Multi-stem and Single-stem Processing in Long-dead Pine Stands Using Multiple Processors with Different Sort Specifications

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Executive Summary

High log-processing costs are making many stands in central British Columbia uneconomic to harvest, especially those with small-volume trees that are heavily impacted by the mountain pine beetle epidemic. Previous work showed that multi-stem processing with a stroke delimber could reduce processing costs, but produced lower-quality sawlogs that severely impacted sawmill production. Alternative methods for multi-stem processing that generate sawlogs of acceptable quality need to be developed.

The Quadstar 500 dangle-head processor from Southstar Equipment Ltd is a new to processor in British Columbia designed for multi-stem processing. Its productivity and quality performance relative to conventional single-stem processing method was evaluated in a stand of small, dead pine west of Quesnel, BC. The trials also evaluated the cost and benefit of using a modified log specification and processing technique intended to reduce the amount of in-woods processing, and instead deliver more non-sawlog fibre to a central yard where it could be removed. The modified sort specification was to cut stems to a pulp-log diameter limit instead of a stud-log length limit. The modified sort specifications were used for both the Quadstar processor and an older stroke delimber.

Multi-stem processing with modified sort specifications increased productivity by approximately 4 m^3/PMH and reduced processing costs by approximately \$2/m^3 compared to the conventional single-stem processing. Several factors contributed to the productivity increase, including more fibre utilization and the nature of multi-stem processing itself. The modified log specifications resulted in more volume being produced from the available stems with less roadside residues, and more cycles where a log was produced. Although the multi-stem processor was slower than the conventional processor when processing just a single stem, its time per stem was less when it processed two stems simultaneously.

The log quality in the dimension sawlogs was approximately equal for multi- and single-stem processing. However, the multi-stem processing with the modified sort specification generated 50% less roadside residue than the conventional log specification. Subsequently, the pulp sort that was delivered to the mill, and that normally contained less than 1% waste, had 19% of its volume in a form that was unsuitable for stud logs. Since the pulp sort comprised 40% of the volume in the modified sort specification, about 8% more fibre was delivered to the mill and was suitable only for pulp or biomass.

Multi-stem processing using the stroke delimber with modified sort specification shows promise because of its higher productivity, however, the trial was conducted with old equipment and additional validation with modern equipment is required.

Acknowledgements

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1 Introduction

The mountain pine beetle (MPB) epidemic in the British Columbia central Interior over the last decade has created significant ecological, economic and social challenges for the forest industry especially with regard to harvesting operations. High log-processing costs are making many stands uneconomic to harvest, especially those with small-volume trees. Innovative techniques are required to lower production costs in such marginal dead pine stands and increase their economic accessibility. Multi-stem processing is one possible solution to meet this need, however, the cost, productivity, and viability of such operations is not well understood. FPInnovations evaluated multi-stem processing in such stands in 2011, with mixed results. Production costs were reduced and the amount of fibre recovered from the site was increased, but log quality was reduced below acceptable limits.

This study builds on the previous work by evaluating two other processing systems in several scenarios. The Quadstar 500 dangle-head processor from Southstar Equipment Ltd is a new to processor in British Columbia designed for multi-stem processing. Tolko Industries Ltd, the industrial collaborator for this trial, wanted to evaluate its productivity and quality performance relative to the single-stem method using conventional processing equipment. Tolko also wanted to evaluate the cost and benefit of using a modified processing technique that would reduce the amount of in-woods processing, and instead deliver more non-sawlog fibre to a central yard where it would be removed.

Trial 4 involved using a Denis 3000 stroke-delimber for single- and multi-stem processing. In comparison to 2011 trial with a stroke delimber, the objective of this trial was to determine the productivity when pulp logs were produced in addition to sawlogs, similar to what was done with the Quadstar 500.

2 Harvesting System and Equipment, Site and Stand Description

Trees were mechanically felled, skidded, and decked at roadside before processing. Four trials were run with the three machines for approximately one full day-shift each (Table 1). The Quadstar 500 was provided on short-term demonstration by the equipment supplier, the Waratah 616 was a new machine used in regular service, and the Denis 3000 was over 10 years old, and was only returned into service for the trial. The Quadstar 500 was installed on a Hyundai 2925 carrier (Figure 1), the Waratah 616 was on a John Deere 2154D, and the Denis 3000 was on a John Deere 790DL (Figure 2). One operator was used for Trials 1-3 while a second operator was used on Trial 4.

Being on a short-term demonstration, there was insufficient time to use the Quadstar 500 in a single-stem trial, and the Waratah did not have the optional multi-stem processing package, so it could not be used for multi-stem processing. Therefore, direct comparisons of the two machines under identical conditions were not feasible, nor were they the objective of the trial. The objective of the trial was to compare multi-stem processing with conventional single-stem configuration using the available equipment.

The preferred log length for all trials was 6.2 m (20 feet, 4 inches) for logs large enough to produce dimension lumber, and 3.1 m (10 feet, 1 inch) for stud logs. All the butt logs in trial 4 were cut to the 6.2 m length, while shorter lengths were allowed in the other trials if the logs met the top diameter quality standards. Trials 1 and 4 used modified log specifications in which pulp logs were cut at minimum 6–8cm top diameter at a variable log length, rather than to the 3.1 m stud length.

Table 1 Equipment and sort specifications for each trial

Trial	Processor	Product	Processing Type	Log Lengths
1	Quadstar 500	Sawlog/Pulp	Multi-stem	2-ft multiples up to 20'4", variable (pulp)
2	Quadstar 500	Sawlog	Multi-stem	2-ft multiples up to 20'4", 10'1"
3	Waratah 616	Sawlog	Single stem	2-ft multiples up to 20'4", 10'1"
4	Denis 3000	Sawlog/Pulp	Single and Multi-stem	20'4", variable (pulp)

All trial sites were located in the Sub-Boreal Pine and Spruce (SBPS) biogeoclimatic zone. Trials 1-3 were conducted near Nazko, approximately 80 km west of Quesnel, while Trial 4 was conducted approximately 110 km southwest of Williams Lake. The stands were predominantly lodgepole pine that had been dead about 10 years since pine beetle attack. The cruise in Trial 4 indicated a minor component of live hybrid interior spruce, and the operator in Trials 1-3 remarked it contained a small component of spruce. The average tree size ranged from 15.7 – 18.4 cm DBH and 0.12 m^3 – 0.18 m^3 gross merchantable volume (Table 2). The average tree size in Trial 4 was 30% larger than the tree size in Trials 1-3.

Table 2 Stand and site characteristics

	Trials 1-3	Trial 4
Elevation (m)	1190	1530
Average slope (%)	18	13
Species composition (%)	Pl100	Pl97 Sw3
Net-merch. Volume (m^3/Ha)	138	152
Stand density (stems/Ha)	1311.1	1430
Avg. Net-merch. (m^3/stem)	0.10	0.13
Avg. DBH (cm)	15.7	18.4
Avg. Tree Ht. (m)	16.0	14.3

Figure 1 Quadstar 500 dangle-head processor

Figure 2 Denis 3000 stroke delimber

3 Methods

Each trial site was identified and selected as representative of the surrounding stand by FPInnovations and Tolko. Each trial area was marked so its volume could be kept separate for loading and hauling. The volume of processed and hauled logs from each trial site was provided by Tolko from their conventional weight scale data. At the mill yard, Tolko personnel measured length accuracy, and scaled and classified the logs from each trial area into sawlog and waste that did not meet the merchantable log specification. Approximately 3% of merchantable volume in Trials 1-3 was in excess of full loads and left at the roadside to be scaled by Tolko personnel.

The total productive time for Trials 1-3 was derived from MultiDAT data loggers installed on each machine. Productive machine time was calculated from the engine running time less any delays over 10 minutes duration. Productivity (m^3/PMH) was calculated by dividing the production for each sort by total productive time.

Reliable shift-level timing and volume data were not available from Trial 4 due to technical issues. The detailed timing data showed promising results, and Tolko was interested to repeat the trial with a newer machine, however, they were unable to acquire a replacement machine before the end of the logging season. Accordingly, the analysis for the stroke delimber is less comprehensive than for the dangle-head processors and is based only on the detailed timing data.

Detailed timing data were collected over 2 to 3 hours of continuous activity in each trial to record individual work cycles. The butt diameter classes on selected piles of stems were measured, marked on each stem, and counted in the detailed timing areas for Trial 1-3. The work time elements were grabbing the logs, processing, moving, non-productive working time, and delays under 10 minutes duration. Non-productive working time occurred when the processor grabbed a stem and attempted to cut a log but eventually rejected the entire stem. The numbers of processed stems by butt diameter class, rejected stems, and logs by sort were also recorded for each work cycle.

The volume produced during the detailed timing for each trial was derived from a count of the logs produced in each of the log sorts multiplied by the average log size for each sort from the sample scale of delivered logs.

For residue measurement in Trials 1-3, sections that were trimmed from the butts during the detailed timing were estimated to be over or under 30 cm in length. The sections under 30 cm were counted and multiplied by an estimated piece size, while the length and diameter of sections over 30 cm were sampled, and the average size derived from the measurements was applied to calculate their total volume.

The large-end diameters of the tops in the residue piles were sampled to calculate the average topping diameter for each trial. This value was subsequently used to calculate the average volume of the top section using FPInnovations' tree size calculator, which was multiplied by the stem count to calculate the volume of tops in the residue piles.

Costs were calculated using FPInnovations standard method (Appendix).

4 Results

Productivity for the stroke delimber was significantly higher than the dangle-head processors, however, caution should be taken when making direct comparisons. Productivity was calculated using detailed timing for the stroke delimber which often reports higher values than the shift-level method. The tree size was 30% larger for the stroke delimber and the productivity is based on gross volume. Results are encouraging, but more detailed evaluation is required.

For the dangle-head processors, overall productivity for multi-stem processing with conventional log sorts was about 5% higher than single-stem processing using the same log specifications (13.6 m^3/PMH versus 12.9 m^3/PMH). However, these results were from two different machines operating under different conditions, and caution should be used when interpreting the values (Table 3). The detailed timing results (see below) provide additional context.

Productivity for the multi-stem processing with modified log specifications (sawlogs plus pulp logs, Trial 1) was 26% higher than multi-stem processing with conventional sawlog specifications. Much of this productivity improvement was due to improved fibre recovery from each stem, as described below.

Table 3 Overall productivity by processing system

	Multi-stem Modified (Quadstar)	Multi-stem Conventional (Quadstar)	Single-stem Conventional (Waratah)	Multi-stem Modified (Denis)*
Productive time (working + short stops) (h)	5.98	7.87	6.23	2.52
Volume (m^3)	102.8	107.1	80.4	76.7
Productivity (m^3/PMH)	17.2	13.6	12.9	30.4

*Based on detailed timing

The highest productivity with the dangle-head processors was achieved by the Quadstar processor while multi-stem processing under the modified log specifications. The Quadstar also processed the most stems per hour and averaged the highest number of stems per cycle when it was multi-stem processing with the modified log specifications (Table 4). Under conventional log specifications, productivity was about equal for the Quadstar while multi-stemming and the Waratah while single-stemming. The slight difference in average stem size accounts for the productivity difference. The Denis operator felt he produced inferior quality logs when handling multiple stems and therefore only handled one stem at a time for about 80% of the cycles.

Table 4 Summary of detailed timing

	Multi-stem Modified (Quadstar)	Multi-stem Conventional (Quadstar)	Single-stem Conventional (Waratah)	Multi-stem Modified (Denis)
Cycle time (hr)	1.89	3.17	2.47	2.52
Cycles with logs produced	193	344	369	294
Stems processed	333	476	372	363
Stems/PMH	175.9	150.1	150.4	144.0
Stem/cycle	1.73	1.38	1.01	1.23
Logs produced				
• sawlog – 6.2 m long	185	254	181	349*
• sawlog – less than 6.2 m long	143	158	157	n/a
• Stud	n/a	143	134	n/a
• pulp	99	n/a	n/a	182**
Average log size (m^3)				
• sawlog	0.089	0.110	0.098	0.166
• stud	n/a	0.043	0.044	n/a
• pulp	0.035	n/a	n/a	0.098
Total volume (m^3)	32.66	51.47	39.02	76.66
Productivity (m^3/PMH)	17.25	16.23	15.77	30.4

* Butt logs

** Top logs

Despite having lower overall productivity, single-stem processing with the Waratah produced the shortest time per cycle, at 0.30 min/cycle (Table 5), including the shortest actual grabbing and processing times. Grabbing the stem from the supply pile occupied 50% of the cycle time for the Quadstar. FPInnovations observed that the operator often picked several stems from the pile and spread them out for better viewing. This allowed the operator to pick two stems with similar dimensions so they would feed well together through the processor.

Table 5 Summary of cycle element times

Cycle Element	Multi-stem Modified (Quadstar)		Multi-stem Conventional (Quadstar)		Single Stem Conventional (Waratah)		Multi-stem Modified (Denis)	
	Min	**%**	**Min**	**%**	**Min**	**%**	**Min**	**%**
Grab	0.25	50	0.16	42	0.10	33	0.13	29
Process	0.21	42	0.14	36	0.12	40	0.23	51
Move	0.00	0	0.01	3	0.01	2	0.01	2
Non-productive working	0.04	8	0.08	19	0.07	23	0.08	17
Short delays	0.00	0	0.00	0	0.01	3	0.00	1
TOTAL	**0.50**	**100**	**0.39**	**100**	**0.31**	**100**	**0.45**	**100**

The non-productive working time in Table 5 is when the processor picks a stem from the pile, starts processing, but then discards the entire stem without generating a merchantable log. Table 6 shows that the multi-stem modified system had significantly fewer cycles where no log was produced than either the multi-stem processing with conventional log specifications, or with single-stem processing.

Table 6` Proportion of cycles that did not produce a merchantable log

	Multi-stem Modified (Quadstar)	Multi-stem Conventional (Quadstar)	Single stem Conventional (Waratah)
Number of cycles	229	474	507
Cycles without production	36	130	138
Proportion of cycles without production	16%	39%	27%

The average cycle times shown in Table 5 also depend on the proportion of cycles with single or multiple stems. Multi-stem processing takes longer per cycle, however, handling multiple stems at once should decrease the processing time per stem. Table 7 shows that the Quadstar processed up to five stems per cycle, with most cycles having one or two stems. Its processing times per stem are substantially less with two stems per cycle than with one stem (0.27 min/stem vs 0.48 min/stem). There were similar differences between one and two stems per cycle when the Quadstar was processing conventional log specifications. By contrast, the processing time per stem for the Waratah was only marginally shorter when it processed two stems per cycle instead of one stem. However, caution should be exercised when interpreting processing times with more than two stems with the Quadstar or with more than one stem with the Waratah because of the limited number of cycles under those conditions.

Table 7 Average time per stem for various numbers of stems per cycles

Trials and Number of Stems Processed Together	Min/stem	Number of Cycles
Multi-stem Modified (Quadstar)		
1	0.48	60
2	0.27	129
3	0.32	2
4	0.25	1
5	0.30	1
Avg	0.34	193
Multi-stem Conventional (Quadstar)		
1	0.41	218
2	0.25	122
3	0.29	2
4	0.21	2
Avg	0.35	344
Single stem Conventional (Waratah)		
1	0.31	366
2	0.27	3
Avg	0.31	369

About 40% of the sawlogs produced by the dangle-head processors were shorter than the maximum preferred length (6.2 m). For trials 1-3, the log length accuracy assessment using Tolko's conventional standards (+/- 5 cm) found that dimension sawlogs had similar length accuracy when produced from multi-stem processing as the conventional single-stem processing (Table 8). About 3 – 4% of the multi-stem dimension sawlog sort did not meet Tolko quality specifications (e.g., crook, sweep, catface, etc.), compared to 1.4% with the single-stem processing. The pulp sort contained 19% of volume in logs that did not meet the company sawlog specifications.

Table 8 Log quality summary

	Multi-stem Modified (Quadstar)		Multi-stem Conventional (Quadstar)		Single stem Conventional (Waratah)	
	Dimension	**Pulp**	**Dimension**	**Stud**	**Dimension**	**Stud**
Scaled volume (m^3)	25.5 60%	17.3 40%	23.1 69%	10.6 31%	27.6 72%	10.7 28%
Saw log volume (m^3)	24.5	14.0	22.4	10.5	27.2	10.6
Waste (%)	3.8	19.1	3.2	0.6	1.4	0.4
Length Accuracy (%)*	98.6	n/a	96.7	98.8	99.3	100.0

* Proportion of logs cut within +/- 2 inches trim allowance

The non-merchantable portion of the pulp volume that was delivered to the mill yard represented volume that did not contribute to roadside residues. Figure 3 shows that the multi-stem trial with modified sort specifications produced less than half the roadside residues than either of the trials using the conventional sort specifications, as measured by the biomass ratio. The biomass ratio is the volume of residues divided by the volume of hauled logs. In all cases, the volume of tops was slightly more than the volume of long butts.

Since the pulp sort comprised 40% of the volume delivered in the multi-stem trial and 19% of the pulp sort was non-merchantable volume that would normally be left at roadside, this would result in 8% additional fibre being delivered to the mill that would be suitable for pulp or biomass.

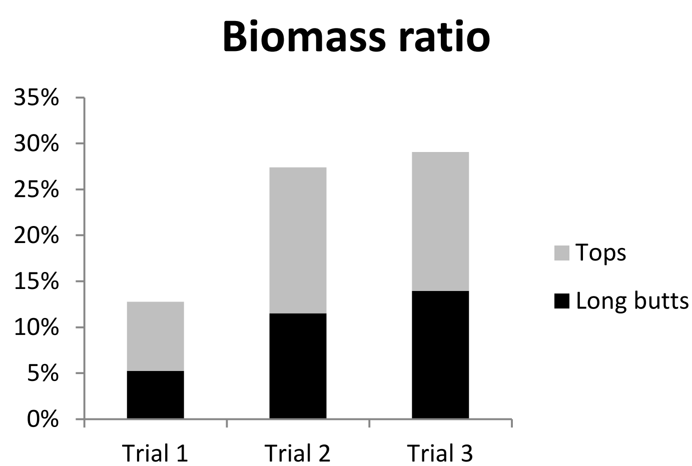

Figure 3 Biomass ratio stratified by tops and long butts

Processing costs are shown in Table 9. Processing costs for the stroke delimber, which were only available from detailed timing data, were about half of the lowest cost for the dangle-head processors. However, site conditions and measurement methods were different, which would contribute to the difference in productivity and cost.

The multi-stem modified trial had the lowest cost at $8.69/m^3, compared to $10.96/m^3 for the single-stem method, a savings of $2.27/m^3 or 21%. However, the multi-stem modified trial included a significant amount of non-merchantable fibre, therefore, costs were also calculated using the net merchantable volume (Figure 4). By this method, the cost savings for the multi-stem modified system were $1.97/m^3, or 18%.

Table 9 Productivity and cost summary

Trial	Multi-stem Modified (Quadstar)	Multi-stem Conventional (Quadstar)	Single-stem Conventional (Waratah)	Multi-stem Modified (Denis)
Gross productivity (m^3/PMH)	17.17	12.90	13.62	30.44
Net productivity (m^3/PMH)	16.02	12.74	13.22	-
Gross cost ($/$m^3$)	8.69	11.53	10.96	4.8
Net cost ($/$m^3$)	9.28	11.72	11.25	-

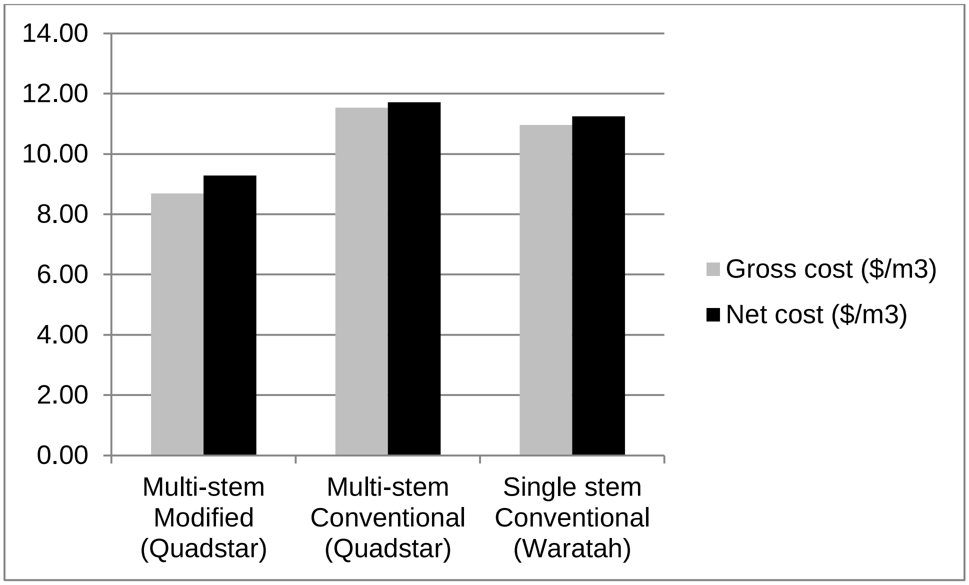

Figure 4 Processing cost from shift-level based on gross and net volume

5 Discussions and Conclusions

Multi-stem processing with modified sort specifications increased productivity by approximately 4 m^3/PMH and reduced processing costs by approximately $2/$m^3$ compared to the conventional single-stem processing. Several factors contributed to the productivity increase, including more fibre utilization and the nature of multi-stem processing itself. The relaxed log specifications resulted in more volume being produced from the available stems with less roadside residues, and fewer cycles where a log was not produced. Although the Quadstar 500 processor was slower than the Waratah processor when processing just a single stem, its time per stem was less than the Waratah when it processed two stems simultaneously.

The log quality in the dimension sawlogs was approximately equal for multi- and single-stem processed logs. However, the multi-stem processing with the modified sort specification, in which stems were cut to a pulp-log diameter limit instead of a stud-log length limit, generated 50% less roadside residue than the conventional log specification. Subsequently, 19% of the pulp sort was unsuitable to use as stud logs. Since the pulp sort comprised about 40% of the volume, this would result in about 8% additional fibre at the mill that would be suitable for pulp or biomass.

The operator was new to the Quadstar 500 and not yet comfortable with the multi-stem method. He commented that he required more focus and decision-making, which increased his fatigue. He felt that more practice with the machine and the processing system would likely increase his productivity. He also commented that pine and spruce stems have different taper and are not suitable to be processed together. Dropping a stem of one species to process them separately, or picking trees by species from the pile, would consume additional time. This could become a larger factor at night when visibility is poor or when working in mixed piles.

Multi-stem processing with the stroke delimber shows promise because of its higher productivity, however, additional validation with modern equipment is required.

Appendix

Machine Type:	Dangle-head processor		StrokeDelimber
Carrier	**Hyundai 2925**	**John Deere 2154D**	**John Deere 790DL**
Processing head	**Quadstar 500**	**Waratah 616**	**Denis D3000**
Year of Costing	2012	2012	2012
Ownership Costs			
Total purchase price (P) $	550000	520000	500000
Expected life (Y) y	5	5	5
Expected life (H) h	12000	12000	12000
Scheduled hours/year (h)=(H/Y) h	2400	2400	2400
Salvage value as % of P (s) %	25	25	25
Interest rate (Int) %	6.0	6.0	6.0
Insurance rate (Ins) %	3.0	3.0	3.0
Salvage value (S)=((P*s/100) $	137500	130000	125000
Average investment (AVI)=((P+S)/2) $	343750	325000	312500
Loss in resale value ((P-S)/H) $/h	34.38	32.50	31.25
Interest ((Int*AVI)/h) $/h	8.59	8.13	7.81
Insurance ((Ins*AVI)/h) $/h	4.30	4.06	3.91
Total ownership costs (OW) $/h	**$47.27**	**$44.69**	**$42.97**
Operating Costs			
Fuel consumption (F) L/h	24.0	24.0	27.0
Fuel (fc) $/L	1.10	1.10	1.10
Lube & oil as % of fuel (fp) %	10	10	10
Track & undercarriage replacement (Tc) $	28000	28000	28000
Track & undercarriage life (Th) h	6000	6000	6000
Annual repair & maintenance (Rp) $	60000	65000	50000
Shift length (sl) h	10.0	10.0	10.0
Operator	28.32	28.32	28.32
Wage benefit loading (WBL) %	39	39	39
Fuel (F*fc) $/h	26.40	26.40	29.70
Lube & oil ((fp/100)*(F*fc)) $/h	2.64	2.64	2.97
Track & undercarriage (Tc/Th) $/h	4.67	4.67	4.67
Repair & maintenance (Rp/h) $/h	25.00	27.08	20.83
Wages & benefits (W*(1+WBL/100)) $/h	39.36	39.36	39.36
Prorated overtime (((1.5*W-W)*(sl-8)*(1+WBL/100))/sl) $/h	3.94	3.94	3.94
Total operating costs (OP) $/h	**$102.01**	**$104.09**	**$102.97**
Total Ownership and Operating Costs (OW+OP) $/h	**$149.27**	**$148.78**	**$145.94**