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Flail-Delimbing of Loblolly Pine—A Case Study

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SUMMARY

Flail-delimbing was tested in small-diameter loblolly pine. Most of the limbs left on the stems were less than 6 inches long. Over 75 percent of the delimbed stems had three or fewer remaining limbs. The cost was determined by comparing skidding-flailing with skidding only. The cost difference was approximately $6.00 per cunit.

Additional keywords: Skidding, production rates, costs.

INTRODUCTION

Delimbing is a major operational concern of the Southern pulpwood industry. Because of the costs and dangers of chainsaw delimbing, at the deck or in the woods, other methods are needed to efficiently and safely delimb trees on the site with the comparable quality of the chainsaw. A possible alternative to manual chainsaw-delimbing is flail-delimbing. In this study, the operation of a Hydro-Ax LL64[1] portable chain flail delimber was studied and evaluated in south Alabama during 1982 (fig. 1). The unit consisted of a 7.75-ft-wide flail drum with eight sections of alloy steel chains spaced along the length of the drum. The drum was powered by a 55-horsepower auxiliary diesel engine. The chain flail was mounted on a Clark 667 grapple skidder, which was utilized to perform both skidding and flail-delimbing.

[1]The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

OPERATION

The machine was part of a shortwood operation in a dense, 20-year-old pine stand that was being clear cut. The harvesting system was comprised of a Drott 40 feller buncher, a Hydro-Ax 511 feller buncher, the skidder flail, and a Barko Loader with a slasher. The skidder either skidded bunches and flailed at the deck or flailed bunches in the woods and then skidded. Trees delimbed at the deck were placed onto the slasher with the loader and bucked into shortwood. Trees delimbed in the woods were skidded to the deck and processed with the slasher. The shortwood was loaded onto set-out trailers.

When the full (undelimbed) trees were skidded to the deck, the skidder picked up bunches made by the feller buncher. If the bunches had only a few trees, several bunches were consolidated into one large bundle of trees for skidding. The bundle was dropped in front of the slasher at the deck. On the ground, the bundle maintained its skidded configuration, with the tree butts clumped and stacked together. The crowns and tops of the trees in the bundle were slightly spread out, depending on the number of stems in the bundle. No attempt was made to spread the stems to facilitate the flailing process.

After dropping the bundle at the deck, the operator secured the empty grapple of the skidder and drove the skidder backward, straddling the bundle, to the base of the crowns. If the bundle had many stems and created an obstacle too large to straddle, the operator drove the skidder around to the tops of the trees in the bundle and then drove down the bundle with the flail held high and prepared for delimbing.

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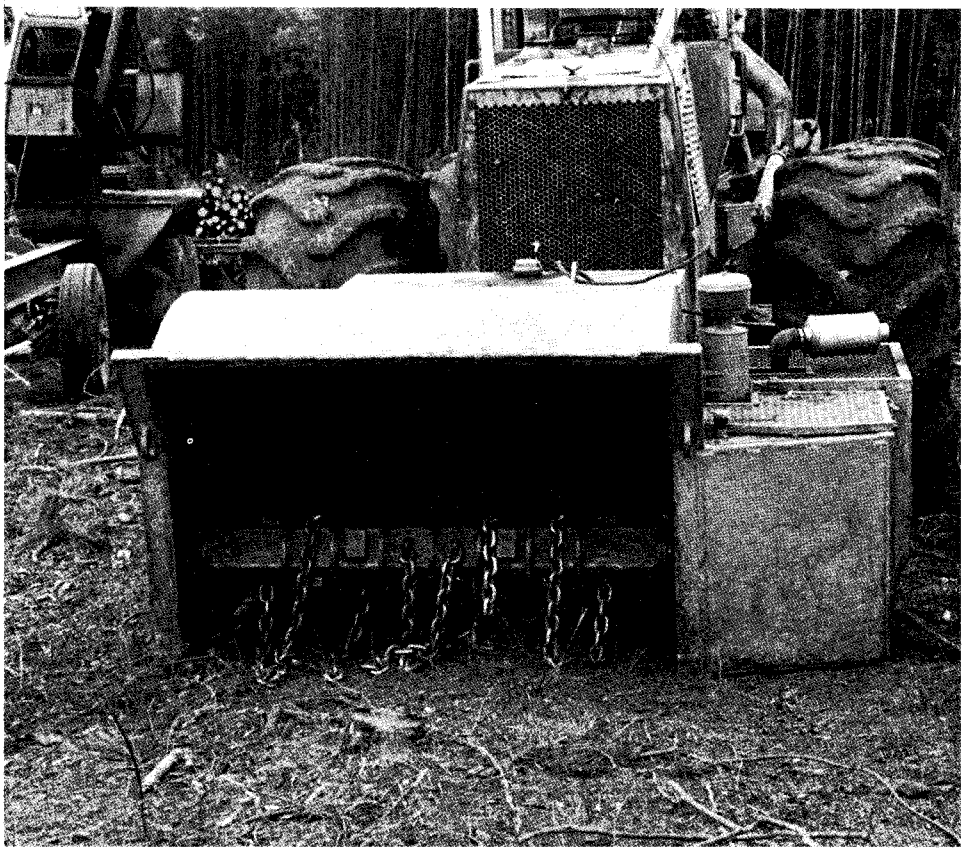

Figure 1.—*The Hydro-Ax LL64 Flail Delimber and Clark 667 Skidder.*

Flail delimbing was always done from the base of the crown to the top of the tree. The flail engine ran continuously with the flail drum disengaged. To delimb, the operator engaged the drum, positioned and lowered the flail head, and drove backwards.

In the woods, the skidder operator always approached the bunches made by the feller buncher from the tops of the trees and drove down the limbs and tops to the bases of the crowns. There the operator engaged the drum, lowered the flail head, and drove backwards to delimb the trees in the bunch. After delimbing a bunch in the woods, the skidder operator grappled the bunch and skidded it to the deck. If the bunch was small, with too few trees for a full grapple load, the operator would flail-delimb other bunches. Then the skidder was used to accumulate these bunches into a bundle for skidding. At the deck, the bundle of delimbed stems was dropped in front of the slasher to be processed into shortwood.

During the flail delimbing process, the flail drum width did not always adequately cover all the crowns of the trees in the bunches in the woods or the bundles at the deck. In that case, the operator would reposition the skidder and make another pass. In doing this, he raised the flail head and then maneuvered the skidder over to cover the unprocessed stems. Then he drove the skidder down to the bases of the crowns and made another delimbing pass on the bunch or bundle. Sometimes, several passes were made on the same trees without repositioning the skidder. This was done to improve the delimbing quality.

DATA COLLECTION

When a bundle was flailed at the deck, each tree-butt diameter was measured. Total heights, clear-bole lengths, merchantable heights, and d.b.h. were measured for two trees per bundle. These data were used to determine the number of stems, average d.b.h., average total height, average merchantable height, average clear-bole length, bundle volume, and bundle basal area for production analyses. The same information was collected for the individual bunches that were flailed in the stand.

Time study data of the operation were recorded on video tape. Elements were timed from the video

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tapes and analyzed; no skidding time data were collected. After the skidder had pulled full-tree bundles to the deck, the following time elements were recorded after dropping the load: (1) travel and positioning to flail, and (2) flailing. In the woods, the same time elements were recorded after the skidder had traveled empty to the first bunch to be delimbed.

At the deck, the travel and positioning time included the time to secure the empty grapple, travel to the crown tops, position the flail, and engage the flail drum. In the woods, this element began upon arrival at the first bunch to be delimbed, when the operator stopped to engage the drum. It also included travel between bunches in the woods during the delimbing process. The flailing element included the actual flail time while traveling up and down the trees for delimbing. It included travel from the crown top to the lowest limb at the bottom of the crown, with the flail head positioned above the trees. Then the head was lowered, and the machine was driven backwards for delimbing. When delimbing at the deck, travel and position time was either the time to back-up the bundle or to drive around the bundle and position and engage the flail drum.

A pass consisted of travel with the head down over the bunch or bundle while the trees were delimbed. The number of passes required varied because of the number of stems and the quality of delimbing. Bunches and bundles with many trees had crowns that covered such a large area that it took more than one positioning of the flail. The flail element was the time to make the passes and also included the repositioning of the skidder and flail head when multiple passes were required. The number of passes and repositioning occurrences were recorded for each bunch or bundle.

The quality of delimbing was measured by determining the number and length of limbs remaining after flailing. Remaining limb lengths were categorized as (1) 2 inches or greater, but less than 6 inches; (2) 6 inches or greater, but less than 12 inches; and (3) 12 inches or greater.

DATA ANALYSES

Preliminary analyses of data on bunches and bundle characteristics, travel and positioning times, and flail times are shown in table 1. For simplification, characteristics and time were on a bundle basis. A bundle is defined as accumulated bunches of trees skidded to the deck and delimbed or as one bunch of trees that was delimbed in the woods. The average bundle consisted of about 38 trees. The average total time for delimbing a bundle was 1.80 minutes. The operator made an average of 3.57 passes per bundle and had to reposition 2.71 times per bundle on the average. Thus, the average number of flail passes per position was 1.32.

Passes per position approximates the number of passes over a stem. From the data, it was impossible to determine exactly how many times the flail was operated over each individual stem. The configuration of the bundle dictated how many positions and passes were needed to adequately cover all the crowns in the bundle. However, the number of passes over a stem directly controls the quality of

Table 1.—*Summary of the bundle characteristics and time data*

Variable	Statistics			
	No. Observ.	Mean	Std. Dev.	Range
Flail time (min/bundle)	21	1.10	0.34	0.67–1.81
Secure grapple[1] time (min/bundle)	17	0.28	0.04	0.22–0.37
Travel & position time (min/bundle)	17	0.39	0.06	0.30–0.48
Total delimbing time (min/bundle)	17	1.80	0.43	1.32–2.55
Average d.b.h. per bundle (in)	21	4.33	0.29	3.5–5.3
Average total height (ft)	21	46.32	1.26	44.2–49.9
Passes per bundle	21	3.57	1.21	2–7
Flail repositions per bundle	21	2.71	0.72	1–4
Passes per position[2]	21	1.32	0.51	1–3
Stems per bundle	21	38.43	12.29	7–54

[1]Secure grapple was inherent to the type of grapple used and not necessarily a portion of cycle for all skidders.

[2]Passes per position = (passes per bundle/positions per bundle) = approximate passes over a stem.

the delimbing. Overlapping of the flail results in a portion of the stems having multiple passes. For an indication of the average number of passes over all the stems in a bundle, the total number of passes per bundle is divided by the number of positions per bundle. As an example, if the operator makes two passes before changing positions and one pass at a new position, there would be three passes and two positions for the bundle, an average of 1.5 passes over all the stems in the bundle.

Multiple regression analysis was used to model the time elements as a function of the bundle characteristics, whether delimbing was done at the deck or in the woods. An equation for the travel and positioning element could not be developed from the limited data; therefore, the mean was used for this production element. An attempt was made to predict flail time as a function of stems per bundle, average d.b.h., total height, merchantable height, clear-bole length, crown ratios per bundle, bundle volume and basal areas, passes and positions per bundle, and average passes per position.

Correlation coefficients and graphs were used to determine the influence of the variables in the model. The only significant variable in the final model was the average number of passes per position. The equation was: Bunch flail time (productive minutes) = $0.1867 + 0.7066 \times NPT$, $[R^2 = 0.51]$

where NPT = Number of passes per position (i.e., passes per stem).

Limb removal quality was analyzed using two methods. First, the average number of limbs left on each stem was calculated for each limb-length category. Most of the limbs left were those of less than 6 inches in length, with a mean of 1.21 limbs per stem (table 2). Also, the percentage of stems with limbs left was computed; this was based on the total number of stems tallied and the number of limbs left per stem (table 3). This analysis showed that 75.4 percent of the stems had three or fewer limbs left on the stems after flailing. Also, 20.8 percent of the stems had no limbs greater than 2 inches in length left on the boles (see figs. 2 and 3).

As an observation, delimbing quality tended to decrease as the number of stems in a bundle increased. Also, the longer limbs remaining after delimbing were confined to the tops of the stems, above the merchantable limit; these limbs were discarded after slashing.

Table 2.—*Overall delimbing quality*[1]

Limb length (in)	Limbs-per-tree statistics		
	Mean	Std. Dev.	Range
2-<6	1.21	1.25	0–5
6-<12	0.68	1.13	0–5
≥12	0.70	1.14	0–5

[1]During the case study, no attempt was made to determine factors affecting delimbing quality. Logically, delimbing quality is a function of the number of passes over the stems (passes per position). In the study, the average was 1.32. Any major deviation would probably result in a different quality.

Table 3.—*Remaining limbs per tree*

No. limbs	No. trees	Percentage
0	11	20.8
1	6	11.3
2	13	24.5
3	10	18.8
4	4	7.5
5	2	3.8
6	2	3.8
7	3	5.7
8	2	3.8
	Total	100.0

PRODUCTION AND COSTS

Fixed costs (1984) were calculated and operating costs were estimated for the machines used in the study. Because of the short length of the study, availability and utilization of the machines were not determined. The skidder with flail was estimated to have a utilization rate of 70 percent for 2,000 scheduled machine hours per year. Flail production machine hours (PMH) was estimated to be 33 percent of the skidder productive hours. This was based on the field study and is assumed to be conservative. Table 4 summarizes the skidder and flail-delimbing costs.

Production analysis for the machine was based on the skidding and flailing operations under the average study conditions. The skid time per turn was based on a production equation for a 112-hp grapple skidder used in clear cutting (Tufts and Stokes 1983). Table 5 shows that for an average skid of 600 feet, the production for skidding only was 4.0 cunits (CCF) per PMH (100 ft^3 of solid wood per productive machine hour). At the same distance, skidding and flailing production was 3.0 CCF per PMH. Over the range of the skidding distance, the average difference in production would be 0.58 CCF per PMH.

Costs per CCF for skidding and skidding-flailing over a range of distances are shown in table 6. In determining these costs, the skidder was charged for the entire productive hour, whether it was used

Figure 2.—*Flailed trees.*

Figure 3.—*Flailing quality.*

Table 4.—*Cost analysis for the skidder-flail combination*

Item	Skidder		Flail[1]	
	Per year	Per PMH	Per year	Per PMH
Fixed cost				
Depreciation[2]	$19,000	$13.54	$ 3,905	$ 8.45
Taxes, int., & ins.	13,000	9.29	3,212	6.95
Total	$32,000	$22.83	$ 7,117	$15.40
Operating costs				
Repair & maint.	$17,100	$12.21	$ 3,124	$ 6.76
Fuel	3,892	2.78	887	1.92
Lube & oil	1,168	.83	266	0.58
Total	$22,160	$15.82	$ 4,277	$ 9.26
Total fixed and operating	$54,160	$38.65	$11,394	$24.66
Skidder and flail Labor[3]	$14,300			$10.21
Total fixed and operating	$65,554			$63.31
Total with labor	$79,854			$73.52

[1]Based on one-third of skidder production hours. Repair and maintenance costs were 80% of annual depreciation. Fuel was 1.6 gallons per hour, with lube 30% of fuel cost. These were considered conservative estimates.

[2]Skidder and flail life were 4 years; annual productive machine hours were 1,400 and 462, respectively.

[3]Base wage was $5.50 per scheduled hour and 30 percent fringe benefits.

Table 5.—*Production for skidding and skidding-flailing*

Skid distance	Skidding: Time[1] per turn	Skidding: No. turns per PMH	Skidding: No. trees per PMH	Skidding: CCF[2] per PMH	Skidding and flailing: Flail time[3] per turn	Skidding and flailing: Total time per turn	Skidding and flailing: No. turns per PMH	Skidding and flailing: No. trees per PMH	Skidding and flailing: CCF[2] per PMH
ft	*min*				*min*				
300	3.07	19.5	351	6.1	1.56	4.63	13.0	234	4.1
400	3.61	16.6	299	5.2	1.56	5.17	11.6	209	3.7
500	4.16	14.4	259	4.5	1.56	5.72	10.5	189	3.3
600	4.71	12.7	229	4.0	1.56	6.27	9.6	173	3.0
700	5.25	11.4	205	3.6	1.56	6.81	8.8	158	2.8
800	5.80	10.3	185	3.2	1.56	7.36	8.2	148	2.6
900	6.35	9.4	169	3.0	1.56	7.91	7.6	137	2.4
1,000	6.89	8.7	157	2.7	1.56	8.45	7.1	128	2.2
1,100	7.44	8.1	146	2.6	1.56	9.00	6.7	121	2.1
1,200	7.99	7.5	135	2.4	1.56	9.55	6.3	113	2.0
1,300	8.53	7.0	126	2.2	1.56	10.09	5.9	106	1.9

[1]Productivity is based on turn size of 18 trees as sized in footnote 2. A turn is a complete skidding cycle.
[2]CCF (cunit) is 100 cubic feet of wood. Tree volume based on study average of 4.5-in d.b.h. and 46-ft total height. Volumes were to 3-in (o.b.) merchantable top.
[3]Total flail time per turn is the time required to flail-delimb a bundle, based on 1.0 passes per stem using the equation and adding travel and position average time, and average time to secure grapple.

Table 6.—*Costs for skidding and skidding-flailing*[1]

Skid distance	Skidding: Skidder	Skidding: Labor	Skidding: Total	Production machine hour: Skid	Production machine hour: Flail	Skidding and flailing: Skidder[2]	Skidding and flailing: Flail[3]	Skidding and flailing: Labor	Skidding and flailing: Total	$/CCF difference[3]
ft	*dollars per CCF*			*percent*		*dollars per CCF*				
300	6.34	1.67	8.01	67	33	9.43	1.98	2.49	13.90	5.89
400	7.43	1.96	9.39	70	30	10.45	2.00	2.76	15.21	5.82
500	8.59	2.27	10.86	73	27	11.71	2.02	3.09	16.82	5.96
600	9.66	2.55	12.21	76	24	12.88	1.97	3.40	18.25	6.04
700	10.74	2.84	13.58	78	22	13.80	1.94	3.65	19.39	5.81
800	12.08	3.19	15.27	79	21	14.87	1.99	3.93	20.79	5.52
900	12.88	3.40	16.28	81	19	16.10	1.95	4.25	22.30	6.02
1,000	14.31	3.78	18.09	82	18	17.57	2.02	4.64	24.23	6.14
1,100	14.87	3.93	18.80	83	17	18.40	2.00	4.86	25.26	6.46
1,200	16.10	4.25	20.35	84	16	19.33	1.97	5.11	26.44	6.09
1,300	17.57	4.64	22.21	85	15	20.34	1.95	5.37	27.66	5.45
						Avg.	1.98			Avg. 5.92

[1]For 1 hour of production, costs are based on the actual time for skidding and the actual time for flail-delimbing at these distances.
[2]The skidder was charged for the entire hour because it is the carrier for the flail. The flail was only charged for that portion of the hour that it was actually delimbing.
[3]Differences are due to rounding errors; with all factors constant for flailing portion of cycle, the flail costs should be constant.

for skidding or flailing. Flail-delimbing costs are based on the actual flailing time. At the 600-foot distance, the cost per CCF for skidding only was $12.21. Skidding-failing cost at 600 feet was $18.25 per CCF, a difference of $6.04 per CCF. This represents the actual cost for flail-delimbing at that distance. The average cost for flailing was $5.92 per CCF.

SUMMARY AND CONCLUSIONS

The machine in this study worked well on small pines in the range of 3 to 5 inches d.b.h. The average time to completely flail-delimb a bundle was 1.8 minutes of productive time. An average bundle consisted of 38 stems. Most of the limbs left on the stem after delimbing were less than 6 inches long. Over 75 percent of the stems had three or fewer limbs remaining after delimbing. No trees in this test had limbs large enough to determine the upper limb diameter that could be removed by the flail.

Flail cost was determined by the difference between skidding and skidding-flailing because of the productivity loss of the skidder when flailing. The average cost difference for the stand type in the study was $5.92 per CCF. More field studies of the flail method of delimbing should be obtained under various stand conditions to better evaluate the potential of such a system.

LITERATURE CITED

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