Thinning Productivity and Cost for a Mechanized Cut-to-Length System in the Northwest Pacific Coast Region of the USA

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ABSTRACT

A production study of a single-grip harvester and forwarder was conducted in a second-growth thinning operation in western Oregon, USA. Production levels for the harvester exceeded 30 m^3/PMH (productive machine hour, delay-free). There was no significant difference in harvester production between stands marked prior to logging and those in which the trees were selected by the operator. Production levels for the forwarder ranged from 10.2 m^3 to 14.5 m^3/PMH. When landing space was limited, a two-pass forwarding technique (separate loads of sawlogs and pulpwood) was more productive than a single-pass technique (products mixed on each load and sorted at the landing). Regression equations were developed to predict harvester production per PMH on the basis of tree dbh and to predict forwarder production per PMH on the basis of product type, volume per load, and travel distance. Thinning cost for this cut-to-length system was US\$12.49/m^3 [US\$35.37/cunit], excluding hauling and a profit-and-risk allowance.

Keywords: *mechanized logging, single-grip harvester, forwarder, logging cost, thinning productivity.*

INTRODUCTION

Harvesting activities are rapidly shifting from old-growth to second-growth stands in the Pacific Northwest region of the USA. Approximately 60% of the commercial timberland in western Oregon could be operable for various types of in-woods mechanized equipment [5]. Of this operable timberland, about 58% of the sawtimber stands and about 64% of the poletimber stands are on slopes of less than 35%. Information is lacking, however, on the productivity and environmental effects of certain machines, such as multi-function harvesters and forwarders, working in partial cutting operations with small timber (dbh < 30 cm [12 in.]) on such medium slopes (20-40%) [12].

Mechanized logging provides end products of more consistent and higher quality, smaller crew sizes, and a safer work environment than does conventional logging [10]. Some ground-based harvesting equipment, however, may not be suitable for the large tree sizes and broken and steep terrain in parts of the Pacific Northwest. But where ground-based machinery is suitable and results in minimal environmental impacts, harvesting economics and logistics may favour it over cable systems.

Various logging methods, from those with small skyline yarders to ground-based cut-to-length systems, can be used for thinnings in the Pacific Northwest. Cut-to-length systems are operations in which all of the processing (delimbing and bucking) occurs in the woods. These systems are derived from modern Nordic harvesting technology and offer a wide range of alternatives for thinnings and clearcuts [8]. Cut-to-length systems are different from conventional logging systems in that less labour, road construction, and landing areas are needed. They also produce end products of higher quality and more consistent dimension than do conventional systems, and they also allow for lower costs for woodyard management [1]. Furthermore, several states have recognized the safer work environment these systems provide and now offer lower worker's compensation rates for them than for conventional logging [7].

Cut-to-length systems are generally comprised of two machines, a harvester (single-grip or double-grip) and a forwarder. The harvester fells and processes trees in the direction of its path, and the forwarder transports cut-to-length logs to roadside. Both machines travel over a mat of limbs and tops, which potentially reduce soil compaction and erosion. The distribution of limbs and tops throughout the stand may also be more aesthetically pleasing and beneficial for nutrient recycling than would a residue pile at a landing.

Harvester productivity may be highly variable, depending on individual tree size, operator skill and motivation, branch size, numbers of unmerchantable

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and merchantable trees per unit area, slope and ground conditions, and undergrowth density [13, 17]. A compilation of results from several similar harvesting studies [12] shows that harvester productivity generally is closely related to tree size. Baumgras [3] found that the cost per tree decreases rapidly as tree size increases and that the effect on productivity of equipment moves between trees and of the number of trees harvested per move is more pronounced in thinnings or when small trees are harvested than in clearcuts and harvests of larger trees. In another study [14], the number of unmerchantable trees in a harvest area had the greatest influence on productive time. Total product length has also been found to greatly influence the number of trees harvested per productive machine hour [20].

A Swedish study of 35 medium-sized forwarders showed that primary transportation of sawlogs was faster than that of pulpwood and that primary transportation in clearcuts was faster than in partial cuts [11]. The average mechanical availability of the 35 forwarders was 93% and utilization was 84%. Productivity averaged 10.3 m^3 per gross effective hour. Other forwarder studies have reported production rates of 9.6 m^3 per operating hour [19] and 12.7 tonnes per productive machine hour [16] for average forwarding distances of 170 m and 658 m, respectively.

Steep slopes may pose difficulties to harvester and forwarder operations, because these machines must generally travel straight up and down a slope to maintain stability [17]. Equipment operators must spend extra time manoeuvring the machines in undulating terrain. When the operator faces downhill, the view of the harvester head may become blocked by the wheels of the chassis. Small trees and underbrush also affect visibility and may cause downtime by damaging the chain, bar, or hydraulic hoses [17]. High capital costs have also been noted as a disadvantage of harvesters and forwarders [15].

This study was conducted to provide basic information on production and cost for a cut-to-length system applied by a logging contractor in thinnings in the Pacific Northwest. The objectives of the study were to detail harvester and forwarder production and cost, to develop regression equations to predict productivity on the basis of stand and operating conditions, and to determine overall thinning economics for these systems. Further objectives were to compare time elements for harvesters in premarked stands and in stands where the operators selected the trees and for two different forwarding techniques. Research on soil compaction [2] and stand damage [4] was also conducted but is not reported here.

METHODS

The study was located approximately 11 km south of Lyons, Oregon, in the Cascade Mountains. The operation consisted of thinning a 47-year-old Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) stand with a Timberjack 2518 harvester (equipped with a Koehring Waterous 762 head) and an FMG 910 forwarder. The entire thinning area was approximately 40.5 ha [100 acres]; two harvester/forwarder systems were operating there. Only one of these systems was studied, and only on a portion of the thinning area—the forwarder on 5.7 ha [14 acres] and the harvester on 0.90 ha [2.2 acres]. The harvester operator had approximately 18 months of experience in similar terrain, while the forwarder operator had approximately 9 months of experience. The products produced by the operation were sawlogs (5.4 m [17 ft 10 in.] long, to a 15.2-cm [6-in.] top) and pulpwood (6.1m [20 ft] long, to a 5.1-cm [2-in.] top).

Harvester

The study area for the harvester was broken down into two treatment areas: one in which the trees to be left were marked by a forester and one in which they were unmarked and selected by the harvester operator. Each stand consisted of 3 equipment trails with similar terrain and length. Each tree in the study area was measured for diameter at breast height (dbh) and successively numbered prior to the beginning of the study. The difference between the average values for dbh in the two stands prior to thinning was not statistically significant ($P \leq 0.05$). Average stand conditions before and after harvesting are shown in Table 1. The average slope was 15° (26%) for the marked stand and 17° (31%) for the unmarked stand.

A detailed time study was conducted on the harvester. All activities associated with harvesting each tree were considered collectively as one sample and were broken out into basic time elements (Table 2). The data were recorded with a special program, called SIWORK3 [6], and run on a Husky Hunter 2

Table 1. Average site conditions in the marked and unmarked stands, before and after thinning, for the harvester production study.

Condition	Marked Stand	Unmarked Stand
Area in ha [acres]	0.46 [1.14]	0.44 [1.08]
Before thinning		
Total trees/ha [acre]	998 [404]	914 [370]
Dbh in cm [in.]	25.91 [10.2]	26.16 [10.3]
Volume/ha in m^3	663	633
[/acre in ft^3]	[9,479]	[9,044]
Basal area/ha in m^2	60.8	57.1
[/acre in ft^2]	[264.7]	[248.9]
After thinning		
Total trees/ha [acre]	353 [143]	381 [154]
Dbh in cm [in.]	35.31 [13.9]	33.78 [13.3]
Volume/ha in m^3	424	421
[/acre in ft^3]	[6,061]	[6,015]
Basal area/ha in m^2	36.6	36.3
[/acre in ft^2]	[159.6]	[158.3]

computer [9]. The SIWORK3 program records time elements to the centi-minute and allows the user to enter other numerical data such as tree number. The data were downloaded to a personal computer, imported into a spreadsheet program, and used for analysis. A simple linear regression equation was developed to predict productivity [m^3 per productive machine hour, delay-free (PMH)] on the basis of tree dbh.

Forwarder

Average site conditions on the study area for the forwarder before and after thinning are shown in Table 3. Within the study area, 2 methods of forwarder operation were evaluated: (1) a two-pass technique that involved sorting in the woods and forwarding only one product type (pulpwood or sawlogs) in a load, and (2) a single-pass technique that involved forwarding both product types mixed in a load and sorting at the landing. The study area was not separated into 2 distinct stands (one for each method of forwarding operation) because the forwarder operator preferred to remain flexible about the products needed for trucking. Therefore, both methods were used throughout the stand; the goal was to obtain a representative sample for each method of operation. Ground slope for the study area ranged from 0 to 23° (0 to 42%). The north side of the area was bounded by a creek, the south side by steeper slopes (19 to 22° [35 to 40%]), and the east side by a previously thinned area. A flat bench ran east-west through the middle of the study area. Trails were flagged by an equipment operator before the harvester operation began (Figure 1); trail spacing was approximately 15 to 18 m [50 to 60 ft].

A detailed time study was conducted on the forwarder. All activities associated with forwarding one load were considered one sample and were broken out into basic time elements (Table 4). Time-study data on the forwarder were also collected by using the SIWORK3 program and analysed in a spreadsheet. In addition, a map of the equipment trails was used to detail the actual path of the forwarder during each cycle (Figure 1). This information was used to determine forwarding distances, as well as the number of machine passes on the trails for a soil compaction study [2].

Table 2. Activities (and an associated term) in the harvester time study.

Moving machine: begins when the harvester tracks start moving, ends when the harvester stops moving to perform some other task.

Positioning to cut: begins when the boom starts to swing toward a tree, ends when felling head rests on a tree.

Felling and dropping: begins when the felling head is attached to a tree, ends when the tree hits the ground, or when processing begins.

Processing: begins when the tree hits the ground, or when the felling head begins to pull the tree through the delimbing knives, ends when processing is complete.

Brushing: removal of saplings and brush and felling of unmerchantable trees.

Piling: piling or sorting logs in the woods.

Planning: assessment by the harvester operator of area or trees to cut, while remaining in the stationary machine.

Delays: operational, mechanical, and personal delays that interrupt the normal work activity of the harvester.

Logs: the number of logs produced by the harvester from a particular tree.

Table 3. Average site conditions, before and after thinning, for the forwarder production study.

Condition	Unit
Area in ha [acres]	5.67 [14.0]
Before thinning	
Total trees/ha [acre]	1,327 [537]
Dbh in cm [in.]	20.9 [8.2]
Volume/ha in m^3	520
[/acre in ft^3]	[7,430]
Basal area/ha in m^2	55.1
[/acre in ft^2]	[240.1]
After thinning	
Total trees/ ha [acre]	427 [173]
Dbh in cm [in.]	29.9 [11.8]
Volume/ha in m^3	344
[/acre in ft^3]	[4,921]
Basal area/ha in m^2	33.1
[/acre in ft^2]	[144.1]

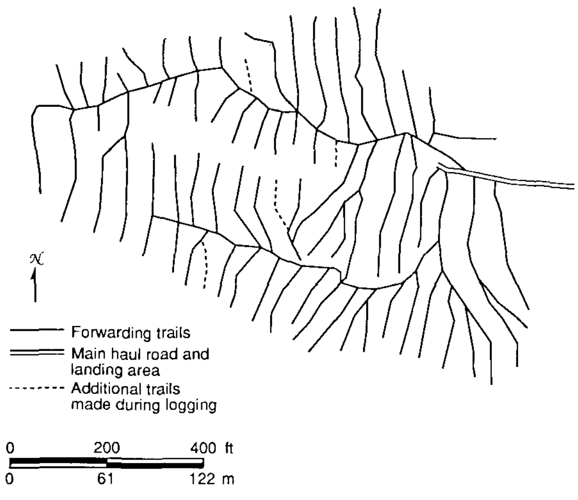

Figure 1: Trail layout of the study area for the forwarder.

Table 4. Activities (and associated terms) in the forwarder time study.

Travelling empty: begins when the forwarder leaves the landing area, ends when the forwarder stops to begin loading or some other task.

Loading: begins when the forwarder starts to load logs, ends when the boom is rested in a stationary position, ready for a machine move.

Moving between loading: begins when the boom is rested stationary on the bunk, ends when the forwarder stops moving.

Travelling loaded: begins when the boom is rested stationary on the bunk, ends when the forwarder stops at the landing area.

Unloading: begins when the forwarder raises the boom for unloading, ends when the boom is rested stationary on the bunk for a return trip to the woods or some other task.

Sorting: sorting products (sawlogs or pulpwood) in the woods.

Brushing: clearing brush (limbs and tops) from the bunk.

Repositioning: movement from one corridor to another while loading in the woods.

Delays: operational, mechanical, and personal delays that interrupt the normal work activity of the forwarder.

Distance out: the distance travelled by the forwarder from the landing area to the location where loading begins.

Travel in unit: the distance travelled in the unit while in the loading mode.

Distance in: the distance from the last loading location to the landing area.

Logs: the number of logs loaded.

Product: the product of the load (sawlogs, pulpwood, or mixed).

RESULTS

Harvester Productivity and Cost

The harvester was studied for approximately 12 hours in the marked and unmarked stands. The average time per tree to harvest was slightly less in the marked than in the unmarked stand, and the harvester processed more trees per PMH in the marked stand (Table 5). There were no treatment-specific delays; because the duration of the study was relatively short, all of the delays were averaged and a time was allocated to each individual tree harvested for calculating machine availability and utilization. Availability and utilization are therefore slightly lower for the marked than for the unmarked stand because of the differing cycle times per tree. However, availability and utilization would be expected to be the same for both stands. Most of the delays (43.9%) were for personal reasons, such as lunch and miscellaneous breaks. Repairs accounted for a substantial portion (34.6%) of the delay time. The most common repair delay consisted of chain and bar replacement, which averaged 6.90 minutes. The rest of the delay time consisted of miscellaneous operational delays, such as cutting away large stumps or old logs.

Even though average dbh was similar in both stands prior to logging, average dbh of the harvested trees was 21.8 cm [8.6 in.] in the marked stand and 23.6 cm [9.3 in.] in the unmarked stand. Thus, the average volume per tree harvested was 0.09 m^3 [3.3 ft^3] higher in the unmarked than in the marked stand. This difference contributed to the higher volume productivity obtained in the unmarked stand.

With the higher average volume per tree harvested in the unmarked stand, there were also slightly higher average *positioning to cut* and *processing* times in this stand than in the marked stand. There was also a greater *planning* time per tree in the unmarked stand.

Table 5. Summary of productivity of the Timberjack 2518 equipped with a Koehring Waterous 762 single-grip harvesting head, operating in a marked and an unmarked thinning in western Oregon.

Time Element	Marked Stand[a] Average time (min.)	Marked Stand[a] Proportion of total time (%)	Unmarked Stand[b] Average time (min.)	Unmarked Stand[b] Proportion of total time (%)
Moving machine	0.132	8.8	0.138	8.8
Positioning to cut	0.182	12.1	0.211	13.4
Felling and dropping	0.172	11.5	0.169	10.7
Processing	0.335	22.3	0.364	23.1
Brushing	0.316	21.0	0.284	18.1
Piling	0.009	0.6	0.004	0.3
Planning	0.040	2.7	0.088	5.6
Delays	0.315	21.0	0.315	20.0
Total	**1.501**	**100.0**	**1.573**	**100.0**

Tree and Log Condition or Productivity Measure	Marked Stand (unit)	Unmarked Stand (unit)
Avg. dbh of trees in cm [in.]	21.8 [8.6]	23.6 [9.3]
Range in dbh of trees in cm [in.]	10.2-43.3 [4.0-17.1]	13.5-50.3 [5.3-19.8]
Logs/tree	2.9	2.9
Vol./tree in m^3 [ft^3]	0.41 [14.6]	0.51 [17.9]
Trees/PMH[c]	73.1	68.0
Machine availability, %	81.5	82.4
Machine utilization, %	67.6	69.1
Vol./PMH in m^3 [ft^3]	30.3 [1,070]	34.4 [1,215]
Vol./SMH[d] in m^3 [ft^3]	20.5 [723]	23.8 [839]

[a]Sample size = 211 trees.
[b]Sample size = 160 trees.
[c]Includes time elements for moving the machine, positioning to cut, felling and dropping, and processing.
[d]SMH = scheduled machine hour.

Regression analysis of the time elements and volumes on production per PMH created an equation designed to predict production levels on the basis of dbh. Type of treatment (marked or unmarked stands) was not used in the regression equation because it did not result in a statistically significant difference ($P \leq 0.05$) in productivity (Vol./PMH). For both stands (combined sample size = 371 harvester cycles), the resulting regression equation was

$$\text{Vol./PMH } (m^3) = -17.48 + 2.11 \text{ dbh (cm)} \qquad r^2 = 0.75$$

or

$$\text{Vol./PMH } (ft^3) = -617.22 + 189.31 \text{ dbh (in.)} \qquad r^2 = 0.75$$

Average dbh and the range in dbh for the stands studied are shown in Table 5. These conditions are fairly typical of second-growth stands in western Oregon.

The purchase price of the Timberjack 2518 harvester is approximately US $340,000. The 1992 hourly owning and operating cost of this machine was calculated by the PACE program [18] to be US $88.56/scheduled machine hour (SMH) for a one-shift operation. Costs per unit volume exclude a profit-and-risk allowance.

If we assume that, on the average, the harvester processed trees 22.8 cm [9 in.] in dbh and had a machine-utilization rate of 69%, then productivity would be 30.8 m^3/PMH [1,087 ft^3/PMH] and 21.2 m^3/SMH [750 ft^3/SMH] for both the marked and unmarked stands. Cost per unit volume would then be US $4.17/$m^3$ [US $11.81/cunit] in the unmarked stand. Marking costs were determined by assuming a US $37.50 marking cost per hour (for labour, paint, etc.) and a production rate of 0.27 ha [0.67 acre] per hour; thus, the marking cost would be US $138.90/ha [US $56/acre]. Given that 239 m^3/ha [3,418 ft^3/acre] were harvested in the marked stand, the marking cost is US $0.58/$m^3$ [US $1.63/cunit]. Therefore, cost (including marking) per unit in the marked stand would be US $4.75/$m^3$ [US $13.45/cunit].

Forwarder Productivity and Cost

The forwarder was studied for approximately 111 hours over a 3-week period. Production results for the two-pass and the single-pass techniques are shown in Tables 6 and 7. The average time per load ranged from a low of 46 minutes for pulpwood loads to a high of 67.62 minutes for mixed loads. While loading the bunk generally took longer with pulpwood than with sawlogs, there was little *sorting* involved because sawlogs were typically picked up in the first pass by the forwarder.

Loading generally took less time with the mixed-load technique than with either sawlogs or pulpwood. *Unloading*, however, took considerably longer with the mixed-load technique because the roadside landing was not wide enough to accommodate 2 trailers for the sawlog and pulpwood sorts. Thus, because of the limited space available at the landing in this study, *unloading* with the mixed-load technique included sorting the products at the landing, loading one product onto a trailer, leaving the second product on the ground, and subsequently loading and moving the second product to another trailer, sometimes at another landing. The unloading time would have been substantially decreased with alternative landing operations such as using two trailers (one for each product) had the landing been wide enough, loading both product types on one trailer, or using an independent loader.

Approximately 41% of the 120 loads studied consisted of sawlogs, 27% consisted of pulpwood, and 32% were mixed loads. The average distance travelled to a point where loading began (distance out) was similar among the treatments, as was the distance travelled back to the landing (distance in). However, substantial differences occurred in the travel distance during loading (travel in unit), which ranged from 51 m [166 ft] with mixed loads to 111 m [365 ft] with pulpwood loads. There was an inverse relationship between logs per load and volume per load, with fewer logs and higher volumes per load with sawlogs and a greater number of logs and lower volumes per load with pulpwood.

Machine utilization was similar among the forwarding techniques. Productivity per PMH was greatest with sawlogs. The sawlog/pulpwood two-pass technique was more productive per PMH and SMH than the mixed-load, single-pass technique. However, in situations where 2 trailers could be positioned side by side at a landing, we could estimate forwarder production by excluding the time required in our study to reload the sorted product from the ground and transport it to another trailer at a different location. In such a case, production with the mixed-load, single-pass technique would increase to 13.3 m^3/PMH [468 ft^3/PMH] and 9.6 m^3/SMH [337 ft^3/SMH], making the two techniques (two-pass and single-pass) similar in productivity.

The following regression equation predicted productivity on the basis of indicator variables for product type, volume per load, and distances travelled (sample size = 120 forwarder cycles):

$$
\begin{aligned}
\text{Vol./PMH } (m^3) = {} & 16.245 \\
& - 1.689 \text{ mixed} \\
& - 3.478 \text{ pulp} \\
& + 0.2707 \text{ vol./load} \\
& - 0.008 \text{ DO} \\
& - 0.0057 \text{ trav} \\
& - 0.0039 \text{ DI} \\
& r^2 = 0.52
\end{aligned}
$$

Table 6. Summary of productivity in terms of work activities for the FMG 910 forwarder in a thinning in western Oregon.

	TwoPass Technique[a]						Single-Pass Technique[c] (mixed loads)		All loads	
	Sawlogs		Pulpwood		Sawlogs and pulpwood[b]					
Time Element	**Avg. time (min.)**	**Proportion of total time (%)**	**Avg. time (min.)**	**Proportion of total time (%)**	**Avg. time (min.)**	**Proportion of total time (%)**	**Avg. time (min.)**	**Proportion of total time (%)**	**Avg. time (min.)**	**Proportion of total time (%)**
Travelling empty	4.32	8.3	4.50	9.8	4.39	8.8	4.52	6.7	4.43	8.0
Loading	16.75	32.1	20.40	44.3	18.19	36.6	15.73	23.3	17.39	31.3
Moving	1.94	3.7	2.07	4.5	1.99	4.0	1.67	2.5	1.89	3.4
Brushing	0.29	0.5	0.37	0.8	0.32	0.6	0.30	0.4	0.31	0.6
Repositioning	0.87	1.7	1.39	3.0	1.08	2.2	0.71	1.1	0.96	1.7
Sorting	8.62	16.5	0.07	0.1	5.24	10.5	0.02	0.0	3.54	6.4
Travelling loaded	3.26	6.2	3.44	7.5	3.33	6.7	4.14	6.1	3.60	6.5
Unloading	6.10	11.7	4.86	10.5	5.61	11.3	25.12	37.1	11.95	21.5
Delays	10.03	19.2	8.99	19.5	9.62	19.3	15.42	22.8	14.42	20.7
Total	52.18	100.0	46.09	100.0	49.77	100.0	67.62	100.0	55.58	100.0

[a]The two-pass technique involves sorting products in the woods and forwarding one product to the landing at a time.
[b]This column is the total data set for sawlog loads and pulpwood loads.
[c]The single-pass technique involves forwarding both products to the landing and sorting there.

or

$$
\begin{aligned}
\text{Vol./PMH (ft}^3\text{)} &= 573.676 \\
&- 59.659 \text{ mixed} \\
&- 122.810 \text{ pulp} \\
&+ 0.2707 \text{ vol./load} \\
&- 0.086 \text{ DO} \\
&- 0.062 \text{ trav} \\
&- 0.042 \text{ DI} \\
r^2 &= 0.52
\end{aligned}
$$

where
In mixed loads, mixed = 1 and pulp = 0,
In sawlog loads, mixed = 0 and pulp = 0,
In pulp loads, mixed = 0 and pulp = 1,
Vol./load = volume per load (m^3 or ft^3),
DO = travel distance to where loading begins (m or ft),
trav = travel distance during loading (m or ft),
DI = travel distance to the landing after loading is completed (m or ft).

Average values and the ranges for the variables in the regression equations are shown in Table 7. Results for mixed loads reflect landing conditions such that the 2 products can be transferred directly from the forwarder to trailers without rehandling.

All variables were found to be statistically significant ($P \leq 0.10$) and useful in estimating the productivity of the forwarder under the conditions of this study. Productivities and costs among the various types of loads as predicted by the regression equation are shown in Table 8. The cost of the FMG 910 forwarder is approximately US $235,000. The 1992 hourly owning and operating cost of this machine was calculated by using PACE [18] to be US $70.41/SMH for a one-shift operation. Costs per unit volumes exclude a profit-and-risk allowance. Forwarding cost per m^3 would be US $6.80 [US $19.26 per cunit] with the mixed-load technique (Table 8). Forwarding cost was approximately 43% higher for pulpwood than for sawlogs.

Table 7. Summary of productivity measures for the FMG 910 forwarder in a thinning in western Oregon.

Productivity measure	Two-Pass Technique[a]			Single-Pass Technique[c] (mixed loads)	All Loads
	Sawlogs	Pulpwood	Sawlogs and Pulpwood[b]		
Number of cycles	49	32	81	39	120
Avg. distance out in m [ft]	267 [877]	296 [971]	279 [914]	280 [918]	279 [916]
Range in m	77-728	83-632	77-728	115-612	115-728
[in ft]	[252-2,387]	[271-2,075]	[252-2,387]	[378-2,008]	[378-2,387]
Avg. travel in unit in m [ft]	73 [241]	111 [365]	88 [290]	51 [166]	76 [250]
Range in m	5-206	38-233	38-233	8-419	5-419
[in ft]	[15-676]	[125-766]	[125-766]	[25-1,376]	[15-1,376]
Avg. distance in, in m [ft]	230 [754]	280 [920]	250 [820]	265 [868]	254 [835]
Range in m	47-643	19-602	19-643	19-633	19-643
[ft]	[155-2,108]	[63-1,974]	[63-2,108]	[63-2,078]	[63-2,108]
Avg. logs/load	60	109	79	86	82
Range	16-88	33-155	16-155	47-112	16-155
Avg. vol./load in m^3 [ft^3]	9.93 [351]	5.99 [212]	8.38 [296]	9.34 [330]	8.69 [307]
Range in m^3	3.0-15.1	2.2-7.8	2.2-15.1	5.0-12.3	2.2-15.1
[ft^3]	[105-534]	[77-275]	[77-534]	[178-433]	[77-534]
Machine availability, %	87.1	87.1	87.1	86.2	86.7
Machine utilization, %	78.6	76.7	77.9	75.7	77.0
Vol./PMH in m^3 [ft^3]	14.5 [513]	10.2 [359]	13.0 [458]	10.9 [386]	12.2 [430]
Vol./SMH in m^3 [ft^3]	11.4 [403]	7.8 [275]	10.1 [357]	8.3 [293]	9.4 [331]

[a]The two-pass technique involves sorting products in the woods and forwarding one product to the landing at a time.
[b]This column is the total data set for sawlog loads and pulpwood loads.
[c]The single-pass technique involves forwarding both products to the landing and sorting there.

In our study, sawlogs comprised 60% of the total material harvested and pulpwood comprised 40%. Given this condition, the weighted average cost for the two-pass technique was the same as that for the single-pass technique.

Productivity Variation and Support-Equipment Cost

When the regression equations for the harvester and forwarder were used to indicate productivity rates over various values for tree dbh within the stand studied and distance travelled out by the forwarder (while other variables were held constant), harvester productivity ranged from 15.8 m^3/PMH [558 ft^3/PMH] with a dbh of 15.76 cm [6.2 in.] to 43.2 m^3/PMH [1,526 ft^3/PMH] with a dbh of 28.76 cm [11.3 in.] (Figure 2). Forwarder productivity dropped almost 8 m^3/PMH [282 ft^3/PMH] within each type of load as the *distance out* increased from 60 to 720 m [200 to 2,360 ft] (Figure 3).

Table 8. Forwarding productivity and cost as predicted with the regression equation developed for forwarders.[a]

Productivity or Cost Measure	**Two-Pass Technique**		**Single-Pass Technique (mixed loads)**
	Sawlog	**Pulpwood**	
Vol./PMH in m^3 [ft^3]	15.3 [540]	10.7 [376]	13.4 [475]
Vol./SMH in m^3 [ft^3]	11.8 [416]	8.2 [290]	10.4 [366]
Cost/SMH in $/$m^3$ [$/cunit]	5.98 [16.94]	8.58 [24.29]	6.80 [19.26]

[a]Predictions based on the following assumptions (average rounded-off values for each variable): average load sizes are 9.9 m^3 [350 ft^3] for sawlogs, 5.7 m^3 [200 ft^3] for pulpwood, and 9.3 m^3 [330 ft^3] for mixed loads; average distances are 274 m [900 ft] for *distance out*, 76 m [250 ft] for *travel in unit*, and 259 m [850 ft] for *distance in*; utilization rate is 77%.

The cost of support equipment for the cut-to-length thinning system is US $1.52/$m^3$ (US $4.30/cunit). This total is based on equipment usages of 10 hr/day for trailers hauling sawlogs and pulpwood, 2 hr/day for a crew truck, 2 hr/day for a fuel truck, and 1 hr/day for a small all-purpose tractor for manoeuvring trailers, as well as on a total cost per day for the support equipment of US $158.55 and a daily production of 9.4 m^3 [331 ft^3] (Table 7).

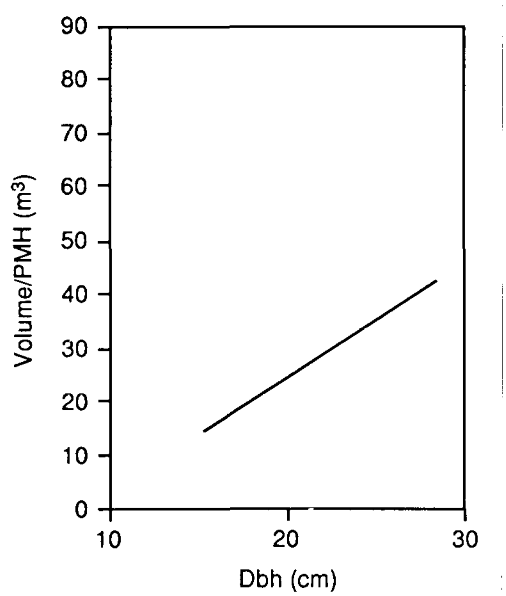

Figure 2: Productivity of the Timberjack 2518 single-grip harvester as it relates to tree dbh within the stand studied (productivity range is shown for one standard deviation around the mean dbh).

SUMMARY

Production rates for the harvester in marked and unmarked stands were not significantly different in this study. The additional cost of tree painting made the marking technique slightly more costly than the operator-selection technique. (A subsequent study at this site revealed scarring of residual trees to be low, with no observable differences between marked and unmarked stands [4].)

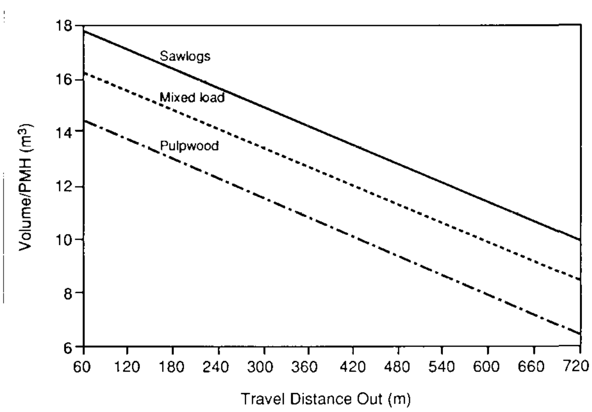

Figure 3: Productivity of the FMG 910 forwarder as it relates to travel distances out to the start of loading the stand studied.

The two-pass forwarding technique evaluated in this study provided more flexibility in locating trailers along the side of the road and was more cost efficient than the mixed-load forwarding technique. The latter would be more efficient with side-by-side trailer locations. The forwarder operator could then sort products and load to either trailer.

Study data on production and cost indicated an operation cost of US $4.17/m^3 [US $11.81/cunit] for the harvester in the unmarked stand and US $6.80/m^3 [US $19.26/cunit] for the forwarder. When the cost of support equipment was added, the total stump-to-track thinning cost (excluding hauling) was US $12.49/m^3 [US $35.37/cunit] for this study, excluding profit-and-risk allowance.

ACKNOWLEDGEMENTS

This research was supported by the USDA Wood Utilization Special Grant Program and by Oregon State University's Strachan Forestry Research Fund. The authors wish to thank Avery Properties and Mason, Bruce and Girard for their cooperation and for providing the study site; 4M Fiber, Sweet Home, OR, for their cooperation during the thinning operation; and Earl Eckley for assistance with data collection. This is Paper 2940 of the Forest Research Laboratory, Oregon State University.

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