Evaluation of two loader-forwarder configurations on steep slopes

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Disclosure for Commercial Application: If you require assistance to implement these research findings, please contact FPInnovations at info@fpinnovations.ca.

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Abstract

Ground-based harvesting systems typically provide lower operating costs than cable systems on steep terrain. Expanding the operating range of ground-based equipment on steeper slopes is critical to the sustained economic health of the forest industry.

FPInnovations monitored the productivities of two loader-forwarders, a levelling-cab Tigercat LS855C and non-levelling cab Tigercat 880, operating on an old-growth coastal cutblock. The study indicated that both machines were capable of negotiating all the slopes in the operating area which averaged 34%. Productivity was primarily influenced by forwarding distance. The effect of forwarding distance on productivity remained almost the same with varying slope. Felling method and forwarding direction had the next largest effects on loader-forwarder productivity. Mechanical falling improved productivity most when used on short forwarding distances. The average measured reach of the LS855C was about 89% that of the 880, compared to the nominal ratio of 73% based on machine specifications. The smaller, levelling-cab machine was less productive than the larger machine in all situations, although the differences in machine productivities decreased as slope increased and was minor on the steepest slopes.

Keywords

Steep slopes, Harvesting, Equipment, Loaders, Forwarders, Productivity, Costs.

INTRODUCTION

Significant volumes of fibre are available on slopes normally considered inaccessible to ground-based harvesting systems. A levelling-cab loader-forwarder may expand the range of sites where ground-based equipment can replace cable yarding equipment, thus improving fibre access. Knowledge about this recent innovation and its suitability to coastal conditions is lacking, and is required to enable implementation.

OBJECTIVES

Assess the productivity and cost of a levelling-cab loader-forwarder while operating under coastal British Columbia steep-slope conditions.

SITE, STAND, AND HARVESTING SYSTEM

The study site was located on Island Timberlands' Oyster River operation near Campbell River, B.C. The contractor was Roga Contracting Ltd. The site was a high-elevation, old-growth stand, with a high proportion of hemlock and yellow cedar (Table 1).

Table 1. Site and stand description

Study area parameters	Sample values
Average elevation (m)	1180
Average slope (%)	34
Average extraction/external distance (m)	37.6/67.1
Stand density (stems/ha)	694
Gross merchantable volume (m^3/ha)	526
Gross average stem size (m^3)	0.76
Average dbh (cm)	32.4
Average tree height (m)	21.9

Approximately 50% of the cutblock was felled with a feller-buncher while the remainder was hand-felled. The study area included both felling systems. The extraction equipment used in the study area was a levelling-cab Tigercat LS855C (Figure 1 and Table 2) that was teamed with a non-levelling Tigercat 880. The LS855C was smaller than the 880; its grapple had a smaller opening, and its boom reach was 10.3 m compared to 14.2 m for the 880.

Table 2. Harvesting system and equipment used in the cutblock

Item	Description
Extracting[a]	loader-forwarder and grapple yarder
Equipment make and model	Tigercat LS855CLS855C / Tigercat 880
Nominal boom reach (maximum, m)	10.3 / 14.2
Grapple size	122 (Rotobec 4048)/152 (T-mar HD60)

[a] Study was limited to loader forwarding phase only.

Figure 1. Tigercat LS855C forwarding on adverse slope.

STUDY METHOD

The study used shift-level timing and detailed timing methods, with the detailed timing data collected with two intensities. Extensive detailed timing (EDT), which was conducted only for the LS855C, measured the time and volume for each full chuck, i.e., “one trip per cycle”, from the time the machine left the road until the final stem from that area was decked at roadside. It measured the total time for all the activities required to forward the stems to the road. Additional data consisted of the external (i.e., from road to felling boundary) and average forwarding distance of each sample area, number of stems delivered to roadside, slope, forwarding direction, felling method, machine travelling/moving distance, and number of setups required to complete the area.

A second level of detailed timing, called intensive detailed timing (IDT), was based on “one swing per cycle”. Data collected during IDT comprised the load–unload time per cycle; travel–move time; delay time; and number of stems per load by felling method, slope, and forwarding direction. It also recorded the “handle class”, i.e., 1st touch, intermediate, and final handling of the stem. The “1st touch” cycles occurred when the machine initially moved the stem, and the “final” cycles occurred when it placed the stem in the roadside pile. IDT data were collected for the Tigercat LS855C covering all combinations of slope, felling method, and forwarding direction except for hand-felled wood on adverse slopes under 35%. IDT data were also collected for the Tigercat 880, but for a limited number of operating conditions.

MultiDAT data loggers were used to record working and delay time to calculate machine utilization based on productive machine hours (PMH) and delay times.

RESULTS

Extensive detailed timing

The EDT data for the Tigercat LS855C are summarized in Table 3. The average productivity from the 28 sample areas was 59.2 m^3/PMH, or about 600 m^3/shift, and the average forwarding distance was 37.6 m.

Since productivity is strongly influenced by forwarding distance, FPInnovations calculated productivity rates for the average forwarding distance of the cutblock and a standardized 100-m distance. The average forwarding distance for the entire cutblock was 69.0 m and the average productivity was 29.5 m^3/PMH. The productivity for a standardized 100-m average forwarding distance was 20.3 m^3/PMH.

Table 3. EDT productivity summary for LS855C loader-forwarder

Parameter	Study area	Cutblock	Standardized
Average forwarding distance (m)	37.6	69	100
External distance (m)	67.1	133	-
Stems/PMH	78.2	38.9	26.8
Productivity (m^3/PMH)	59.2	29.5	20.3

Figure 2 shows the productivities under different operating conditions based on a standardized forwarding distance of 100 m. Of the three factors that were measured against productivity, felling method caused the greatest difference in productivity, followed by forwarding direction with hand-felling on slopes over 35%. Slope class had some effect on productivity (Figure 3) but less than felling method. The highest productivity occurred with downhill forwarding of mechanically felled wood on slopes under 35%, while the lowest productivity occurred with hand-felled stems on slopes over 35%.

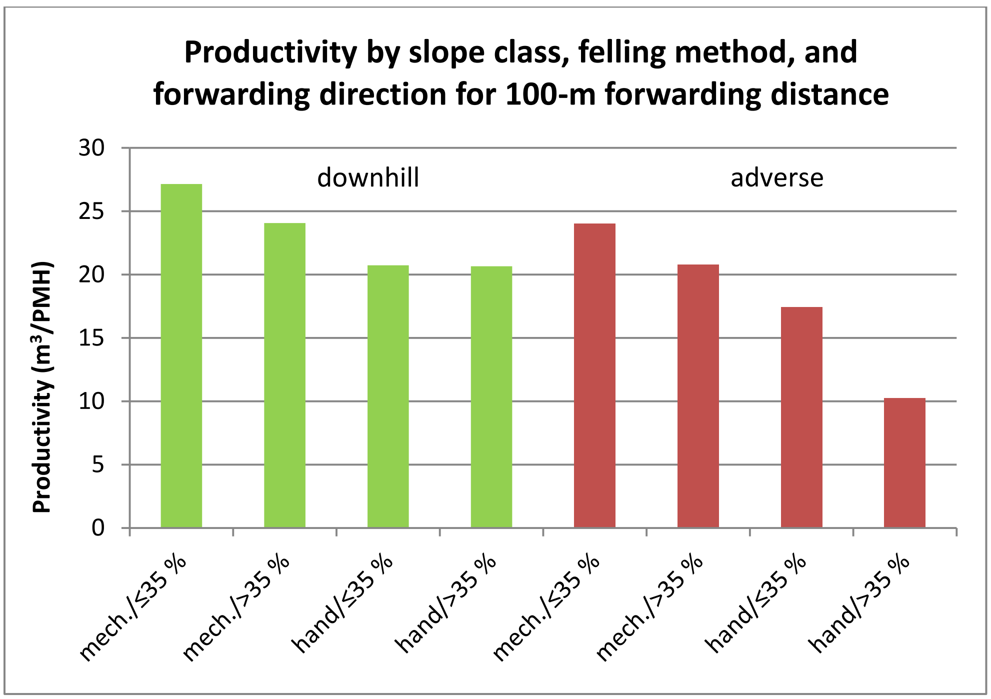

Figure 2. Productivity for LS855C for standardized 100-m forwarding distance.

Figure 4 shows a 10–15 m^3/PMH difference between the trend lines for mechanically and hand-felled datasets. The largest difference occurs with short forwarding distances, with a gradual decrease for longer forwarding distances because longer forwarding distances have a lower proportion of “1st touch” cycles; such cycles require more time for hand-felled stems. For cycles after the “1st touch”, there is no difference between the time required to move a hand-felled stem or a machine-felled stem.

The productivity trend line for downhill forwarding in Figure 5 had the highest R^2 value of all the observations. However, 70% of the “downhill” observed wood was also mechanically felled. Together, these indicate that productivity is most predictable for downhill, mechanically felled timber. By contrast, the adverse trend line had among the lowest R^2 value, which indicates that productivity for adverse forwarding is dependent on other factors besides forwarding distance.

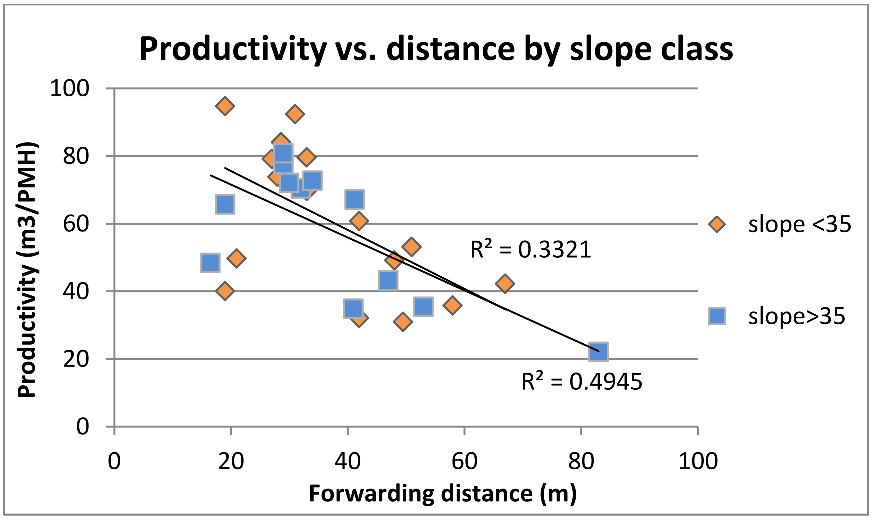

Figure 3. Productivity versus forwarding distance by slope class.

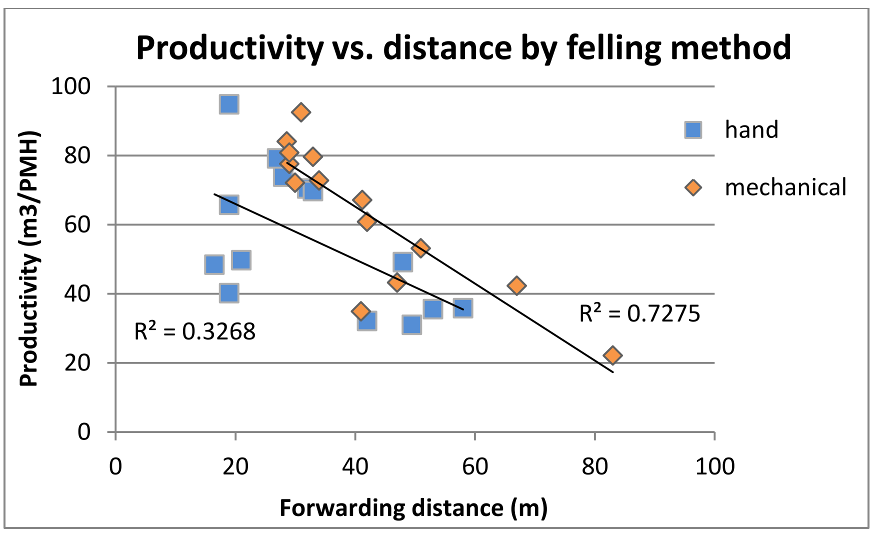

Figure 4. Productivity versus forwarding distance by felling method classes.

Intensive detailed timing

The distribution of time elements for the various combinations of slope, felling method, and forwarding direction is shown in Figure 6. Positioning time is the time required to build a flat working area after moving.

The 880 had shorter cycles: 0.47 min vs. 0.51 min in mechanically felled wood on slopes under 35%, and 0.55 min vs. 0.62 min in hand-felled wood on slopes over 35%. Part of the difference was attributed to operator skill level; the LS855C operator had less than two months' experience on a levelling-cab machine while the 880 operator was highly experienced.

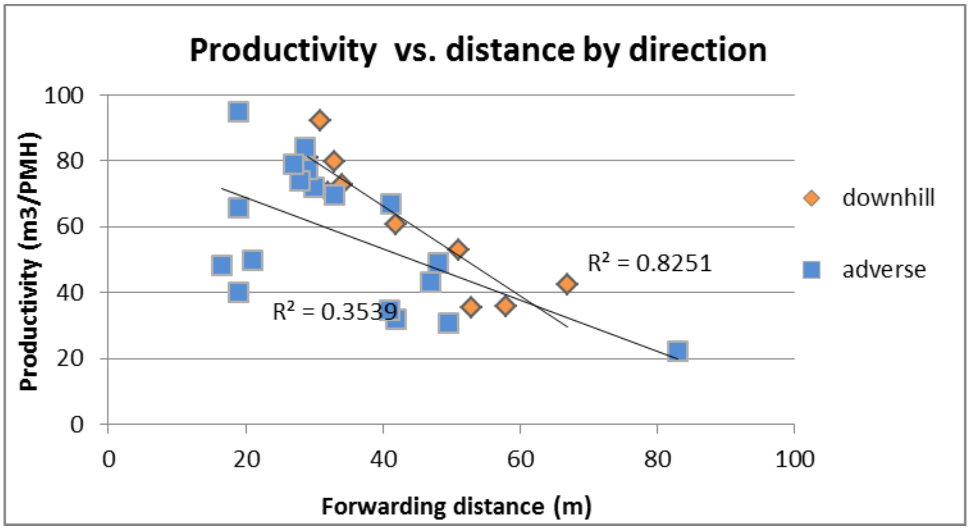

Figure 5. Productivity versus forwarding distance by forwarding direction.

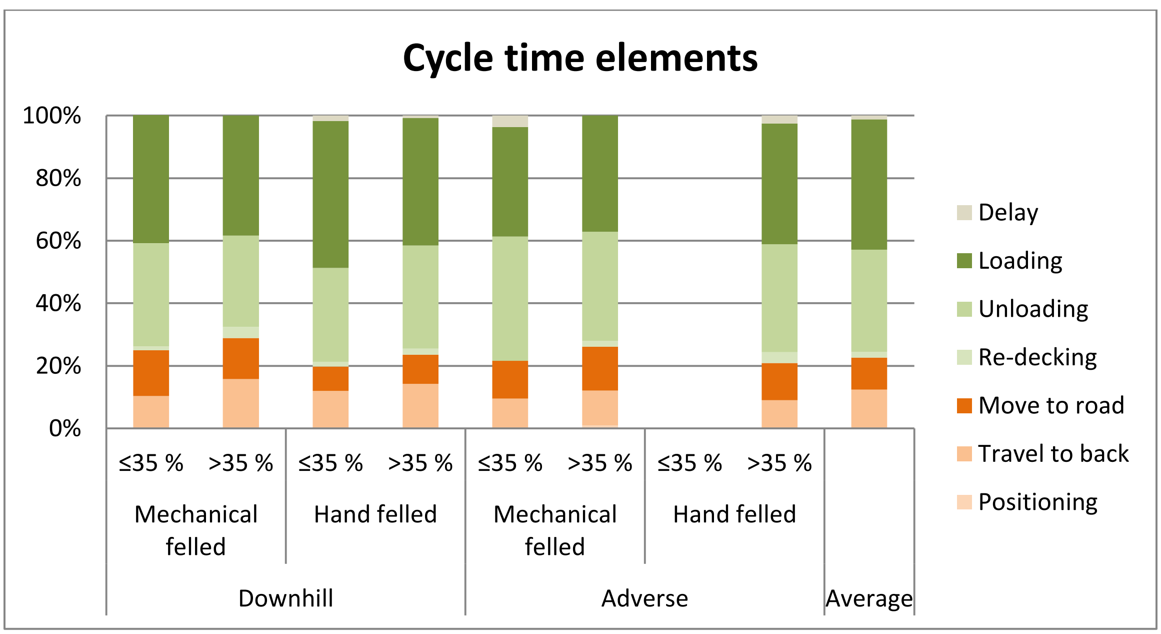

Figure 6. Time element proportion for LS855C in different harvesting conditions.

The proportion of travel–move time was slightly higher for the levelling-cab LS855C (29.2%) than for the non-levelling 880 (24.1%). This difference could be partially explained by the different size or reach of the machines (10.2 vs 14.3 m), which provided an advantage to the 880, especially when working near the road on short chucks.

Reach

The average reach of the two machines was calculated by dividing the length of the GPS track for each sample area by the number of setups. This value provides a measurement of the distance the logs are moved on each setup, independent of its nominal reach (Table 2). The average reach of the LS855C was about 89% of the 880's reach, while its nominal reach was 10.3 m versus 14.2 m for the 880, a ratio of 73%. It is unknown whether this relative increase in reach for the LS855C was attributed to its levelling-cab capability or to some other operating conditions.

The LS855C reach was about 1.6 m shorter for hand-felled stems on slopes over 35% than with mechanically felled stems on slopes under 35% (Table 4). For similar conditions, the reach loss for the 880 was 2.0 m.

Shift-level results and forwarding costs

Shift-level timing (Table 5) was used only to calculate the machine utilization.

Table 4. Productivity comparison of LS855C and 880 loader-forwarders

Downhill forwarding	Mech. felled ≤35%		Hand felled >35%		Average	
	LS855C	880	LS855C	880	LS855C	880
Cycle time (min)	0.51	0.47	0.62	0.55	0.57	0.52
Handle wood (%)	75.0	83.1	67.3	69.1	70.8	75.9
Travel–move (%)	24.9	14.8	32.7	30.9	29.2	24.1
Stems/minute	5.90	6.61	3.15	3.10	4.53	4.69
Average reach (m)	16.3	18.5	14.7	16.5	15.5	17.5
Productivity index (m^3/min x m)	72.97	92.73	35.12	38.69	53.20	62.12

Table 5. Summary of shift-level timing

Parameter	LS855C	880
Working time (h)	45	38.4
Short delay time (h)	0.3	1.8
Total productive time (PMH)	45.3	40.2
Scheduled time (SMH)	50	44
Machine utilization (%)	90.6%	91.4%

Machine costs were calculated using FPInnovations' standard method (Appendix 1). Machine life for the LS855C was assumed to be 93% of the 880's life based on discussions and analysis with various equipment dealers and operating personnel, resulting in machine costs of \$149.88/SMH and \$159.36/SMH for the LS855C and 880, respectively. The average productivity for the LS855C in the sampled area was 59.2 m^3/PMH, or 53.3 m^3/SMH based on the 37.6-m average extraction distance and 90% utilization, resulting in an average forwarding cost of \$2.81/m^3. The corresponding costs were \$5.66/m^3 for the cutblock average forwarding distance (69.0 m), and \$8.20/m^3 for the standardized 100-m forwarding distance. Using productivity from Figure 2, costs for various forwarding conditions using the 100-m forwarding distance at 90% machine utilization are shown in Table 6.

Table 6. LS855C forwarding cost for 100-m standardized forwarding distance (\$/m^3)

	Downhill forwarding		Adverse forwarding	
Slope class	≤35%	>35%	≤35%	>35%
Mechanically felled	6.13	6.92	6.93	8.01
Hand-felled	8.03	8.06	9.56	16.27

For comparison, the forwarding cost of the 880 was derived for the operating conditions where it was monitored, i.e., mechanically felled on downhill slopes under 35% and manually felled on downhill slopes over 35%. The estimated productivity and corresponding forwarding cost are presented in Table 7 based on 90% machine utilization.

Table 7. Productivity and forwarding cost for the 880

	Downhill/mech. felled/<35% slope	Downhill/man. felled/>35% slope
Productivity[a] (m^3/PMH)	31.07	20.49
Forwarding cost[a] (\$/m^3)	5.13	7.78

[a] 100-m standardized forwarding distance.

OTHER OBSERVATIONS

FPInnovations observed both machines operating on very steep slopes during the study; the LS855C climbed short sections with slopes over 75%. According to the operator, the onboard inclinometer indicated a maximum inclination of 42^o (90%). Although the LS855C was observed to climb steeper slopes than the 880 during the study period, the data do not show that the levelling-cab machine can negotiate steeper terrain than the non-levelling machine. Operator skill may have had a major role in the terrain ability of the two machines since the LS855C operator had only a few months' experience on the machine, while the 880 operator had many years of experience.

Both operators commented that either machine was capable of negotiating the slopes in the operating area, but that the levelling-cab machine provided a more comfortable environment. However, the 880 operator mentioned that he preferred the better feedback about the terrain and undercarriage performance from a non-levelling machine, based on his previous experience. Uphill visibility from the raised cab of the 880 was better than that of the LS855C, especially when forwarding hand-felled stems on downhill slopes.

IMPLEMENTATION

FPInnovations monitored the productivity of a levelling-cab Tigercat LS855C loader-forwarder and non-levelling cab Tigercat 880 operating in an old-growth coastal cutblock. The study revealed the following:

- Productivity was primarily influenced by forwarding distance, and its effect on productivity was nearly identical for slope classes over and under 35%. For either slope class, productivity was reduced by about 27% when the forwarding distance was increased from 40 m to 60 m.
- After forwarding distance, felling method had the most effect on productivity. For example, productivity with hand-felled stems was 49–86% of the productivity with mechanically felled stems. The impact of felling method was greatest for short forwarding distances, i.e., mechanical felling improves loader-forwarding productivity most when used near the road. The average measured reach of the LS855C was about 89% that of the 880, compared to the nominal ratio of 73% based on their specifications. This is likely related to its levelling-cab capability although this cannot be proven conclusively. The reach for both machines was reduced by 1.6–2.0 m when forwarding hand-felled stems compared to mechanically felled stems.
- The lowest forwarding cost for the LS855C was obtained when working with mechanically felled wood on slopes under 35%, while the most costly operating conditions occurred when hand-felled stems were forwarded on adverse slopes over 35%. The forwarding cost of the LS855C working on mechanically felled wood and downhill slopes under 35% was $\$1.00/m^3$ higher than the 880's cost under the same conditions The smaller, levelling-cab machine was less productive than the larger machine in all situations, but it regained some advantage in the more difficult conditions.
- Both machines were capable of negotiating all the slopes in the operating area. The levelling-cab machine operator commented that this machine was more comfortable to operate, and was perhaps less fatiguing, which could contribute to a long-term productivity benefit. Conversely, the non-levelling cab machine operator mentioned that he preferred the better feedback about the terrain and undercarriage performance from a non-levelling machine

APPENDIX 1. COSTS PER SCHEDULED MACHINE HOUR

	Model carrier:	**Tigercat LS855C**	**Tigercat 880**
	Attachment:	Rotobec 4048	T-Mar HD60
Ownership costs			
	Total purchase price (P) $	535 000	605 000
	Expected life (Y) y	6	6
	Expected life (H) h	15 600	16 800
	Scheduled hours/year (h)=(H/Y) h	2 600	2 800
	Salvage value as % of P (s) %	25	25
	Interest rate (Int) %	5.0	5.0
	Insurance rate (Ins) %	3.0	3.0
	Salvage value (S)=((P•s)/100) $	133 750	151 250
	Average investment (AVI)=((P+S)/2) $	334 375	378 125
	Loss in resale value ((P-S)/H) $/h	25.72	27.01
	Interest ((Int•AVI)/h) $/h	6.43	6.75
	Insurance ((Ins•AVI)/h) $/h	3.86	4.05
	Total ownership costs (OW) $/h	36.01	37.81
Operating costs			
	Fuel consumption (F) L/h	27.2	33.3
	Fuel (fc) $/L	1.20	1.20
	Lube & oil as % of fuel (fp) %	10	10
	Track & undercarriage replacement (Tc) $	41 000	41 000
	Track & undercarriage life (Th) h	8 000	8 000
	Annual operating supplies (Oc) $	1 000	1 000
	Annual repair & maintenance (Rp) $	75 792	80 667
	Shift length (sl) h	10.0	10.0
	Operator wage $/h	28.32	28.32
	Total wages (W) $/h	28.32	28.32
	Wage benefit loading (WBL) %	39	39
	Fuel (F•fc) $/h	32.64	39.96
	Lube & oil ((fp/100)•(F•fc)) $/h	3.26	4.00
	Track & undercarriage (Tc/Th) $/h	5.13	5.13
	Operating supplies (Oc/h) $/h	0.38	0.36
	Repair & maintenance (Rp/h) $/h	29.15	28.81
	Wages & benefits (W•(1+WBL/100)) $/h	39.36	39.36
	Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL/100))/sl) $/h	3.94	3.94
	Total operating costs (OP) $/SMH	113.87	121.55
Total ownership and operating costs (OW+OP) $/SMH		**149.88**	**159.36**
These costs use FPInnovations' standard methodology for estimating machine ownership and operating costs of new machines. Costs do not include supervision, profit and overhead, and are not the actual costs for the contractor or the company.			

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