% in the study area. The access road was built along the top of the block.

Figure 1. Study site: a thinned, 40-year-old, second-growth stand of mixed conifer species on a steep slope.

4. STUDY METHODOLOGY

FPInnovations conducted detailed timing studies to determine the equipment's productivity. Detailed timing data were used to calculate productive machine hours (PMH). For a feller-buncher, PMH is the time a machine spends on its primary tasks, i.e., felling and bunching stems. Productive support time was excluded from PMH. Productive support time included anchor testing, changing the falling corridor, and moving the anchor machine. All delays >10 min were excluded from PMH.

The machine operators were interviewed about equipment performance and operating procedures.

A sample of felled stems was scaled to determine an average gross merchantable stem volume. Study volume was calculated by multiplying the average gross merchantable stem volume by the number of felled stems recorded during detailed timing.

Machine costs were calculated as cost per scheduled machine hour ($/SMH) and then converted to $/PMH based on estimated equipment utilization. Winch-assist technology is new to the Pacific Northwest, therefore no local machine-utilization data were available for making comparisons.

FPInnovations captured video of the system in operation at the study site—see https://www.youtube.com/watch?v=8VfBjeGY1_o (Boswell, 2016).

5. SYSTEM DESCRIPTION

The harvesting contractor was Wyss Logging Inc. of Yakima, Washington. The harvesting plan specified clearcutting, yarding to the road located above the block, and mechanized processing at roadside. Trees were felled by a Tigercat LX830 C feller-buncher equipped with a Tigercat 5702 continuous-rotation disc saw (hot saw) (Figure 2). Stems were yarded by a FMC Link-Belt yarder equipped with an Eagle carriage and then processed by a Pierce Denharco stroke delimber on a Linkbelt 290 carrier.

The feller-buncher received traction support from an anchor machine positioned on the road above the block. (Figure 3).

Winch-assist system

The winch-assist system was designed and built by Summit Attachment and Machinery LLC of Castle Rock, Washington.

A Caterpillar 330C L excavator is the system's anchor machine (Figure 3).

Mounted on the anchor machine's counterweight is a Lantec Model 540 hydrostatic winch (Figure 4). Winch capacity is 594 m (1 950 ft) of 2.5-cm (1-inch) compact swaged cable. The working load of the cable is 51 708 kg (114 000 lbs) which is three times the tension limit of 17 236 kg (38 000 lbs). The winch cable passes through a sheave mounted on an extension to the boom's stick (Figure 5) and then through a pivoting fairlead block mounted on the excavator bucket (Figure 6). Chains attach the bucket to the track frame, bracing the bucket and providing additional stability to the anchor machine (Figure 7).

The cable attaches to a 4-m-long chain by a pressed eye and shackle which is shackled to a custom-built, bolt-on, reinforced attachment point on the feller-buncher (Figure 8).

Figure 2. Tigercat LX830 C feller-buncher equipped with a Tigercat 5702 continuous-rotation disc saw, working below the road on a ~40% slope.

Figure 3. Caterpillar 330C L anchor machine positioned on the road above the harvesting area.

Figure 4. Winch mounted on the anchor machine's counterweight.

Figure 5. Sheave mounted on the anchor machine's stick extension.

Figure 6. Boman fairlead sheave mounted on the bucket of the anchor machine.

Figure 7. Chains securing the bucket to the anchor machine's track frame.

Figure 8. Swaged cable attached to a 4-m-long chain shackled to the feller-buncher.

Identical touchscreens are located in both the feller-buncher cab and the anchor machine cab (Figure 9). The screens let the operators monitor system functions, and control cable tension and winch brake activation.

The displayed information includes:

- Cable tension (Figure 9, top left), which is measured by a load pin in the stick extension's sheave.
- Length of cable deployed from the anchor machine (Figure 9, top centre).
- Spikes in cable tension >17 236 kg (38 000 lbs) — spikes cause the displayed figures to change from green to red.
- Drum speed, in percent (Figure 9, left).
- Pressure relief, in percent (Figure 9, left).

Cable tension is maintained automatically by the winch when the feller-bunch operator actuates the feller-buncher's foot pedals; tension is based on a pre-set limit (Figure 9, bottom left). However, the operator also has the option of tightening or slackening the line tension by using the drum's forward and reverses controls, which are located on the touchscreen in the cab (Figure 9, two blue buttons at right).

The winch brake is a hydraulic, pressure-release, multi-disc brake that is activated through the touchscreen in the feller-buncher cab (Figure 9, green button in centre).

A video camera mounted on the back of the anchor machine and a display screen in the feller-buncher cab and one in the anchor machine cab provides the operators with live monitoring of the winch drum.

Some of the features described in this subsection are explained in a video taken by FPInnovations at the study site — see https://www.youtube.com/watch?v=8VfBjeGY1_o (Boswell, 2016).

Summit Attachment and Machinery recommends installing the winch-assist system on a used excavator because of its lower capital cost compared to a new machine; the excavator idles most of its working time so a used machine will still have a long machine life.

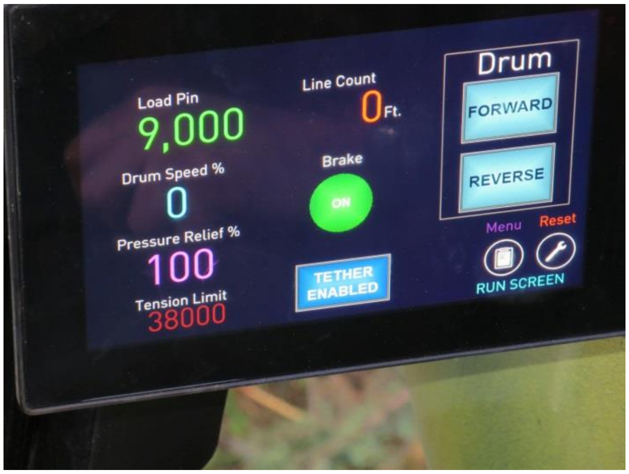

Figure 9. Touchscreen in the cab.

6. OBSERVATIONS OF THE OPERATIONS

The feller-buncher worked in lines straight up and straight down the hillside. It cut trees when it faced both uphill and downhill (Boswell, 2016). In one area the feller-buncher followed a technique of cutting a stem and then carrying it uphill 10 to 30 m before placing it in a pile. “Forwarding while felling” was the term given to this activity. Piles were situated so they could be reached by a loader or processor from the road.

A full-time anchor-machine operator was employed in order to reposition the machine whenever a new felling line was started or when a small position adjustment was required.

The feller-buncher operator had been working with the winch-assist system installed for only 2 months, although he had over 20 years of experience on feller-bunchers. He told FPInnovations that one of his safe operating methods was to avoid swinging the saw head over the cable, although the head was observed to occasionally cross the cable. The operator intentionally “siwashed” (partially wrapped) the cable around a stump or standing tree to redirect the cable when the feller-buncher was not in lead with the anchor machine. The feller-buncher operator regularly used the feller-buncher head’s grab arms to lift the chain over an obstacle, such as a stump, so that the chain would not interfere with the machine’s movements. This operation was performed while the saw was rotating. The operator stated that the winch-assist system made him feel more secure when operating on slopes, and that he even used the winch-assist system on slopes <30% because of the added traction assistance. However, occasionally the feller-buncher was observed rocking with the uphill section of tracks lifting off the ground, indicating poor machine stability. This occurred when the machine was facing downhill and swinging with a stem held in the buncher head (Figure 10).

Stumps were cut to normal height specifications. When the operator could not avoid creating a high stump he would re-cut the stump to a lower height so that it would not interfere with yarding.

He stated that when the slope exceeds 55% and the feller-buncher is facing downhill it is difficult to avoid creating high stumps.

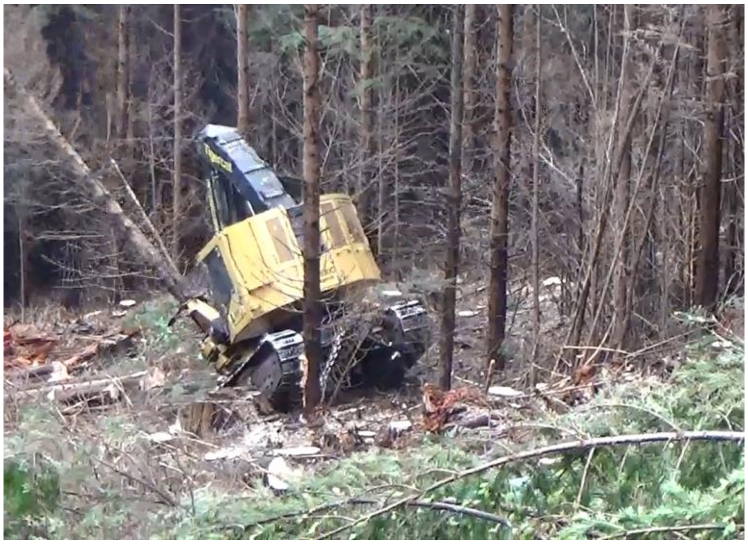

Figure 10. Feller-buncher with tracks rocking off the ground.

7. RESULTS

Productivity

Table 1 summarizes the feller-buncher's productivity. FPinnovations' FPInterface software for modelling harvesting productivity and costs[1] estimated the productivity would be 106 m^3/PMH for a stand-alone feller-buncher operating on a similar slope and handling a similar piece size (0.9 m^3). However, the machine's actual productivity, when felling both uphill (139 m^3/PMH) and downhill (145 m^3/PMH), was higher than predicted by FPinnovations' model. The high productivity in this study was attributed to: the site having been precommercially thinned, to the site having very little brush and few undersized stems, to the site's uniform terrain, to the operator's skill and experience, and to the added traction provided by the winch-assist system.

The average cycle time was 0.76 min when forwarding while felling, compared to 0.43 min for felling uphill and 0.46 min for felling downhill (Table 2). The longer average cycle time for forwarding while felling occurred because cut stems were carried up the hill by the feller-buncher, resulting in more time spent moving than felling.

[1] FPInterface (modelling software for timber-harvesting operations) — http://fpsuite.ca/l_en/fpinterface.html.

Table 1. Feller-buncher productivity: summary

Element	Direction of feller-buncher		Forwarding while felling
	Facing uphill	Facing downhill	
Cycles (no.)	216	363	206
Stems (no.)	254	423	225
Stems/cycle (no.)	1.2	1.2	1.1
Average stem volume (m^3)	0.89	0.89	0.89
Average slope (%)	40	40	42
Volume (m^3)	226	376	200
Productive machine hours (PMH)	1.64	2.60	2.60
Stems/PMH (no.)	155	163	86
Cycles/PMH (no.)	132	140	79
M^3/PMH	139	145	77

Table 2. Distribution of the feller-buncher's cycle time: summary

Activity	Direction of feller-buncher				Forwarding while felling	
	Facing uphill		Facing downhill			
	Average (min/cycle)	% of total cycle time	Average (min/cycle)	% of total cycle time	Average (min/cycle)	% of total cycle time
Grab, cut, and bunch	0.28	61	0.25	59	0.36	47
Move	0.10	21	0.12	28	0.23	30
Brush	0.07	15	0.04	8	0.09	12
Other	0.01	3	0.02	5	0.08	11
Total	0.46	100	0.43	100	0.76	100

Costs

Winch-assist technology is new to the Pacific Northwest, therefore local data on factors that affect equipment cost, such as repair and maintenance, salvage value, and equipment life expectancy, do not exist.

Instead, costing was based on estimates and information from experts in New Zealand, where winch-assist technology is more commonly used. New Zealand experience has found utilization ranges from 30 to 70%.[2] An estimated 60% utilization was used for this study; however, actual utilization for the operation is not known.

Table 3 and Appendix I summarize the estimated felling costs. The relatively low cost of uphill and downhill felling, at $4.15/m^3 and $3.95/m^3 respectively, occurred because of good productivity (m^3/PMH).

Table 3. Machine costs: summary

Machine	Machine costs		Direction of feller-buncher		Forwarding while felling ($/m^3)
	($/SMH)	($/PMH) [a]	Facing uphill ($/m^3)	Facing downhill ($/m^3)	
Tigercat LX830 C feller-buncher	225.08	375.14	2.72	2.59	4.87
Caterpillar 330C L excavator (anchor machine)	118.29	197.14	1.43	1.36	2.56
Total	343.37	572.28	4.15	3.95	7.43

[a] Based on 60% utilization to convert SMH to PMH.

8. DISCUSSION

The use of a continuous-rotation disc saw in this steep-slope harvesting operation had both advantages and disadvantages, compared to using a directional felling head or harvester head.

Advantages:

- Capacity to build neat, well-placed piles and bunches of felled stems, because stems are held by the felling head — well-built piles improve cable-yarding productivity.
- Potentially less stem breakage, because of the ability to hold and place the stem.
- Efficient in small-diameter stands, because stems can be accumulated in bunches in the head.
- Good for removing brush and woody debris in the stand.
- Ability to forward stems in an upright position.
- Robust felling head eliminates bent saw bars and periodic changing of the saw chain that occur with the chainsaw heads that are used in feller director and harvester heads.

[2] Personal communication Rien Visser, Associate Professor, School of Forestry, University of Canterbury, Christchurch, New Zealand; January 2016.

Disadvantages:

- A narrower cutting swath compared to a feller director or harvester head, because the continuous-rotation saw's heavier weight requires a shorter boom with less reach.
- Can be time-consuming to use the feller buncher grab arms to reposition the chain over obstacles if the disc saw must be stopped each time.
- Extra care and caution is required to prevent the saw from contacting the cable/chain because it does not retract the way saws on feller director and harvester heads do.
- Difficult to avoid creating high stumps when felling downhill although this can sometimes be remedied by re-cutting the stump.
- Cannot forward stems as easily as a feller director which can be an efficient forwarder (shovel logger or hoe chucker).

In addition to allowing mechanized tree falling to occur on steep slopes that would otherwise require hand falling, dual-machine type winch-assist systems such as this one have other applications and benefits (Amishev, 2016):

- The anchor machine can be used for other duties, such as road building.
- The system can provide traction assistance for extraction functions, such as hoe chucking or skidding.
- The winch system's components are easily adapted to an excavator base.

Summit Engineering is now designing a two-line winch-assist system as a two-line system is thought by some people to provide greater safety, e.g., in an event where one cable fails.

9. SUMMARY

In May 2016, FPInnovations conducted a short-term productivity assessment of a winch-assisted Tigercat LX830 C feller-buncher equipped with a continuous-rotation disc saw working on a steep block in northwestern Washington State. The productivity of uphill felling (139 m^3/PMH) and downhill felling (145/m^3/PMH) were similar. The high productivity was attributed to a number of factors, including large stem size (0.89 m^3/stem), operator skill and experience, stand and terrain conditions, and the traction assistance provided to the feller-buncher by the winch-assist system.

High productivity led to the felling costs being relatively low, at \$4.15/m^3 for uphill felling and \$3.95/m^3 for downhill felling.

A continuous-rotation disc saw offers advantages over a directional felling or harvester head, including:

- Efficiency in stands with small stem sizes.
- Effectiveness in stands containing heavy brush and or a large percentage of non-merchantable stems.
- A robust felling head.

Some drawbacks of using a continuous-rotation disc saw are:

- Extra time required if the saw is stopped before using the felling buncher grab arms to lift the chain or cable over obstacles.
- Operator vigilance required to prevent the saw from contacting the chain/cable.
- The likely occurrence of high stumps when felling downhill on slopes steeper than 55%.

10. REFERENCES

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APPENDIX I: MACHINE COSTS

Machine costs	New Tigercat LX830 C feller-buncher	Used Caterpillar 330C L excavator (anchor machine)
Ownership costs		
Purchase price (P), $	697 750	200 000
Winch system installed (new)	–	264 380[a]
Total purchase price (P), $	697 750	464 380
Expected life (Y), y	5	8
Expected life (H), h	10 000	16 000
Scheduled hours/year (h)=(H/Y), h	2 000	2 000
Salvage value as % of P (s), %	30	10
Interest rate (Int), %	5.0	5.0
Insurance rate (Ins), %	3.0	3.0
Salvage value (S)=((P•s)/100), $	209 325	46 438
Average investment (AVI)=((P+S)/2), $	453 538	255 409
Loss in resale value ((P−S)/H), $/h	48.84	26.12
Interest ((Int•AVI)/h), $/h	11.34	6.39
Insurance ((Ins•AVI)/h), $/h	6.80	3.83
Total ownership costs (OW), $/h	66.98	36.34
Operating costs		
Wire rope (wc), $	–	5 340
Wire rope life (wh), h	–	1,500[b]
Fuel consumption (F), L/h	38.0	10.0
Fuel (fc), $/L	1.00	1.00
Lube & oil as % of fuel (fp), %	10	10
Track & undercarriage replacement (Tc), $	40 000	40 000
Track & undercarriage life (Th), h	5 000	45 000
Annual operating supplies (Oc), $	600	500
Annual repair & maintenance (Rp), $	135 000	65 000
Shift length (sl), h	8.0	8.0
Wages (W), $/h	30.00	25.00
Wage benefit loading (WBL), %	35	35
Wire rope (wc/wh), $/h	–	3.56
Fuel (F•fc), $/h	38.00	10.00
Lube & oil ((fp/100)•(F•fc)), $/h	3.80	1.0

Machine costs	New Tigercat LX830 C feller-buncher	Used Caterpillar 330C L excavator (anchor machine)
Track & undercarriage (Tc/Th), $/h	8.00	0.89
Operating supplies (Oc/h), $/h	0.30	0.25
Repair & maintenance (Rp/h), $/h	67.50	32.5
Wages & benefits (W•(1+WBL/100)), $/h	40.50	33.75
Prorated overtime (((1.5•W−W)•(sl−8)•(1+WBL/100))/sl), $/h	–	–
Total operating costs (OP), $/SMH	**158.10**	**81.95**
Total ownership and operating costs[c] (OW+OP), $/SMH	**225.08**	**118.29**

[a] In C$, converted from US$200 000.

[b] Based on New Zealand experience; no actual values exist for the Pacific Northwest because the technology is new to this region.

[c] These costs are estimated using FPInnovations' standard costing methodology for determining machine ownership and operating costs for new machines. The costs shown here do not include supervision, profit, and overhead, and are not the actual costs for the contractor or the company studied.

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