MECHANIZED OR HAND OPERATIONS: WHICH IS LESS EXPENSIVE FOR SMALL TIMBER?

Robert Rummer and John Klepac

ABSTRACT

Two harvesting systems, one manual post-and-rail and one small-scale cut-to-length harvester, were compared in a lodgepole pine thinning. Elemental time study data were collected, along with estimates of residual stand damage. The harvester was about as productive as a manual crew of five. For material 5" and larger, the cost for felling, processing and piling small material with the harvester was less than the manual operation. However, the mechanized system resulted in considerably more residual stand damage.

Keywords: costs, cut-to-length, harvester, lodgepole pine

INTRODUCTION

The USDA Forest Service, like other western forest land managers, is increasingly challenged to deal with small-diameter removals. Prescriptions to reduce stocking for fuels management and partial cuttings to improve forest health generally produce significant volumes of small diameter material. Small diameter material has little product value that can be used to offset treatment costs. In fact, since the cost of most physical operations per unit volume handled increases exponentially as diameter decreases, many smalldiameter treatments are breakeven at best. Higher operational costs and lower product values mean the economics of fuel reduction treatments must be critically examined.

Several approaches have been taken to provide cost-effective small diameter treatments. One approach is to package a total stand prescription with enough larger diameter material to offset the costs of treating the small stems. Conventional equipment is used, but operates less efficiently in the small wood. A second approach is to find specialized contractors that are equipped to operate in small material. These are often low-capital manual operations using chainsaws. These systems suffer from higher accident and safety costs, low productivity, and limited availability. An alternative smallwood operation may utilize high-tech equipment rather than manual labor. These systems represent higher capital investment and thus require maximum utilization of the machines.

Selection of appropriate systems for working in small-diameter requires a good understanding of operating costs and the effect of site and stand conditions on performance. The objective of this study was to compare the cost and performance of a small-scale harvester to manual operations in a smallwood lodgepole pine thinning on the Medicine Bow-Routt National Forest in Wyoming.

STUDY OVERVIEW

The study site was a lodgepole pine stand marked for thinning "products other than logs." The initial stand had about 2000 stems per acre. Part of the unit was cut tree marked with green removal down to 3.5 inches. Dead material down to 1 inch was also merchandized. An adjacent block was leave tree marked with removals (dead or live) down to 1 inch. Table 1 summarizes the removals. The average DBH of removed material was 4.1 inches, however half of the volume removed was in stems greater than 5.6 inches. The prescription also required all slash to be left less than 2 feet above ground. Removals were merchandized into post-and-rail products.

Table 1.—Summary of lodgepole pine removals by diameter class.

Dbh Class (in)	Trees/acre	Vol/acre (ft^3)	% of TPA	% Vol removed
1	10	1.2	0.7	0.03
2	250	76.4	17.0	2.1
3	290	251.1	20.0	7.1
4	390	671.6	27.0	18.9
5	220	666.8	15.0	18.8
6	170	829.5	12.0	23.4
7	80	523.2	6.0	14.7
8	30	308.3	2.0	8.7
9	20	223.6	1.0	6.3
Total	1460	3551.7		

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The manual operation consisted of a 5-person crew using chainsaws to fell, limb, and buck the material into product lengths. Pieces were then manually piled to extraction corridors that were spaced approximately 100 feet apart. To aid loading, 6.5-ft and 8-ft products were oriented perpendicular to the skid corridor, while 13-ft and 16-ft products were oriented parallel to the skid corridor. A well-used prehauler collected the stacked pieces, forwarded them to roadside, and loaded the truck for transport to the yard. The crew was experienced, using proper felling techniques, and paid on a piece rate basis. The owner/contractor operated the prehauler and did the trucking.

The second system evaluated was a Neuson 11002 HV harvester. A small-capacity harvester, the Neuson represents state-of-the-art harvesting technology scaled down to reduce capital and operating costs of the machine. Designed in Austria, the Neuson is a purpose-built tracked forestry machine. The self-leveling cab operates like the larger conventional tracked feller-bunchers utilized in North America. The harvesting head can handle up to 19-inch stems with computerized bucking to extract any potential product material. Table 2 compares specifications of the Neuson with a typical full-size machine.

With the constraint of boom reach, the Neuson operated in study blocks with a 60-ft corridor spacing. The harvester felled stems, processed them near the trail and sorted by product into piles. Both the manual and mechanized crews used the same prehauler for extraction. The operator of the Neuson was an experienced logger and equipment operator, although he had relatively little time on this particular machine.

Felled trees were bucked into a variety of products that included 6.5-ft and 8-ft fence posts, fence stays, 13-ft large and small corral rails, and 16-ft corral rails. Of the total pieces handled, 33% were 8-ft.fence stays, 39% were 13-ft corral rails, and 20% were 16-ft corral rails. Only 1% of the pieces observed were 6.5-ft fence posts, while the remaining 7% were 8-ft fence posts.

DATA COLLECTION

Standard elemental productivity data were collected for manual felling, processing, and piling. Manual operations were videotaped and individual tree data were collected from felled stems. Dependent variables associated with each cycle included walk, acquire, fell, process, slash, and delay times. Piling elements included walk, wait, lift, pile, and straighten.

Productivity of the mechanized harvester was measured on two fixed area (~0.5 ac) study plots. These were centered on the extraction trail extending 30 feet to each side. All cut trees within the plots were measured and tagged prior to harvest. While the harvester worked through the plot, move distance was estimated for each setup. Dependent variables associated with each cycle included move, fell, process, place tops, and delay times.

Finally, after all harvest activities were complete, residual tree damage was assessed. Two 0.05-acre fixed radius plots were installed for each system. For the manual system plots were placed at random locations within the stand. For the mechanized system, plots were centered on the corridor. Within each plot all trees were measured for DBH. On damaged trees, scar length, width, and height above ground were measured. Type of damage was classified as either cambium exposed or wood damage. Distance of damaged trees from the center of the skid corridor was also measured for the mechanized system.

RESULTS

Manual Felling

A total of 44 manual felling cycles were measured during the study (Table 3). The largest amount of time spent during a cycle was processing, which accounted for 61% of the total time. This included limbing, topping, and bucking the tree into desired products. Cutting the remaining slash down below the 2-ft depth requirement accounted for approximately 17% of the time. Felling and walking accounted for 12% and 9% of the total cycle time, respectively. Acquire accounted for less than 1% of total cycle time.

Table 2.—Small-scale vs. conventional tracked harvester specifications.

Specification	Neuson 11002 HV	Timbco 425
Engine horsepower	4-cylinder, 102 hp	215 hp
Cab tilt, forward/side	25°/15°	27°/20°
Overall width (in)	96	116
Total weight (lbs)	25,000	52,000
Ground pressure (psi)	5.5	7.4
Boom reach (ft)	30	30
Cutting capacity (in)	15.9	various
Approx. Cost	$270,000	$350,000

Table 3.—Manual felling summary statistics.

Variable	N	Mean	Std. Dev.	Min.	Max.
DBH (in)	44	4.37	1.59	1.6	8.5
Total height (ft)	44	36.91	10.71	16.0	51.0
Walk distance (ft)	43	16.80	11.22	2.0	48.5
Walk (min)	44	0.16	0.09	0.05	0.44
Acquire (min)	7	0.09	0.08	0.03	0.23
Fell (min)	44	0.21	0.11	0.02	0.43
Process (min)	41	1.16	0.69	0.16	2.67
Slash (min)	32	0.41	0.30	0.08	1.45
Total time (min)	44	1.76	1.03	0.10	4.42
Volume/tree (ft^3)	44	2.55	2.03	0.14	9.80
Productivity (ft^3/PMH)*	44	82.26	43.20	24.91	295.19

*PMH = Productive Machine Hour

The relation between tree size and total cycle time is displayed in the scatter diagram in Figure 1. There is a strong trend of increasing cycle time as tree size increases. A regression equation to predict total cycle time as a function of tree diameter was developed. Other independent variables were tested and were not significantly related to total cycle time.

*Total cycle time (min) = -0.83 + 0.5929*DBH*

R^2 = 0.83; C.V. = 24.23

where: DBH = Diameter Breast Height (in)

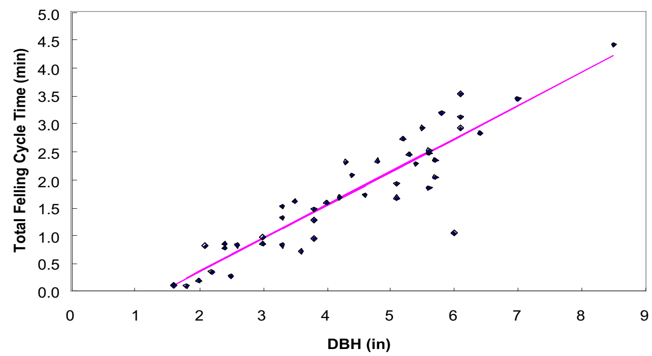

Figure 1.—Relation between DBH and total cycle time for manual felling.

Manual Piling

A total of 127 manual piling observations were collected during the study. Two workers were observed performing this function. The first (n=54) worked concurrently with a sawyer, which resulted in the worker having to wait on the sawyer to fell and/or process trees before he could perform his function. The second worker (n=73) observed was also a sawyer, so he piled while he was not felling.

On average, walking accounted for over half (56%) of the total cycle time, followed by waiting with 24%. Lifting pieces of wood to carry and place onto a pile accounted for only 11% of the total time, while piling and straightening piles accounted for about 8% and 1%, respectively (Table 4). There were no significant predictors among the independent variables, therefore the best estimator of piling productivity is the average value of 178.8 ft^3/PMH or about 3.5 tons/PMH.

Table 4.—Summary of elementary statistics for manual piling.

Variable	N	Mean	Std. Dev.	Min.	Max.
Walk (min)	124	0.27	0.15	0.03	0.92
Wait (min)	37	0.39	0.27	0.05	1.15
Lift (min)	127	0.05	0.04	0.02	0.33
Pile (min)	127	0.04	0.03	0.02	0.15
Straighten (min)	3	0.27	0.15	0.16	0.44
Total Time (min)	127	0.47	0.30	0.06	1.40
No. of Pieces	127	1.06	0.24	1.0	2.0
Volume/piece (ft^3)	135	1.04	0.60	0.36	1.81
Productivity (ft^3/PMH)	127	178.80	129.70	24.9	749.0

Mechanized Felling

A total of 111 mechanized felling observations were collected during the study period (Table 5). Placing tops in the skid trail after processing occurred 24% of the time. Twenty-eight percent of the trees handled by the harvester were dead. Productivity averaged 73 trees/PMH, or 3.84 tons/PMH. Reaching for a tree and processing it accounted for the majority of the total cycle time with 35% and 32%, respectively. Felling accounted for approximately 22% of the total time, followed by moving (8%) and placing tops (3%).

The relation between tree size and total cycle time is displayed in the scatter diagram in Figure 2. Again, there is a strong trend of increasing cycle time as tree size increases. The best regression equation to predict total cycle time as a function of tree diameter was:

*Total cycle time (min) = 0.39 + 0.0169*DBH²*

$R^2 = 0.55$; C.V. = 31.68

where: DBH = Diameter Breast Height (in)

Residual Tree Damage

There was significantly more residual damage from the harvester than from manual felling (Table 6). Scars in the manual operation were also significantly smaller. There appeared to be a relationship between the distance from the extraction trail and the incidence of scarring (Fig. 3). Fifty percent of the damaged trees were located 5.1–9 feet from trail center. Since the harvester had to process and pile trees along the skid corridor, more trees were damaged in this area. Only 5% were located mid-reach (9.1– 11 ft), with the remaining 45% located 13.1–21 ft from trail center. This likely reflects the difficulty of handling trees at the extreme limits of the boom reach.

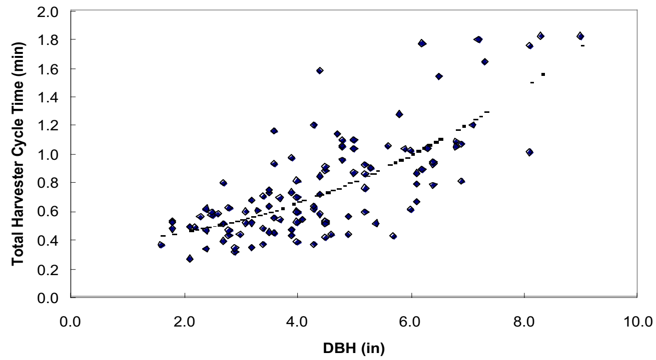

Figure 2.—Relation between DBH and total cycle time for the Neuson harvester

Table 5.—Summary of productivity data for the Neuson harvester.

Variable	N	Mean	Std. Dev.	Min.	Max.
DBH (in)	111	4.43	1.59	1.6	9.0
Total height (ft)	111	38.05	9.49	15.5	57.0
Height to live crown (ft)	80	28.05	6.73	7.0	40.0
Move distance (ft)	36	6.29	5.13	1.5	27.0
Move (min)	36	0.19	0.12	0.027	0.51
Reach (min)	111	0.27	0.13	0.075	0.79
Fell (min)	111	0.16	0.087	0.012	0.62
Process (min)	111	0.25	0.19	0.040	1.17
Place tops (min)	27	0.090	0.063	0.023	0.30
Total time (min)	111	0.76	0.36	0.27	1.82
Volume/tree (ft^3)	111	2.70	2.42	0.16	11.72
Productivity (ft^3/PMH)	111	196.72	126.55	19.55	617.40

Table 6.—Residual tree damage summary.

Variable	Manual Felling	Neuson Harvester
Damaged trees/acre	20	170
Trees/acre with cambium exposed	20	160
Trees/acre with wood damage	0	10
Mean scar size (in^2)	1.24	12.34
Mean scars/tree	2	2.5
Mean height above ground (ft)	9.1	3.5
Mean distance from trail (ft)		11.7

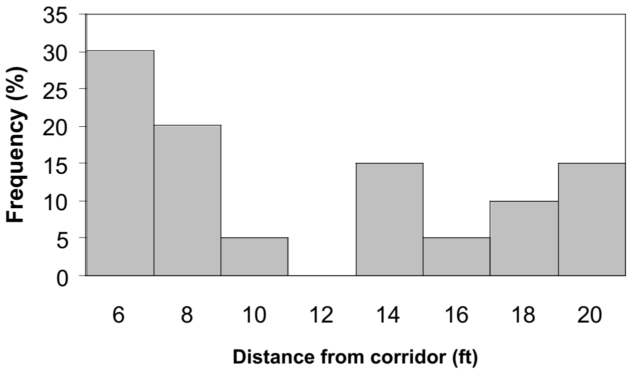

Figure 3.—Frequency of damaged trees from trail center in the harvester plots.

Costs

Machine costs (Table 7) were determined using standard machine rate analysis (Miyata 1980) and common assumptions from Brinker et al. (1989). This approach estimates an average hourly owning and operating cost over the life of the machine. Equipment dealers provided current purchase prices. Salvage value for the harvester was estimated to be 15% of the purchase price, annual insurance cost of 3.5% of the purchase price, repair and maintenance 70% of annual depreciation. A 4-wheeled 112-hp forwarder was used as the basis for the cost analysis of the prehauler. Salvage value was estimated to be 20% of the purchase price, annual insurance cost of 5% of the purchase price, repair and maintenance 100% of annual depreciation. For both machines a 5-year life, an interest rate of 9%, a fuel cost of $1.06/gal, a maximum utilization rate of 75%, and 2000 SMH/year (Scheduled Machine Hours) were used. Labor rates were based on Davis-Bacon wages for Carbon County, Wyoming. Equipment operators were assumed at $11.73/hr and manual laborers at $8.42/hr with 18% benefits added to each. Productivity for the forwarder was estimated at 8 tons/PMH, based on capacity and cycle time.

System costs (Table 8) are estimated for a balanced operation assuming the manual system utilizes a fully-depreciated prehauler, 5 laborers, and the owner/operator. The mechanized system is assumed to utilize a new forwarder in addition to the harvester.

With a manual system consisting of 3.4 chainsaws, 1.6 pilers and one forwarder, the system is limited in production by the chainsaws. With a mechanized system consisting of one harvester and one forwarder, the harvester is the limiting factor. Comparing system cost per ton the mechanized system was 52% higher than the manual system.

The effect of tree size on felling, processing and piling cost is displayed in Figure 4. The 2- to 4-inch DBH classes have a dramatic effect on harvester felling and processing costs, ranging from $30–$123 per ton. Above the 4-inch class felling and processing costs for the harvester approach that of manual felling and processing.

Table 7.—Cost and productivity for individual harvesting functions.

Machine/ Function	Initial Cost	Productivity (tons/PMH)	Max. Utilization (%)	Cost ($/SMH)	Cost ($/ton)
Harvester	$270,000	3.84	75	$69.41	$24.12
Chainsaw	$500	1.60	50	$11.54	$14.38
Piling	3.49	50	$9.94	$5.70	
Forwarder (new)	$170,000	8.00	75	$53.52	$8.92
Forwarder (used)	$20,000	8.00	50	$19.76	$4.94

Table 8.—System productivity and cost for smallwood harvesting.

System	Machine	Qty.	Function (tons/SMH)	System (tons/SMH)	Cost ($/SMH)	($/Ton)
	Chainsaw	3.4	2.72			
Manual	Forwarder	1	4.00	2.72	$73.44	$26.93
	Piler	1.6	2.79			
	Harvester	1	2.88			
Mechanized				2.88	$117.80	$40.94
	Forwarder	1	6.00			

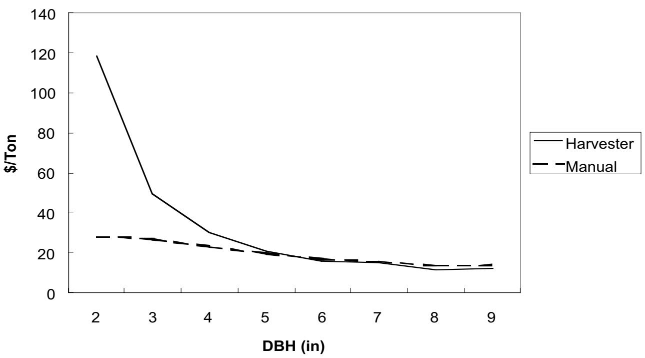

Figure 4.—Effect of tree diameter on total felling, processing, and piling cost.

DISCUSSION AND CONCLUSIONS

The objective of this study was to determine the cost and operational effectiveness of mechanized operations compared to manual operations in small-diameter treatments that are typical of Intermountain lodgepole pine stands. Based on the data collected during the study, two alternative systems can be described: (1) existing manual system using subcontracted chainsaw labor and fully-depreciated equipment; (2) a cut-to-length system using a new harvester and forwarder.

Felling, Processing, and Piling

The Neuson harvester and the manual chainsaw labor performed the same basic harvesting functions: felling, processing and piling. Because of the mechanical functions, the time to cut and process a tree with the harvester is only slightly affected by tree diameter. This results in the characteristic reverse-J cost curve with significantly increasing costs at smaller diameters (Fig. 4). Increasing harvester productivity overall (more operator experience, for example) would reduce costs, but the inflection point would likely remain at about the same diameter. When both systems worked on all the material in the stand, the harvester averaged $24/ton compared to $20/ton for the manual system. If the harvester had only been cutting down to 5 inches, costs would have dropped to $16/ton.

Manual System

The existing manual system with chainsaw labor plus the forwarder and operator can put wood to roadside for about $27/ton. This system underutilizes the forwarder (only about half of its potential output), however this is the most cost-effective configuration since owning costs on the machine are near zero. Manual labor ends up completely balanced in almost any system configuration since the workers can rotate between felling and piling as needed. This system is very flexible because the fixed costs are low. Downtime for moving, weather or waiting on work is not critical when the labor is paid piece-rate. In addition, with the manual labor as the limiting function, the owner-operator can idle the forwarder during loading and hauling without incurring additional costs.

The cost effectiveness of this system depends on the application of a used machine. If the contractor had to charge a new forwarder against the production of the system, costs would increase by 37% (from $27/ton to $37/ton). In addition, delays and downtime would become more critical. Labor is the largest component of wood cost (86%) and thus assumptions about labor rates are very critical. The Davis-Bacon wage rates are based on heavy construction contracts and may overestimate the actual labor rate paid to subcontract employees. Fully compensated manual labor rates should include fringes of 10% for workers compensation and unemployment insurance plus the employer's Social Security contributions. Whether all of these costs are covered in the subcontract piece rate is unknown.

Mechanized System

The CTL system was clearly limited by harvester productivity that in turn was significantly affected by piece size. Working with small diameter materials has a big effect on output, particularly as diameter falls below about 4 inches. Processing post-and-rail products from small-diameter materials resulted in a production of about 2.9 tons per PMH for the harvester in this study. By contrast, a recent comparison of five full-size CTL systems working in hardwood thinning in the Lake States observed system production rates of about 15 tons per PMH. As productivity of the harvester drops, system balance is affected. Most CTL operations have one harvester working with one forwarder. However, the small average diameter coupled with high stocking levels could make a CTL system with two harvesters for each forwarder a more cost-effective system. A 3-machine CTL system would be able to operate in this material for about $35/ton (a 15% reduction in cost). The capital investment in such a system, however, would be a strong disincentive.

Residual Stand Damage

Residual stand damage is more of an issue with the fully mechanized CTL system. A machine performing felling and processing is going to bump into more residual stems than a person with a chainsaw. Research studies show about 10–15% of a residual stand is going to be scarred by mechanical operations. As residual spacing and operator skill increase, scarring may be reduced to 5% or less. This study illustrated the critical importance of matching machine capabilities to operational layout. Higher damage occurred near the trail and at the outer limits of boom reach. This shows that trying to space out extraction trails to reduce soil disturbance will likely increase the amount of residual stand impact that occurs.

In contrast, the manual operation caused little residual damage. Directional felling was employed to select the best direction of fall. Hand piling material created no soil disturbance and could be matched to any desired trail spacing. Common practice for the manual crew was to sort/stack for a 100-ft trail spacing. Walking time was over half of total work time for piling, however the data collection methods did not allow analysis of trail spacing effects on manual productivity.

Other Considerations

While the manual operation is more cost-effective and ecologically-sensitive, there are several limitations. Safety of woods labor is a significant concern. Technically, the contractor and the chainsaw subcontractor are probably exempt from OSHA oversight due to establishment size and organization, but the safety issues are still valid to protect health and well-being. Federal OSHA requires manual chainsaw operations to have hardhats, eye protection, leg protection, and cut-resistant foot protection. Machines manufactured before August 1, 1996 must have a protective canopy constructed to protect the operator from falling trees, limbs, and branches. New machines must have certified rollover and falling-object protective structures as well as fully enclosed cabs. The CTL system would meet the current OSHA safety requirements, while the current manual system would need to address some deficiencies.

Availability of labor is another consideration for the wider application of manual systems. The CTL system produces 11.5 tons per person-day compared to 3.6 tons per person-day for the manual system. In other words, treating the same number of acres would require three times as many workers with manual systems as mechanized. It is likely that a large workforce of manual labor would also increase the average wage rate. However, the workforce of mechanized forest operations would be supported at a higher standard of living than manual laborers.

This project focused on a comparison of two systems engaged in a small-diameter treatment that removed post-and-rail products. The cost-effectiveness of the system is judged based on the product values recovered. The CTL system may still be cost-effective for a POL-type sale if the market value for these products was greater than the costs. If these systems were operating on a different product mix, the economic comparison may also be different. The CTL harvester productivity could increase significantly if all material were cut to maximum length for forwarder extraction, rather than multiple short product lengths.

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Authors

Robert Rummer
USDA-FS/Southern Reserach Station
G.W. Andrews Forestry Sciences Laboratory
520 Devall Dr.
Auburn, AL 36849
334-826-8700
rrummer@fs.fed.us

John Klepac
USDA-FS/Southern Reserach Station
G.W. Andrews Forestry Sciences Laboratory
520 Devall Dr.
Auburn, AL 36849
334-826-8700
jklepac@fs.fed.us