COMPARISON OF TWO THINNING SYSTEMS. PART 2. PRODUCTIVITY AND COSTS

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ABSTRACT

A side-by-side comparison of two popular thinning systems, a skidder system and a forwarder system, was made during winter logging conditions in southern Alabama. The first report of this study addressed stand and site impacts of these two thinning systems. This report focuses on productivity and costs while thinning an 18-year-old loblolly pine plantation. The skidder system used a feller-buncher with a shear head followed by a grapple skidder that transported bunches of trees and delimbed them with agate delimber. A loader/slasher combination processed trees into 7.5foot lengths and loaded tractor trailers. The forwarder system used two machines: a harvester and a forwarder. The harvester felled, delimbed, and bucked trees into 7.5foot or cut-to-length pulpwood. The forwarder loaded processed wood and transported it to setout trailers. Production rates were sampled using time and production studies for each machine in the two systems. Production rates and estimated costs were combined for each system to give overall system costs. System production was limited by the woods transport vehicles, the single skidder for the skidder system, and the forwarder for the forwarder system. Weekly production rates were 261 cords for the skidder system and 249 cords with cut-to-length wood and 200 cords with 7.5-foot wood for the forwarder system. Cost per cord was slightly lower for the forwarder system using cut-to-length wood as compared to the skidder system, a difference of $0.14, and higher for the forwarder system in 7.5-foot wood, a difference of $3.77.

This is the second part of a study comparing two thinning systems: a conventional feller-buncher and grapple-skidder system and a less common harvester and forwarder system. For this report, these systems will be referred to as "skidder" and "forwarder" systems, respectively. The first part of this two-part paper examined stand and site impacts of the two systems working in south Alabama during winter logging conditions (late February and early March 1991) in an 1 g-year-old loblolly pine stand (3). The objective of this part of the study was to compare harvesting costs and productivity of the two thinning systems.

METHODS

THINNING SYSTEMS

Two popular thinning systems were compared: a skidder system and a forwarder system. The skidder system had been operational for 8 years. Equipment included a Hydro Ax 4 11 feller-buncher with 23.1x26 tires, a John Deere 640 grapple skidder with 28x26 tires, a gate delimber, a Dunham knuckleboom loader with a CTR slasher saw, and tractor trailer highway haul vehicles. In addition to a separate operator on each vehicle, a chainsaw operator worked on the landing cleaning off any limbs missed by the gate. The foreman operated the loader/slasher and was a part of the four-person woods crew. Tractors with pulpwood trailers were supplied as needed. Tree-length wood was slashed into 7.5-foot pulpwood.

Valmet of Gladstone, Mich., supplied forwarder system equipment and a trained crew for a Valmet 546 Woodstar harvester and a Valmet 546 Woodstar forwarder. Both harvester and forwarder had single front wheels with 23.1x26/10 Firestone FS tires and tandem rear wheels with 600/55x26.5/16 Nokia ELS tires. Setout trailers for shortwood and cut-to-length wood were supplied as needed. While short pulpwood (7.5 ft.) was the primary product from this thinning operation, some cut-to-length pulpwood (14 ft. to 20 ft.) was produced to develop cost comparisons.

STUDY AREA AND LAYOUT

Test sites consisted of two ridges separated by a stream side management zone (SMZ) where logging activities were not allowed. Trails suitable for small trucks extended from the main haul road down the center of each ridge.

The forwarder tests were conducted first, followed immediately by the skidder tests (3). Forwarders were able to move wood along the ridge trails to setout trailers on the main haul road and required no trail improvement.

During skidder tests, ridge trails required improvement (widening and smoothing), before highway haul vehicles could use them. Due to the weather, skidders were also necessary to pull trucks from landings to the graveled haul

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road. The skidder system used three landings on one ridge (one at the main haul road, one approximately halfway down the ridge trail, and one near the end) and two on the second ridge (one at the main haul road and one approximately halfway down the ridge trail).

PRODUCTIVITY AND COSTS

Each machine was sampled for productivity during the tests. Standard time and production study methods were followed (2). Time cycles, terrain, and work conditions were recorded using video cameras. Production, time by elements, and work conditions were transferred to computer files. Statistical analyses mainly used least squares regression but also included plotting, means, ranges, and other statistical calculations.

Trees were measured prior, during, or after harvesting activities, as appropriate, to determine volume produced during time cycles. In order to estimate the number of pieces from each tree, a model for merchantable height as a function of diameter at breast height (DBH) was constructed from measurements taken from trees that were felled and processed by the harvester. Prediction models for tree volumes were discussed in Part 1 of this study (3).

Due to the study's 2-week duration, only limited machine cost data could be collected. To get comparative cost-per-hour estimates, literature such as that published by Brinker et al. (1) was used. Labor costs were determined by personal communication with individuals knowledgeable about pay schedules. Standard machine rate calculations were used to combine owning, operating, and labor costs for a given machine (5,6).

While machine productivity without time delays is relatively easy to measure during short-term studies, accurate utilization rates must be determined over longer time periods. (Utilization is defined as the ratio of time spent doing the machine's assigned task divided by time scheduled for work.) One way to estimate utilization is from gross production records such as daily or weekly production for the entire system. Utilization for the least productive function can be approximated from the ratio of the daily or weekly production rates in volume per scheduled machine hour (SMH) to that function's production rate in volume per productive machine hour (PMH). (A function may have more than one machine doing the same activity, such as multiple trucks performing the function of hauling from the same woods crew.)

Six practitioners with extensive experience in timber harvesting, including thinning, were asked their opinions about daily and weekly system production rates. These experts included two industry timber harvesting specialists, the owner of the skidder operation being studied, two owners of thinning operations who had experience with both skidder and forwarder operations, and an engineer/sales manager of a company that manufactures skidders, forwarders, and harvesters.

Analysis results from separate machines were combined to estimate productivity and costs for each system. Production rates were based on the stand and tract conditions for this particular study. The Auburn Harvesting Analyzer spreadsheet (7,10) was used to combine cost and production rates.

RESULTS

COMPARISON OF 7.5-FOOT TO CUT-TO-LENGTH PULPWOOD

The effect of two different product lengths, 7.5 feet and cut-to-length, on utilized length was tested. For 36 sample trees, there was no significant difference in the total length of merchantable wood cut. The cut-to-length method of processing utilized the trees just as well as did the 7.5foot processing method.

A regression model for estimating merchantable height from diameter at breast height (DBH) was needed for subsequent analysis and is shown in Table 1. Height-DBH relationships are typically sigmoid in shape except as in cases such as this, where only a segment of the total curve was observed. For this model, extrapolation beyond the study data is not recommended.

MACHINE PRODUCTIVITY

Production rates were sampled for all machines in the study: harvester, forwarder. feller-buncher, skidder, and loader/slasher.

Valmet 546 Woodstar- harvester.- The harvester felled and processed trees one at a time into delimbed and bucked pieces. DBH and number of pieces from each tree were tested for influence on the felling and processing time per tree. For the 26 cycles available. number of pieces per tree ranged from 2 to 7 (4.5 average) and did not significantly affect felling and processing time per tree after DBH had been included in the model. From this limited sample, the length of wood processed did not significantly affect processing time after DBH had been included in the regression model. This is not to say that 7.5foot wood takes no more time than cut-to-length pieces that averaged 17.3 feet in length. It implies that after the tree size (DBH) has been considered, there is too much data variation to detect the additional time required to buck out the shorter 7.5-foot pieces as compared to random lengths produced from cut-to-length wood. Tufts and Brinker (8) found that log length did significantly affect processing time per tree after tree size was included. A DBH square term was also found to be non-significant. A regression model for this harvester is shown in Table 1.

For the trees cut by the harvester, the average trees per PMH from the time study was 105.6 (1.76 trees per productive machine minute (PMM)). The harvester had an onboard computer that recorded productive time and number of trees and gave the following accumulated tally for the entire study period:

Trees cut = 1,373 (merchantable) and 261 (non-merchantable);

Productivity for merchantable trees = 87.8 trees/PMH (1.46 trees/PMM);

Productivity for all trees = 104.5 trees/PMH (1.74 trees/PMM);

Pieces processed = 5,010 (7.5-foot and cut-to-length wood);

Piece productivity = 320.5 pieces/PMH (5.34 pieces/PMM). When comparing the time study sample to the actual count, the productivity rates were almost identical: 1.76 trees for the sample to 1.74 trees per PMM from the harvester's computer. Sixteen percent of the total trees cut were unmerchantable and were removed to provide machine access and to prepare a load-bearing mat for the forwarder that followed.

Valmet 546 Woodstar- forwarder.— Time and production data taken on the forwarder were divided into three time elements: traveling, loading, and unloading times. A typical forwarder cycle included traveling empty from the main haul road to the stump area where the wood had been piled by the harvester, loading the wood, traveling between piles during loading.- traveling loaded back to the trailer, and unloading onto the trailer. The Valmet forwarder was rated at a o-ton capacity. hut load sizes during the

TABLE 1. — *Regression models and summary statistics.*

Data modeled	Regression equation and measured variables	Applicable conditions	No. of observations	R-square	Root mean square error	Descriptive data Minimum	Average	Maximum
Merchantable height	Mh = 3.54 +5.283(DBH)	All	37	0.78	4 58 feet			
	Mh = merchantable height (ft.)/tree					14	37.1	53
	DBH = diameter at breast height (in.)					3	6.3	9
Valmet 546 Woodstar harvester	Fnp = 0.223 +0.0536(DBH)	All	26	0 30	0.141 PMM			
	Fnp = fell and process time (PMM)/tree					0.28	0 509	0.99
	DBH = diameter at breast height (in.)					3	6.2	11
	PMM = productive machine minutes							
Valmet 546 Woodstar forwarder	Swgvol = 0.849(Stpvol) - 0.0165(Stpvol)^2	Length = 7.5-foot and Stpvol <= 20 c.f.	140	0.92 (uncorrected for the mean)	2 89 c.f			
	Swgvol = 10.38	Length = 7.5-foot and Stpvol > 20 c.f.						
	Swgvol = 1.129(Stpvol) - 0.0165(Stpvol)^2	Length = cut-to-length and Stpvol<= 20 c.f.						
	Swgvol = 15.98	Length = cut-to-length and Stpvol > 20 c.f.						
	Swgvol = volume (c.f.)/swing					1.25	8.986	32.13
	Stpvol = volume (c.f.)/stop					1.25	15.713	49.98
	c.f. = cubic feet outside bark							
	Load = 0.028 +0.31395(1/Swgvol)	All	140	0.53	0.0252 PMM			
	Load = loading time (PMM)/c.f.					0.03	0.492	2.14
	Swgvol = volume (c.f.)/swing					1.25	8.986	32.13
	Unload time(PMM)/c.f. = 0.025	Length = 7.5-foot	3			0 022	0.025 1	0.030
	Unload time(PMM)/c.f. = 0.022	Length = cut-to-length	1			0.022	0.0218	0 022
	Travel = 0.428 +0.0155(Dist)	All	102	0.24	0.581 PMM			
	Travel = traveling time (PMM)					0.17	0.580	4.50
	Dist = distance traveled (ft.)					3	98.2	1,029
Hydro Ax 4 11 feller-buncher	Fnb = 0.084 +0.03478(DBH) +0.02996/BA	All	22	0 23	0.116 PMM			
	Fnb = fell and bunch time (PMM)/tree					0.17	0.359	0.67
	DBH = diameter at breast height (in.)					5	6.5	13
	BA = basal area (s.f.)/accumulation					0.12	0.796	1.32
	s.f. = square feet							
John Deere 640 grapple skidder	Skid = skidding time (PMM)/turn		20			2.16	2 851	4.22
	Dist = one way distance (ft.)/turn		20			442	638 2	861
	Load = load size/turn (lb.)		20			661	3,022	5,792
Dunham loader with CTR slasher	Ldnsl = load and slash time (PMM)/tree		5			0.18	0 286	0 57

TABLE 2. — *Stand and stock tables from 64 cruise plots.*

DBH	Initial stocking			Residual stocking			Stocking removed		
(in.)	(trees/acre)	(ft.^{3}/tree)[a]	(vol./acre)	(trees/acre)	(ft.^{3}/tree)	(vol./acre)	(trees/acre)	(ft.^{3}/tree)	(vol./acre)
Forwarder system									
4	40.0	1.51	62.8	18.8	1.49	21.9	21.3	1.64	34.9
5	50.0	2.94	147.0	16.3	2.88	46.8	33.8	2.91	100.2
6	66.3	4.81	318.7	31.3	2.94	91.9	35.0	6.48	226.8
7	80.0	7.68	614.4	42.5	7.97	338.7	37.5	7.35	275.7
8	58.8	10.92	641.6	40.0	10.83	433.2	18.8	11.11	208 4
9	45.0	14.68	660.6	31.3	14.70	459.4	13.8	14.63	201 2
10	30.0	19.39	581.7	22.5	19.06	428.9	7.5	20.38	152.9
11	10.0	23.38	233.8	8.8	23.36	2044	1.3	23.52	29.4
12	3.8	29.10	109.1	3.8	29.10	109.1	0.0	0.00	0 0
13	1.3	34.62	43 3	1.3	34 62	43.3	0.0	0.00	0 0
Total	385.0		3,412.9	216.3		2,183.6	168.8		1,229.4
Skidder system									
4	33.8	1.65	55.7	12.5	1.68	21.0	21.3	1.63	34 7
5	65.0	3.07	199.6	26.3	2.85	74.8	38.8	3.22	1247
6	82.5	5.11	421.6	31.3	5.20	162.5	51.3	5.06	259. 1
7	83.8	7.60	636.5	38.8	7.77	301.1	45.0	7.45	335.4
8	62.5	10.65	665.6	38.8	10.82	419.3	23.8	10.37	246.4
9	50.0	14.63	731.5	36.3	14.54	527.1	13.8	14.87	204.4
10	15.0	20.53	308 0	10.0	20.19	201.9	5.0	21.21	106 1
11	7.5	23.36	175.2	7.5	23.36	175.2	0.0	0.00	0 0
12	5.0	30.14	1507	5.0	30.14	150.7	0.0	0.00	0.0
Total	405.0		3,344.3	206.3		2,033.6	198.8		1,310.7

[a] Cubic foot volume is for outside bark measurements

study averaged 20,666 pounds (10.33 tons).

Since swing volume was considered a key factor in predicting loading time per cubic foot, a model was constructed to predict it from measures that can be obtained from normal cruise data. Swing volume was significantly influenced by both the volume at each stop (stop volume) and the length of wood being loaded. Swing volumes increased as stop volume increased up to stop volumes of 20 ft.” and was constant beyond that amount.[1] Up to grapple loads of 20 ft.‘, the loader was able to pick up all the wood available at a stop location with swing volume increasing as stop volume increased. For piles greater than 20 ft.^{3}, multiple loader swings were required and the swing volume was constant.

There was significantly more volume per stop for cut-to-length wood than for 7.5-foot wood (20.0 ft.^{3} versus 15.1 ft.^{3} per stop). It is not known exactly why this difference occurred but it is probably due to random stand variability rather than machine operation features. Cut-to-length wood had significantly more swing volume than the 7.5foot wood. Cross-sectional area of each log was calculated by averaging the area of large and small ends. Calculating the cross-sectional area of wood in a loader swing for each length gave a maximum of 1.38 ft.^{2} for 7.5-foot wood and 0.92 ft.^{2} for cut-to-length wood, or one third more cross-sectional area of wood per swing for the 7.5-foot wood; but in terms of total cubic feet, the cut-to-length swings averaged approximately one-third more wood than the 7.5-foot pieces. On average, 15.7 ft.” was loaded during each loader swing of cut-to-length wood. **Table 1** gives the regression model for swing volume.

Loading time per cubic foot was affected by how much the loader picked up in each grapple swing. As swing volume increased, loading time per cubic foot decreased. Since cut-to-length wood had larger swing volumes, loading time for cut-to-length wood was less per cubic foot. Table **1** shows the relationship between loading time per cubic foot and volume per swing.

There were four observations of unloading: three with 7.5-foot wood and one with cut-to-length. Average productive time was 0.025 minute per cubic foot for 7.5-foot wood and 0.022 minute for cut-to-length. The coefficient of variation for all four observations was 15.5 percent, which indicated consistency.

Distances and travel times were measured for different road classes. Forwarder trails included a prepared gravel road, woods roads capable of pickup travel, and traveling from stump to stump during the loading process. The different road classes did not significantly affect travel time. Likewise, load size onboard the forwarder did not affect travel time; that is, traveling empty time was no different from traveling loaded time if the distance traveled was considered. A regression model estimating traveling time as a function of distance traveled is given in **Table 1.**

Average one-way forwarding distance between the trailer and the stump area for the turns observed was 1,200 feet. While traveling during in-woods loading, the average distance per move was 34 feet. From an analysis of the study area, an average forwarding distance from stump to loading area was determined to be 924 feet. This assumes that all wood was transported from the stump uphill to the ridge trail and then to the gravel road where setout trailers were positioned. In-woods traveling was determined from the average distance between loading stops and number of stops per load.

Hydro Ax 411 feller-buncher. — Time and production studies were conducted

[1] Cubic foot volume is for outside bark measurements.

TABLE 3. — Machine rate calculations for forwarder and skidder systems

Machines	Initial cost	Depreciation	Salvage value	Interest rate	Insurance and taxes	Scheduled hours	Total owning cost	Fuel and lubrication cost	Repair and maintenance cost	Total operating costs
	($)	(yr.)	- - - - - - - (%) -			(hr./yr.)	($/SMH)[a]	- - - - - - - - - - - - - - - ($/PMH) -	- - - - - - - - - - - - - -	
Harvester	225,000	5	20	12	3.5	2.160	28.81	444	26 86	3 1.30
Forwarder	145,000	5	20	12	1.5	2,160	17.23	2.29	7 95	1024
Feller-buncher	102,000	5	20	12	4.5	2,070	14.12	6 66	14.89	21.55
Grapple skidder	74,306	5	20	12	5.0	2,070	10.47	4 60	10.71	14.81
Loader slasher	63.147	5	20	12	1.5	2.070	7.83	2.79	644	9.23

[a] SMH = scheduled machine hour; PMH = productive machine hour.

throughout the study sites and yielded 22 accumulations of 1 to 6 trees. Productive time elements included moving-to-trees, shearing trees, moving-to-dump, and dumping. Analysis records for time per tree were calculated by summing time elements over each accumulation and dividing by the number of trees in the accumulation. The average DBH and accumulated basal area (BA) were recorded for each accumulation.

DBHs were averaged over the 22 accumulations and found to be the same as that of removed trees calculated from cruise plots (6.5 in.) **(Table 2).** Accumulations averaged 0.79 $ft.^2$ of BA and 3.5 trees. Both DBH and BA were found to significantly influence productive felling and bunching time per tree as shown in the regression model given in **Table 1.** The feller-buncher averaged 2.79 trees per PMM.

John Deere 640 grapple skidder.— Complete skidder turns (cycles) were timed. Single and multiple bunches of trees felled by the Hydro Ax feller-buncher were skidded to a gate for delimbing and then to the loader and slasher combination. Time elements of the skidder turn included traveling empty, grappling, traveling loaded with full trees to the gate, gate delimbing, traveling loaded with tree lengths to the loader, various delays, and gate maintenance, which consisted of cleaning limbs from around the gate. Gate maintenance generally occurred after 4 to 5 turns of wood had clogged the gate, making delimbing difficult.

Twenty skidder turns were observed during the study and descriptive statistics are given in **Table 1.** Average turn size was 3,022 pounds (0.56 cords) and 11.3 trees or 3.15 feller-buncher accumulations. The average skid distance for the study was 638 feet. As with the forwarder analysis, an average skid distance for the study area was calculated to be 5 12 feet if only four landings were used, one on each ridge at the junction of the woods and graveled roads and one on each ridge approximately halfway down the ridge. (This is one less landing than was actually used.)

Total productive time was 2.85 minutes per turn. During the traveling empty portion of turns, the skidder averaged 8 miles per hour. Traveling with full trees from the woods to the gate was at 3.9 miles per hour and traveling loaded with tree lengths from the gate to the loader was at 6.1 miles per hour. Comparison of these skidder rates to those found by Tufts et al. (9) for the same skid distance and turn size revealed that the study results were considerably more productive than those published. Tufts' equations gave total productive time to be 4.27 minutes per turn or 50 percent more time per turn than the study results. Tufts' paper found travel speeds of approximately 5 miles per hour traveling empty and 3 miles per hour traveling loaded. Review of videotapes that recorded the skidder cycles during the study showed that much of the traveling during the time study was either on woods or improved gravel roads, especially during traveling empty.

Dunham loader and CTR slasher.- The grapple skidder delivered tree length wood to the loader and slasher combination. Tree lengths were lifted into the slasher, indexed with the slasher's bumping plate, bucked with a chain and bar style saw, and bucked pieces were loaded onto a haul trailer. The crew's foreman operated the loader and slasher with assistance from a chainsaw operator who cleaned off any limbs missed during the gate delimbing.

Five loader swings were observed and produced 87 pieces (pulpwood bolts approximately 7.5 ft. long) or an equivalent of 18 trees. Loading and slashing required an average of 0.286 productive minutes per tree **(Table 1). The** largest portion of time was spent in bucking (0.082 min. per tree or 29%). In order to estimate the entire loading and slashing of a truckload, the trailer's positioning and binding were extracted from an earlier loader report by Lanford et al. (4): 1.80 productive minutes for positioning and 4.56 productive minutes for binding per trailer load.

MACHINE COSTS

Table 3 summarizes owning and operating costs for all machines in the study. Owning and operating costs for the feller-buncher. skidder, and loader were taken from a compilation of cost data by Brinker et al. (1). Harvester, forwarder, and slasher costs were from a combination of the cost data publication just mentioned, manufacturer suggested retail prices, and logging company operating records for similar equipment.

Depreciation was set at 5 years for all machines. From personal communication with users of these machines, skidders and feller-bunchers are usually traded prior to 5 years and forwarders and harvesters usually last longer than 5 years. Of course each logging company owner has his own philosophy of machine replacement; therefore, the standard 5-year period was used for all machines. Salvage value was set at 20 percent.

Monthly owning costs (the summation of depreciation, interest, insurance, and taxes) were $5,592 for the skidder system and $8,287 for the forwarder system. Monthly operating costs (fuel and lubrication and repair and maintenance) were $4,037 for the skidder system and $5,212 for the forwarder system when harvesting cut-to-length wood and $4,491 when harvesting 7.5-foot wood. Operating costs were not the same for cut-to-length and 7.5-foot wood due to the difference in production rates of the forwarder in the two wood length groups.

Different forwarder rates forced the harvester to have different utilizations. Total monthly owning and operating costs using depreciation were $9,629 for the skidder system and $13,499 for the forwarder system in cut-to-length wood and $12,778 in 7.5-foot wood.

Labor and support costs

Labor costs were not determined from the study but were assigned based on discussions with knowledgeable local practitioners.

Operators were paid the following daily rates: feller-buncher $90, harvester $100, skidder $80, forwarder $95, chainsaw $60, and skidder crew foreman who also operated the loader and slasher $100. Worker's compensation, retirement, social security, health benefits, and any other fringe benefits were assumed to be 30 percent of the base wages. Scheduled work time was assumed to be 9 hours per day and 5 days per week. The skidder crew was assumed to work 230 days per year and the forwarder crew 240 days per year. The distance the crews had to travel to work each day was assumed to be 15 miles and each crew had a pickup for maintenance and crew transportation, which cost $0.45 per mile to own and operate. No overhead (e.g. lawyers, accountants, secretaries, or offices) was included. Likewise, no profit was included. It was assumed that it took 4 hours to move the crews to the harvesting site from the previous operation. The skidder crew moved twice due to weather. The skidder system required 0.3 I mile of road building and four landings for an assumed cost of $325.50. No road or landing cost was assumed for the forwarder system.

Monthly labor cost including benefits was $8.223 for the skidder crew and $5,070 for the forwarder crew. Monthly overhead costs (crew transportation, moving, road construction, and other support items) were $1,580 for the skidder crew and $666 for the forwarder crew with cut-to-length wood and $588 with 7.5-foot wood.

Harvesting systems productivity and costs

From observation and personal communication with the six knowledgeable practitioners, the single skidder was determined to be the limiting function for the skidder system, and a utilization rate of 65 percent was assumed. Two measures of skidder productivity were available: study results at 13.36 cords per PMH or Tufts et al. (9) at 8.91 cords per PMH. Using the skidder time-study results gave a system cost of $14.56 per cord[2] and daily production of 7.7 trailer loads per day (375 cords per week). Use of the published skidder rates instead of study results gave a system cost of $19.46 per cord and daily production of 5.3 trailer loads per day (261 cords per weekj (**Table 4**). The six practitioners reviewed the production and cost estimates and concluded that five loads per day was more realistic based on their past experience. Therefore, the published rates were used because 1) they came from a much larger database; 2) skidder travel speeds during the study seemed too high; and 3) the experienced practitioners considered them to be more reasonable. Utilization for the feller-buncher and loader/slasher was 45 and 44 percent, respectively.

TABLE 4. — Productivity and cost comparisons.

Thinning system	Weekly production	Cost per cord (onboard truck)
	(cords)	($)
Skidder with 7.5-foot	261	19.46
Forwarder with CTL[a]	249	19.32
Forwarder with 7.5-foot	200	23.09

[a] CTL = cut to length.

For both systems, it was assumed that trucking did not impact the system; that is, there were always adequate tractor trailers to take away the wood that was produced by the woods crews.

For the forwarder system, the forwarder was the limiting function and utilization of the forwarder was set at 85 percent based on discussions with the practitioners. Utilization of the harvester when working with cut-to-length wood was 65 percent, and it was 53 percent when cutting 7.5-foot wood. System productivity was 5.53 cords per SMH for cut-to-length wood and 4.54 for 7.5-foot wood. For the 7.5-foot wood, the forwarder had less production due to the double handling during loading and unloading of the two racks of 7.5-foot wood as compared to the single rack of cut-to-length wood. Weekly production was 249 cords for cut-to-length at a cost of $19.32 per cord and 200 cords for 7.5-foot at a cost of $23.09 per cord (Table 4).

Comparing the two systems, the forwarder producing cut-to-length wood was the least expensive, but the skidder system was a very close second. The difference of $0.14 per cord or 1 percent was practically negligible. The sample size was not large enough to detect differences of this small magnitude. On the other hand, the 7.5-foot wood did have a larger difference: $3.77 compared to cut-to-length, or 20 percent more.

Assuming that the forwarder system could deliver cut-to-length wood, the skidder system working in conditions similar to those of the study with a crew of four would produce 12.006 cords annually, and the forwarder system with a crew of two would produce 11,952 cords per year, less than a 1 percent difference. If contractors were being paid $25 per cord from stump to onboard trailer. the skidder system would show an annual profit of $66,5 16, and the forwarder system profit would be $67,980 (2% more). If a ratio of profit to average yearly investment were computed, the skidder system would show a 41 percent return and the forwarder would show 27 percent. It should be pointed out that these income and cost estimates are speculative and would occur only if all assumptions hold true; they may be optimistic or pessimistic in any given year.

Summary and conclusions

Average harvester production from the time study was 1.76 trees per PMM. which compared favorably with rates recorded on the harvester's onboard computer.

The forwarder averaged 0.492 PMM per cubic foot during loading with an average swing volume of 9.0 ft^3. Swing volume strongly affected loading time and was different for the different log lengths. Production during unloading was 0.025 PMM per cubic foot for 7.5-foot wood and 0.022 PMM for cut-to-length.

[2] All system costs per cord are for costs onboard truck prior to hauling.

The feller-buncher production was affected by DBH and BA and averaged 2.79 trees per PMM.

The grapple skidder during the study outperformed published rates by 50 percent due to traveling on prepared roads. The measured rates of 8 miles per hour traveling empty, 3.9 miles per hour traveling with full trees, and 6.1 miles per hour traveling with tree lengths were thought to be higher than would normally be expected. Therefore, published rates were assumed to be more representative.

Loading and slashing were performed at 0.286 PMM per tree with 29 percent of the time being spent in bucking.

Machine productivity rates and costs were combined for each of the two systems and compared. The forwarder system harvesting cut-to-length wood had the lowest cost per cord, but realistically, it was the same as the skidder system cutting 7.5-foot wood (only a 1 percent difference). The forwarder system harvesting 7.5foot wood cost 20 percent more than when harvesting cut-to-length. The skidder system produced 1 percent more wood than the cut-to-length system. If contractors were paid the same, the forwarder system cutting cut-to-length wood showed slightly more annual income (approx. 2% more), and the skidder system showed a better ratio of profit to average yearly investment.

In conclusion, when combined with the first report of this study (3), the forwarder system performed better silviculturally and had less environmental impact at a cost that was basically the same as the skidder system. Since this was a case study of limited time and conditions, conclusions need to be verified by additional research involving other stand and terrain conditions and skidder and forwarder systems' equipment.

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