COMMERCIAL STRIP THINNING WITH A TREE - LENGTH HARVESTER

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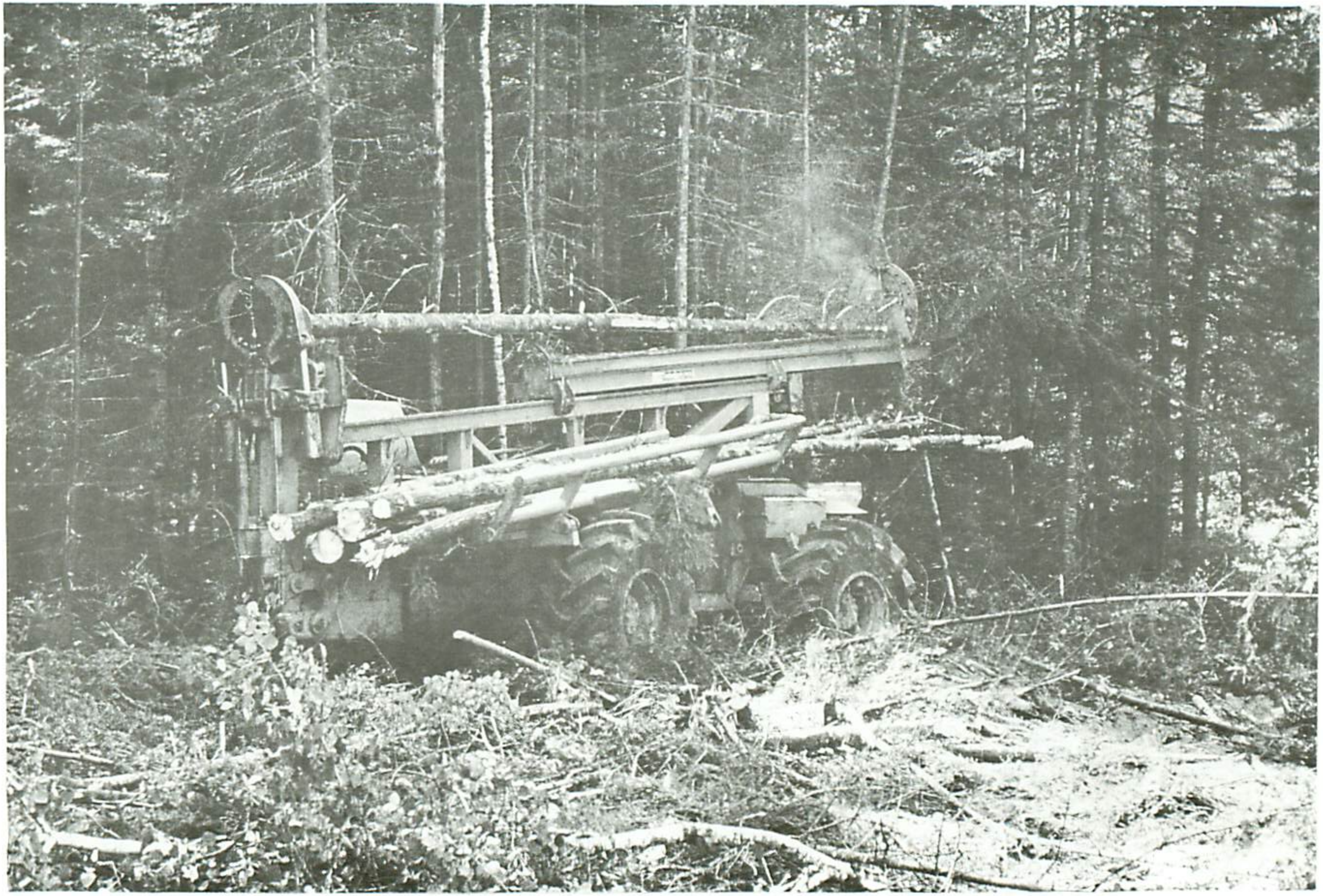

Frontispiece. The Timberjack RW-30 Tree-length Harvester clearcutting a mixedwood stand in New Brunswick.

ABSTRACT

The Timberjack RW-30 Tree-length Harvester which was developed in Australia to thin plantations was introduced to Canada in the spring of 1973 by Eaton Yale Limited of Woodstock, Ontario.

To evaluate its effectiveness in thinning overstocked natural stands the Canadian Forestry Service arranged for a trial in a 48-year-old jack pine (*Pinus banksiana* Lamb.) stand 32.3 km southeast of Chapleau, Ontario. During the fall of 1973, 6.3 ha of forest were thinned in strips with a mean width of cut of 4.8 m and a leave-strip width of 5.2 m. The productivity of the harvester for the entire area as well as for trees of specific diameter was evaluated. Work studies were also conducted on the subsequent skidding operation. Revenues and costs were based on other experience with the harvester in order to predict the profitability for a logging contractor.

The machine easily demonstrated its ability to operate effectively in a thinning harvest. Tree size would probably be the biggest factor influencing its profitability.

RÉSUMÉ

L'engin combiné d'abattage-façonnage de troncs entiers nommé Timberjack RW-30, mis au point en Australie pour éclaircir les plantations, fut introduit au Canada au printemps 1973 par Eaton Yale Limited, de Woodstock, Ontario.

Afin d'évaluer son efficacité à éclaircir des peuplements naturels de densité excessive, le Service canadien des forêts a préparé un programme expérimental dans un peuplement de Pin gris (*Pinus banksiana* Lamb.) âgé de 48 ans, à 32.3 km au sud-est de Chapleau, Ontario. Au cours de l'automne 1973, on a éclairci 6.3 ha de forêt par bandes d'une largeur moyenne de 4.8 m, laissant des rideaux d'arbres d'une largeur de 5.2 m. On a évalué la productivité de la machine dans la superficie totale et selon le diamètre des arbres. Des études furent aussi effectuées sur les opérations subséquentes de débusquage. On calcula les revenus et coûts, fondés sur d'autres expériences avec l'engin afin de prévoir les gains possibles pour l'entrepreneur exploitant.

C'est avec une grande facilité que la machine démontra son efficacité à produire des éclaircies. La grosseur des arbres serait probablement le plus important facteur pouvant influer sur les profits.

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INTRODUCTION

A trial by staff of the Great Lakes Forest Research Centre (GLFRC) during the winter of 1970 near Chapleau, Ontario established that semimature jack pine (*Pinus banksiana* Lamb.) could be strip-thinned at a profit using conventional logging machinery (Mattice and Riley 1975).

Our interests were then attracted by the development of a tree-length thinning harvester (the Timberjack RW-30)[1] in Australia that was designed to row-thin plantations (Silversides 1970). Early in 1973 Eaton Yale Limited of Woodstock, Ontario, which had licensed manufacturing rights to the machine, began testing a prototype unit in slash pine (*Pinus elliottii* Engelm.) plantations in northern Florida. Later that summer another unit was tried on a clearcut harvest operation in New Brunswick (see Frontispiece). During the summer, staff at GLFRC negotiated an arrangement with Eaton Yale whereby one of the units would be made available for a 2-week to 4-week period to strip-thin a semimature, overstocked jack pine stand.

During the summer, approval for the thinning was obtained from the Ontario Ministry of Natural Resources (OMNR), Chapleau District. A suitable stand in Dupuis Township (formerly 12E) (Anon. 1975) was selected for the trial. Since the trial site was part of an area licensed to Wesmak Lumber Company their agreement was sought by OMNR. The merchantable products that the thinnings would produce were offered to them at a reduced stumpage rate because of the small size of the pulpwood. Arrangements were completed and the centre lines of the strips to be cut were marked with paint. The trial was carried out during a 2-week period starting October 27, 1973.

Description of Study Area and Stand

The study area is located in the east-central portion of Dupuis Township immediately south of the reservation on Highway 129 and east of the Sewell Road. The terrain is virtually flat, and the soil is a deep coarse-textured and stone-free sand.

The specific stand is designated Stand 37 in the provincial forest inventory for Dupuis Township. Although the stand is even-aged, having originated from a wildfire approximately 50 years ago, there is a variation in tree age of up to 15 years. The species composition, based on a stem count, is 98% jack pine and 2% black spruce (*Picea mariana* [Mill.] B.S.P.). The latter species is principally a component of the understory. Table 1 shows the distribution of live and standing dead trees per hectare, the gross merchantable volume of the live stems, and the cumulative merchantable volume. The last measure is

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[1] Since this report was written the name of the harvester has been changed to Timberjack TJ-30.

volume cumulated from the largest to the smallest stems accepted by normal utilization standards. The scaling of the wood determined that the cull factor was 1% for jack pine and 3% for black spruce.[2]

The data in Table 1 are based on the measurement of five sample plots, each with an area of 0.5 ha. Although it is not shown in the table, the sample also indicated that 62.1, 22.7, and 15.2% of the live trees are in the codominant, intermediate, and suppressed crown classes, respectively.

Table 1. Diameter distribution and yield of trees in Stand 37, Dupuis Township.

DBH class (cm)	No. of live trees per ha	No. of dead trees per ha	Gross merch. vol per ha[a] (m^3)	No. of trees per m^3	Cumulative vol per ha (m^3)
2.5	25	166			
5.0	119	738			
7.5	627	694			
10.0	968	259	23	42	123
12.5	689	52	42	17	100
15.0	370	5	38	10	58
18.0	94		15	6	20
20.5	15		3	5	5
23.0	7		2	3	2
Total	2,914	1,914	123		

[a] Gross merchantable volumes based on a 30.5 cm stump and a top diameter inside bark of 8.9 cm are taken from Plonski (n.d.).

NOTE: Volume figures exclude any utilization of wood from standing dead trees.

Description of the Timberjack RW-30 Tree-length Harvester

A detailed description of the harvester and its operation is provided in a Logging Research Report issued by the Pulp and Paper Research Institute of Canada (Powell 1974). Figures 1 and 2 in this report show the unit in operation.

[2] J.M. Small, District Manager, Chapleau District, Ontario Ministry of Natural Resources, January 16, 1975 (personal communication).

Figure 1. Rear view of Timberjack RW-30 operating in cut-strip, with severed treelength being lowered onto delimbing carriage.

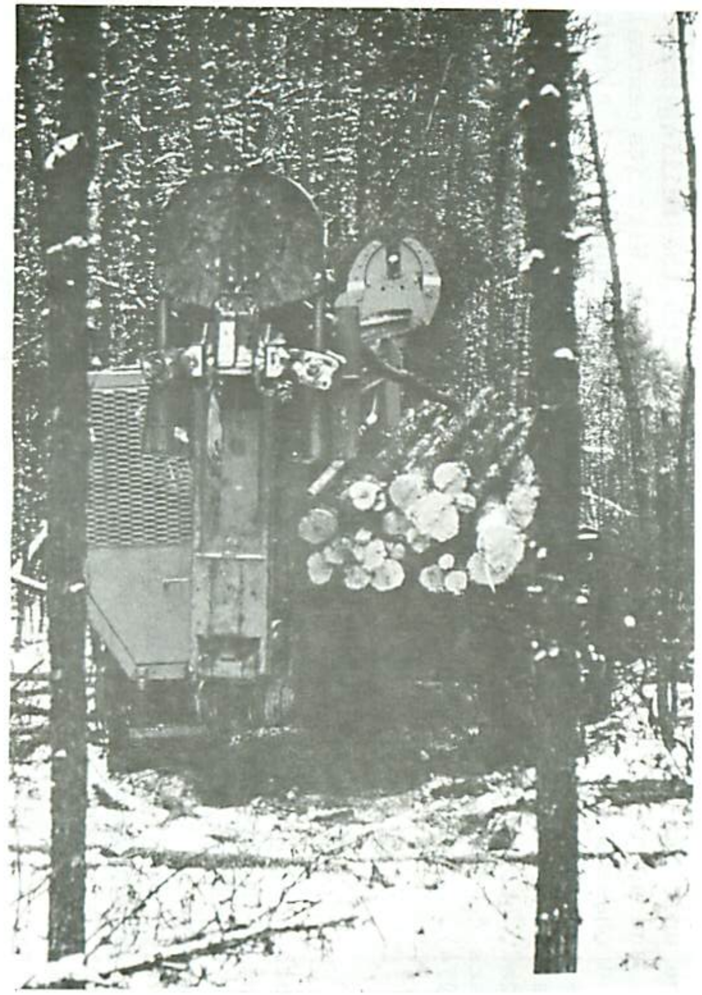

Figure 2. Front view of Timberjack RW-30 with processed tree dropping onto bunk.

The unit has an overall length of 8.3 m with the felling boom retracted, and an overall width of 2.9 m (Anon. 1973). With its centrally articulated chassis and a front-mounted felling boom capable of slewing 35 degrees to either side of the centre line, the unit is capable of clearing a swath of up to 6.4 m. Utilizing only the slewing of the felling head, one can clear a 4.3 m swath. The unit is designed to handle trees up to 30.5 cm in diameter (inside-bark) at stump height (Powell 1974).

STUDY APPROACH

Both biological and operational factors had to be considered in deciding upon the layout of the area as depicted schematically in Figure 3. We wanted a cut-strip wide enough to obtain a significant growth response in the residual trees yet narrow enough to ensure that crown closure, with the resultant promotion of self-pruning, would occur. The minimum acceptable width of cut-strip was dictated not only by the width of the harvester but also by the need to dump each full bunk load of treelengths beside the unit and the interference by the crowns of residual trees as treelengths were lowered onto the delimbing carriage. Since the harvester could clear a swath up to 6.4 m with full frame articulation this represented the maximum acceptable strip width. It was decided that a cut-strip width of 4.6 m and a leave strip of 5.5 m was most appropriate since this was the same layout used in the previous thinning trial with conventional equipment.

To permit entry to and exit from the strips by both the harvester and the skidder, a two-pass swath was clear cut at both ends of the strip-cut area. An adjacent abandoned gravel pit provided a ready-made landing area. Skidding of wood from the strips to the landing was done by Wesmak Lumber Company using a Timberjack 360 grapple-skidder (Fig. 4 and 5). The tree-length material produced was eventually bucked into 2.4 m lengths by chainsaw during the summer of 1975.

Data were collected to provide information on four main areas of the operation:

i) the standing timber and its utilization

ii) the overall performance and productivity of the RW-30 as a thinning harvester

iii) the harvester productivity in relation to tree size

iv) the performance and productivity of the grapple-skidder.

Stand data were obtained through the establishment and measurement of five permanent sample plots (Table 1), one of which was a control plot in the adjacent uncut area (Fig. 3). These plots will also be used to evaluate growth response 5 and 10 years after thinning. The utilization of trees was determined from a number of studies the first of

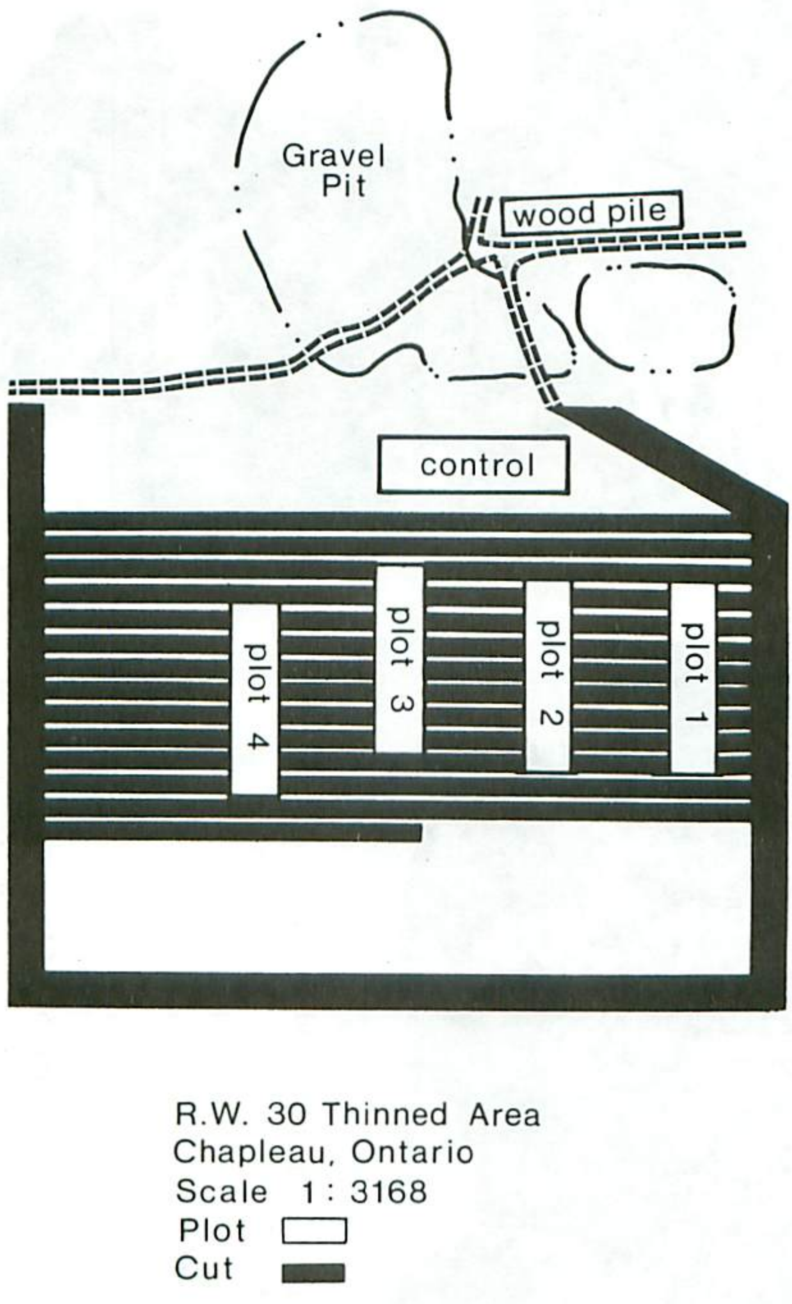

Figure 3. Schematic diagram showing area layout and plot location.

Figure 4. Timberjack grapple-skidder parked at edge of landing area.

Figure 5. Closeup view of grapple. The grapple had virtually the same capacity as the bunk on the harvester.

which was the observation of 69 bunk loads to determine the number of trees dropped, trees broken, and dead trees utilized. Butt and top diameters and merchantable lengths of harvested trees were measured as a part of the tree-size study described later. After harvesting was completed, the scale volume was obtained from a butt-diameter scale by OMNR and the shipped volumes were provided by the licensee.

The second element of data collection consisted of three component studies. First, a complete record was kept of all the work activities involved in the harvest from outset to completion. Second, the harvester operations were subdivided into specific work elements (Appendix) and a full time-point work study was conducted on all the time spent thinning the marked area. Third, the actual operating time was recorded by a Servis Recorder mounted on the harvester. A total tree count was provided by a tree counter in the harvester.

The study of machine performance in relation to tree size entailed the pre-measurement of trees on nine plots scattered throughout the study area. Then the actual time taken to select, approach, and process each of these numbered trees was measured. Most of the numbered trees were measured after cutting to determine butt and top diameters and merchantable length.

Finally, the skidding was subjected to a time-point work study for the time spent by the skidder on the strip-cut area itself. The capacity of the grapple was determined from a count of the number of treelengths skidded in each "turn" studied.

The time-point sampling observations were made every 15 centiminutes using sequentially activated stopwatches and a continuously operating stopwatch. For the record of overall performance a wristwatch was used to note the start of each activity and a stopwatch to measure its duration.

RESULTS

The Servis Recorder charts revealed that the harvester operated 88.8 hours during the 14-day trial. Over this period, 5,110 treelengths, with a net merchantable volume[3] of 548.5 m^3, were harvested from a gross area of 6.3 ha. Of this area, 5.6 ha were strip-cut and the remaining 0.7 ha were harvested as base-line and back-line. In the strip-cut portion 1.9 ha of strip were clear-cut. In total, then, there were 2.6 ha from which all trees were removed. The mean width of "cut" strip was 4.8 m, and the mean width of "leave" strip was 5.2 m.

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[3] See footnote 2.

Harvested wood was skidded in early December, 1973. Approximately 200 loads, averaging 26.9 stems per load, were skidded to the landing over a total operating time of 63 hours.

a) Harvesting

Overall activity data were gathered over 74.2 hours or 84.1% of the total operating time of the harvester. Table 2 shows machine availability and utilization times for the harvester (Bérard et al. n.d.) and provides a breakdown of delay times. Availability was 77.8% and utilization was 64.6%. The reliability of this type of statistic would have been improved had the trial been longer.

Table 2. Availability and utilization of the Timberjack RW-30 in hours and percentage of total scheduled time.

	Duration (hr)		Percentage of total time	
Total scheduled operating time[a]		88.8		100.0
Mechanical delays				
a) repairs	12.6		14.2	
b) servicing	7.1		8.0	
Total	19.7		22.2	
Availability[b]		69.1		77.8
Non-mechanical delays				
a) operation loss	1.5		1.7	
b) personnel	7.6		8.6	
c) in-shift	2.6		2.9	
Total	11.7		13.2	
Utilization[c]		57.4		64.6

[a] A small amount of non-scheduled time was added to this figure.

[b] "Machine availability is the percentage of the scheduled operating time during which a machine is not under repair or in service" (Bérard et al. n.d.).

[c] "Machine utilization is the percentage of the scheduled operating time that is productive time" (Bérard et al. n.d.).

Two operators were used during the trial—a service specialist from Eaton Yale and a professional operator from Miramichi Timber Company in New Brunswick. The differences in their productivity (Table 3) provide some indication of the variation in output, availability, and utilization that can be attributed to the operator.

Table 3. Operator productivity.

	Service specialist	Professional operator
Total sample (hr)	54.6	34.2
Output (trees/PMH)[a]	65	74
Output (m^3/PMH)	2.7	3.1
Availability (%)	74.1	83.9
Utilization (%)	60.5	71.3

[a] PMH = productive machine-hours.

A time-point work study was included for 25.9 hours (29.1%) of the total operating time. This study was based on 14 work elements (Appendix) which have been grouped into four broad categories of productive machine time in Table 4.

Table 4. Time breakdown of harvesting work elements in percentage of productive machine time.

Work element category	Work element (%)					Total (%)
Tree selection	Forward	Reverse	Clear tree	Select tree	Position felling head	
	9.2	1.2	2.8	0.4	10.1	23.7
Tree processing	Shear	Load carriage	Delimb	Load collector	Return limbing head	
	10.7	14.5	24.0	19.5	1.4	70.1
Tree unloading	Align butts	Unload collector				
	2.0	1.3				3.3
Delays	Clear debris	Hesitation				
	2.6	0.3				2.9
Total						100.0

To a very limited degree it was possible for some of the work elements to be in process simultaneously. For example, the delimbing head could return on the carriage while another tree was being selected or the felling head positioned. When this occurred the more important one was timed.

The bunk load analysis was made from two component studies. In the first, 69 bunk load cycles were observed to determine the utilization of dead trees, and the incidence of breaking or dropping trees. This showed that there were 25.3 trees per load and that the average load cycle was 16.2 minutes. Of the 1749 trees loaded, 94% were live trees and 6% were standing dead. There was a certain amount of wastage as a result of trees being dropped or broken during processing (Table 5).

Table 5. Wastage of merchantable trees.

	Trees dropped		Trees broken		Total	
	(No.)	(%)	(No.)	(%)	(No.)	(%)
During transfer to delimber carriage	28	40	15	21	43	61
During limbing cycle	-		16	23	16	23
During transfer to collector	11	16	-		11	16
Total	39	56	31	44	70	100

This constitutes in theory a wastage of 4% of the standing stems. However, in view of the fact that 6% of the processed trees were "standing dead" and that only 4% of the trees were dropped or broken this unit cannot be faulted for poor utilization. Most of the dropped or broken trees were very small and contributed very little in merchantable volume.

The second component of this study was designed to relate harvester performance to tree size. Approximately 280 trees located in nine plots scattered throughout the strip-cut area were blazed and numbered. The actual time taken to harvest each of these trees was observed and recorded. The time was subdivided into the same work elements referred to previously (Table 4 and Appendix). However, only the total processing time is presented in Table 6 in relation to various dimensions of the standing trees and the processed tree-length. Of the original number of trees measured for diameter, outside-bark of stump, and breast height (1.4 m), only 265 could be timed satisfactorily and only 180 could be found for measurement of butt and top diameters (inside-bark) and processed length.

Table 6. Harvester utilization and productivity based on the tree-size study.

Butt diameter (cm)	No. of treelengths scaled	DBH (cm)	Top diam (cm)	Merch. length (m)	Merch. vol[a] per tree (m^3)	Processing time[b] per tree (min)	Trees processed[c] per PMH[d] (trees/hr)	Vol per PMH (m^3/hr)
7.5	95	6.9	3.3	7.4	0.02	0.46	84	1.7
10.0	1,335	8.6	4.3	8.0	0.04	0.38	102	4.1
12.5	1,560	10.2	5.3	8.5	0.08	0.38	102	8.2
15.0	1,230	12.2	6.1	9.8	0.13	0.43	90	11.7
18.0	585	14.0	6.6	10.6	0.19	0.42	92	17.5
20.5	250	16.0	7.4	10.7	0.26	0.44	88	22.9
23.0	45	17.5	8.1	11.0	0.34	0.52	74	25.2
25.5	10	20.1	10.7	11.3	0.43	0.53	74	31.8
Total	5,110							
Averages (weighted)		10.9	5.6	9.0	0.12	0.40	97	11.6

[a] Volumes are based on a tree-length local volume table provided by Chapleau District (OMNR).

[b] Actual productive machine-time spent processing trees in the respective diameter classes.

[c] Processing times have been reduced by percent utilization to reflect time that would be lost over a longer operating period.

[d] PMH = productive machine-hours.

Although larger trees took longer to harvest, this increased time was more than offset by their larger unit volume. The delimber stroke was 9.8 m and consequently trees having a utilizable length greater than this could be completely limbed only by a) lowering the felling head and arching the treelength on the carriage, or b) shifting the treelength forward on the carriage by releasing the butt shear clamps, moving the delimber head forward on the carriage and re-clamping the tree part way along the length with the butt shear clamps before completing the limbing stroke.

b) Skidding

In order to complete the evalution of the thinning harvest, the skidding of the treelengths to the landing area was studied. Over the 7-day period in which the wood was skidded 115 turns were observed. The skidder averaged 26.9 trees (or 1.8 m^3) and 14.1 minutes per turn.

Despite the fact that the operator was experienced only with cableskidders, he was able to attain a high availability and utilization of 85.6 and 81.2%, respectively, of the 62.9 hours studied. Losses in production due to mechanical delays amounted to 14.1% of the time, with servicing accounting for 11.0% and repairs 3.1%.

Non-mechanical delays amounting to 4.4% were divided between "operational lost-time" at 1.9% and "personnel lost time" at 2.5%.

DISCUSSION

In addition to examining the productivity of the harvester and skidder, we compared the revenues and costs with those reported in the thinning operation that employed conventional logging machinery (Mattice and Riley 1975). The comparison is confounded by the 3-year interval between the two logging operations, and the 4-year interval between the sale of the products. To overcome this problem the revenues and costs are discounted to 1970. The comparison is further complicated by the short test period for the harvester. This difficulty is partially met by using costs provided as a result of subsequent testing of the unit in eastern Quebec (Powell 1974).

The following data were used as inputs to the cost-nomogram in Powell's report to arrive at a maximum and minimum operating cost which would reflect favorable and unfavorable operating conditions in a thinning harvest.

Table 7. Estimated range in operating costs.

	Cost item	Operating cost ($ per m³)[a] Favorable	Unfavorable
i)	Purchase price ($)	55,000	55,000
ii)	Machine life (1,000 SMH)[b]	14	10
iii)	Depreciation period (yr)	4	4
iv)	Maintenance costs ($/SMH)	6.97	19.50
v)	Crew wages ($/SMH)	5.00	5.00
vi)	Machine utilization (%)	70	60
vii)	Productivity (m^3/PMH)[c]	12.0	7.2

[a] 1973 dollars.

[b] SMH = scheduled machine-hours.

[c] PMH = productive machine-hours.

The inputs for items ii) and v) are the same as those provided in the Powell report (1974). The purchase price quoted was relevant in 1973, but has since increased drastically. It includes a $5,000 charge for a basic stock of critical replacement parts. The range in machine utilization is concentrated around the trial figure of 64.6%. Actual productivity on this trial was 10.1 m^3/PMH. This could have been increased appreciably by harvesting fewer of the very small trees. Consequently, a somewhat higher productivity figure is used for favorable operating conditions. These figures result in a cost range of $2.45–$7.90/m^3.

In Table 8, which is a comparison of the two operations in terms of actual and discounted revenues and costs, revenues are based on shipped volumes and costs on scaled volumes. (These differences are identified and discussed later.) The assumed discount rate was 10.25%.

Table 8 shows that under favorable conditions such as those encountered in these trials, thinning with the tree-length harvester yielded profits comparable to those obtained with conventional logging equipment. Under less favorable operating conditions productivity would decrease and would result in either reduced profit or a loss.

It is encouraging to learn that a profit can be made using the tree-length harvester. Although operational conditions were near optimal as far as site was concerned, the stand characteristics were far from ideal. The presence of large numbers of undersized live and standing dead trees was a serious constraint to high harvester productivity in terms of wood volume. Table 1 shows that there are 770

Table 8. Actual and discounted revenues and costs for strip-thinning using conventional logging equipment (Nimitz Twp) and the Timberjack RW-30 Tree-length Harvester.

Item	Conventional logging, 1970[a]		Timberjack Harvester			
	Revenues	Costs	Revenues		Costs	
	($)	($)	Actual $	Discounted $	Actual $	Discounted $
Gross sales	44,400		5,470(75)[b]	3,702		
cost of stumpage		3,802			1,176(73)	976
scaling costs		227			39(73)	32
Net revenue	40,371			2,694		
Less operating costs						
felling		15,210			1,076(74) (3,465)	803 (2,586)[c]
skidding/forwarding		2,740			547(73)	454
hauling		6,654			821(75)	556
overhead		5,110			included above	
Total expenses:		29,714				1,813 (3,596)
Total net profit		10,657		881 (-902)		
Net profit/m^3 [c]		2.33		1.99 (-2.06)		
Net profit/ha[d]		375		328 (-338)		

[a] Base year for discounting revenues and costs was 1970; rate of discount was 10.25%.

[b] Numbers "73", "74", "75" in parentheses indicate year in which revenues were accrued or costs incurred.

[c] Figures in parentheses indicate higher costs associated with operating under unfavorable conditions (Table 7). Figures not in parentheses are for operating under favorable conditions.

[d] 4,657 m^3 of pulpwood were harvested from Nimitz Twp and 439 m^3 from Dupuis Twp; 171 ha were "clear-cut" in strips in Nimitz Twp and 16 ha in Dupuis Twp.

undersized "standing live" trees per ha and 1914 "standing dead" trees per ha on this trial area. Together these constitute 55.6% of the total stems.

It is not possible to determine directly just how the harvester handled all these conventionally unmerchantable trees. However, it was determined that 6% of the utilized stems were from standing dead trees. Since 38.6% of the total number of standing trees were dead this means that 32.6% or 1573 stems per ha had to be walked over or knocked aside by slewing the felling head. By observation, except for that portion of the 4% wastage (Table 5) represented by undersized live trees, virtually all were utilized. The net effect was that 28.0% of the trees at the landing (OMNR scale) were in the 7.6-10.2 cm butt diameter class.

Despite this obstacle of unmerchantable stems an average production of 103.8 trees per productive machine-hour was attained. The largest single factor lowering productivity was the small size of the trees. On the basis of OMNR scale the average tree-length volume was 0.11 m^3. This volume is contained in a tree having a butt diameter of approximately 15.0 cm (Table 6). The table shows that a 25.4 cm tree takes 1.4 times as long to process, yet yields 5 times as much merchantable volume. Thus, there would seem to be considerable merit in grooming stands such as this for commercial thinning by reducing density and improving stem distribution at an earlier age.

Undoubtedly the largest gain in productivity would result from a higher percentage of larger trees in the stand. This might be obtained in stands on better sites or in stands with less severe overstocking, or from earlier measures to reduce overstocking. Were the harvester equipped with a multiple felling head to enable the processing of several smaller trees simultaneously, this could also increase productivity dramatically. That the scale volume was 20% higher than the shipped volume suggests that chipping at the landing could improve productivity immediately by increasing utilization.

The combination of grapple-skidder and harvester worked very well. Despite his lack of experience, and the snow cover over the piles of treelengths, the operator was able to skid a complete pile each turn. The strip width could have been wider to facilitate skidder travel along the strip. At the 4.8 m width the wheels often rubbed bark off trees on the edge of the uncut strip. The skidder was frequently forced to drive over the piles of wood, scattering them and making the subsequent grappling more difficult. It also became apparent that piles which had their butts aligned by the harvester operator prior to dumping were far easier to grapple.

CONCLUSION

The basic conclusion is that under the favorable operating conditions encountered in this trial, the Timberjack RW-30 could profitably thin a semimature jack pine stand. To determine whether a stand could be thinned profitably today, it would be necessary to consider diameter distribution, operating conditions, changes in wood prices, and the current cost of harvester operation and maintenance. This report should provide sufficient data on productivity to make that comparison.

If the forest manager contemplates a commercial thinning in natural, overstocked stands, he should consider preparing for it by reducing the number of smaller stems in the stand at an earlier age. This not only removes them as obstacles but should accelerate growth on the remaining trees.

Knowing that thinning of natural stands at this stage in their development can be accomplished at a profit or with minimal net cost should encourage forest managers to determine the extent to which overstocking is a problem in their management areas and to develop a strategy to deal with the problem. It should also emphasize the need to monitor possible overstocking, especially in recent fire-origin stands so that they can detect spacing problems early in the rotation and implement spacing programs which will improve the profitability of commercial thinning and of the final harvest.

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APPENDIX

APPENDIX

Definition of Harvester Work Elements

A. TREE SELECTION

1. FORWARD.

   - the forward motion of harvester along strip while moving between trees. The motion of the wheels themselves provided quickest visual evidence.

2. REVERSE.

   - the rearward motion of the harvester, generally to select trees on the edge of the strip, sometimes to clear debris and dropped trees. Wheel motion provided quickest recognition.

3. CLEAR TREES.

   - the use of the felling head to knock aside or push over standing dead or extremely small live trees. On occasion, when a small tree was dropped by the felling head, the operator himself had to clear it. Generally, this was done only where there was risk of damage to exposed hydraulic hose.

4. SELECT TREES.

   - the period between the termination of the forward motion and the activation of the felling head. With the narrow cut-strip, the operator had to slew edge trees to the strip-centre before starting to lower them onto the delimber-carriage. Otherwise the crown of the severed tree became tangled with those of the trees on the opposite side of the strip. In situations where spacing was particularly close this involved the development of a strategy. This work element was not a part of every cutting cycle.

5. POSITION FELLING-HEAD.

   - the raising, aligning, and lowering of the felling head boom. It started with the movement of the boom and ended with the activation of the shear clamps. With greater operator experience this work element tended to overlap the forward movement of the harvester. In these situations it started with the termination of forward motion.

B. TREE PROCESSING

6. SHEARING.

   - the actual severing of the tree. This started with the activation of the butt shear clamps and terminated with the sudden jerk of the severed stem.

7. LOAD CARRIAGE.

- the tilting of the felling head, alignment and raising of the boom to lay the treelength along the delimber carriage. This work element terminated with the activation of the delimber knives. This includes any problems incurred with tangling of tree crowns.

8. DELIMB.

- the movement of the delimber head along the carriage after removing branches. This started with the activation of the delimber clamps and terminated with the completed shearing of the tree top. Short treelengths often broke near the top without being sheared. In these instances the work element terminated with the opening of the butt shear clamps. When smaller trees were pulled free from the butt shear clamps this element was prolonged. During the delimbing of longer trees the treelengths were often arched by lowering the felling head boom to increase the length of utilized bole. This was included.

9. LOAD BUNK (COLLECTOR).

- the dropping of the treelength into the bunk. This work element started with the dropping of the tree top and terminated with the start of the return of the delimber head.

10. RETURN DELIMBER HEAD.

- the movement of the delimber head along the carriage, often terminating with the start of forward travel of the harvester (while the delimber head was still moving).

C. TREE UNLOADING

11. ALIGN BUTTS.

- the use of the felling boom to align the tree butts on the bunk. This had to be done for individual trees (but not every tree) to avoid interference with subsequent felling. The service specialist tended to leave it until the bunk was completely loaded.

12. UNLOAD BUNK.

- the activation of the bunk to drop trees on the side of the strip, occasionally prolonged when treelengths became lodged against standing trees.

D. DELAYS

13. CLEAR DEBRIS.

- the removal of broken trees from the carriage, or clearing debris from the delimber head or from the front of the window on the operator cab, or clearing debris tangled in hydraulic hose.

14. HESITATION.

- the occasional unexplained hesitation between or within work elements.

NOTE: EXTENDED CUTTING CYCLE

- the infrequent extension of the cutting cycle in processing very long treelengths along the carriage to increase the length of the delimbed tree bole. Because of its infrequency it was deleted from data in tables.