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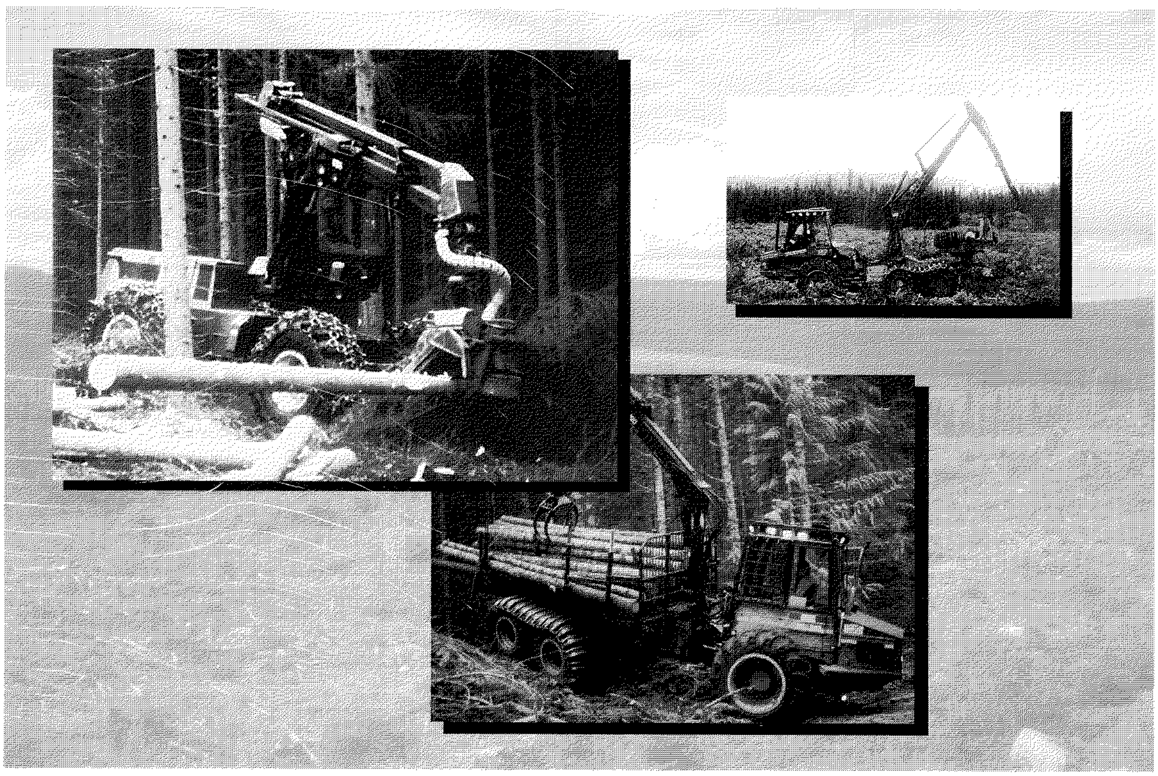
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

THE PERFORMANCE OF CUT-TO-LENGTH SYSTEMS IN EASTERN CANADA

R. Richardson, Eng. and I. Makkonen

November 1994



Technical Report

TR-109

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KEYWORDS: Harvesting systems, Cut-to-length systems, Harvesters, Processors, Forwarders, Productivity, Costs, Environmental aspects, Eastern Canada.

Ce Rapport technique est disponible en français.

Abstract

The report presents a synthesis of information from more than 70 FERIC studies of cut-to-length systems conducted in eastern Canada between 1987 and 1993. The average productivity of harvesters ranged from 4 to 22 m^3/PMH, depending mainly on average tree size, operator skill, and the ratio of the numbers of unmerchantable and merchantable stems. The average processor productivity was higher than the average harvester productivity and ranged from 12-34 m^3/PMH, depending mainly on average tree size. The productivity of forwarders ranged from 12-31 m^3/PMH and was largely influenced by forwarding distance. The direct harvesting costs of cut-to-length systems were calculated to be 10 to 75% higher than those of mechanized full-tree systems. The advantages and disadvantages of cut-to-length systems in terms of total cost, environmental considerations, operational considerations and wood utilization are discussed.

Acknowledgments

This report contains information gathered by all the members of FERIC's Wood Harvesting Group and we thank each one for their contribution.

Special thanks are also extended to FERIC member companies who supported and cooperated in the many studies undertaken. Without their help, this project could never have been realized.

Authors

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Summary

Cut-to-length systems are becoming more prevalent in woodlands harvesting operations across Canada. Mechanized cut-to-length systems usually consist of harvesters and forwarders, or of feller-bunchers with processors and forwarders. FERIC has been collecting information on the productivity, performance and costs of these machines used in cut-to-length systems under various operating conditions. This report synthesizes information from more than 70 different FERIC studies.

Productivities for harvesters ranged from 4 to 22 m³/PMH (Figure S-1), from 12-34 m³/PMH for processors (Figure S-2) and from 12-31 m³/PMH for forwarders (Figure S-3) in the FERIC studies. Harvester and processor productivities are influenced by many factors, including machine technical specifications. During the FERIC studies, the most significant measurable factor affecting productivity for both types of machines was found to be average tree volume. Harvester productivities were also affected by the ratio of the number of unmerchantable trees per hectare to the number of merchantable trees per hectare, and by the number of years of experience of the operator. Forwarder productivities were affected by travel distance.

Cost curves for harvester-based and processor-based cut-to-length systems and for full-tree systems are presented in Figure S-4. In most scenarios, cut-to-length systems are more expensive than mechanized full-tree operations with roadside slashing when considering only owning and operating costs. However, when considering road costs, infrastructure costs, reforestation costs, slash treatment costs and the cost of moving between cut blocks, cut-to-length systems may be more economical overall than conventional full-tree harvesting systems.

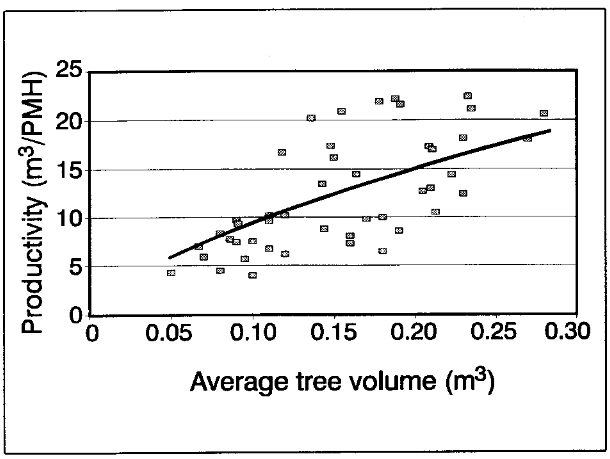

Figure S-1. Effect of tree size on harvester productivity.

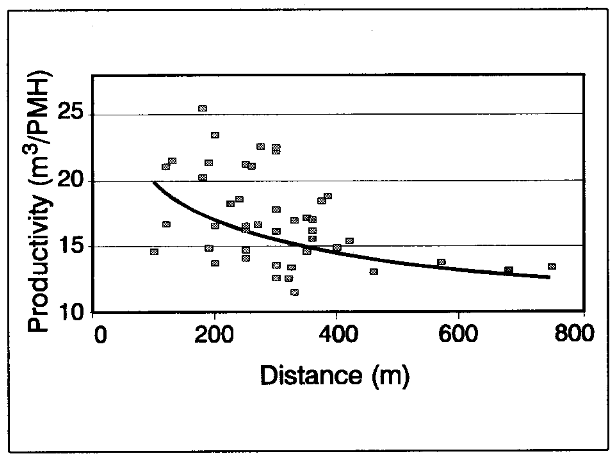

Figure S-3. Effect of distance on forwarder productivity.

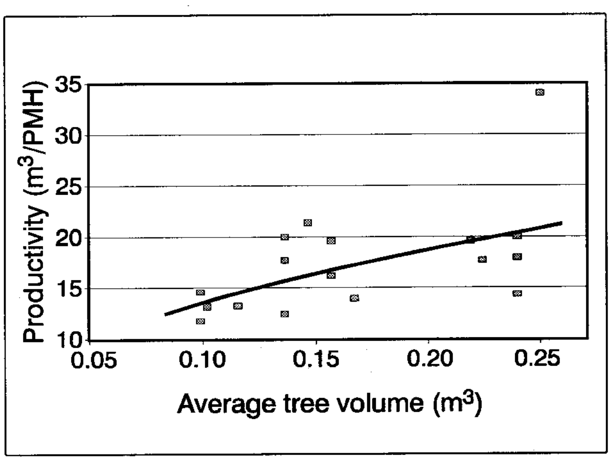

Figure S-2. Effect of tree size on processor productivity.

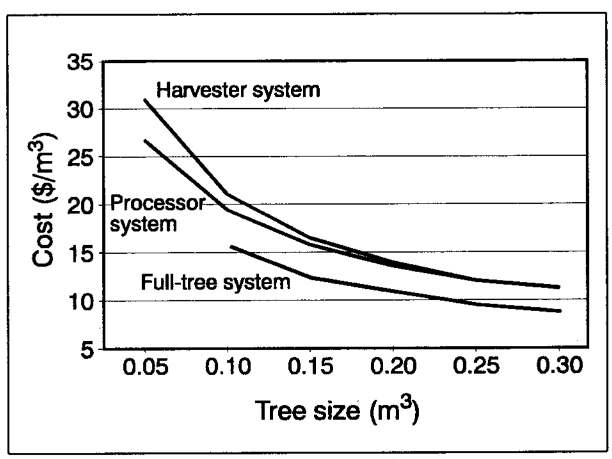

Figure S-4. Costs of a harvester-based system, a processor-based system with a forwarding distance of 400 m, and a full-tree system with a skidding distance of 100 m.

Introduction

Two main types of mechanized cut-to-length systems are increasingly being used in Canada. The most popular system uses harvesters to cut, delimb, measure and buck the stems, and forwarders to transport the shortwood to roadside. In the second system, feller-bunchers fell and bunch or windrow the stems, processors delimb, measure and buck them, and forwarders carry the bolts to roadside. The growth in popularity of the harvester/forwarder system in particular is significant all over eastern and central Canada.

There are several reasons for this rise in popularity. Perhaps the most important is the perceived softer impact on the environment of the shortwood system compared with full-tree operations. For example, the system is seen to cause less nutrient removal from the site, less damage to advance regeneration, and less machine-induced ground disturbance.

FERIC regularly evaluates new machines as they are introduced. Several recent publications on harvesters, processors and forwarders have been produced by Eastern Division, including Gingras (1991, 1992b, 1994), Makkonen (1988, 1989a, 1989b, 1990a, 1990b, 1991), Meek (1993), Raymond (1990a, b), and Richardson (1988, 1989).

The objectives of the present report are:

- to consolidate data, both published and unpublished, on more than 70 FERIC field studies on mechanized cut-to-length systems working in eastern and central Canada, covering a range of field and operating conditions and machine capabilities. Study details are provided in the Appendix;
- to provide information to potential users on the advantages, disadvantages, expected productivities, and basic owning and operating costs of these systems; and
- to compare cut-to-length systems with full-tree harvesting systems. Full-tree systems are not discussed in detail in this report; however, typical productivity rates have been presented by Mellgren (1990) and Favreau (1992).

Long-term machine availability and repair data are not presented in this report because (1) both depend highly on the contractor's commitment to scheduled maintenance programs and (2) the cut-to-length machine market is very active, with equipment continuously evolving and improving. Information on machine availability, repair data and log length accuracy can be found in Gingras (1994a) and Richardson (1989).

The information presented in this report is specific to cut-to-length equipment working in *clearcut* scenarios. Ongoing research is focusing on providing similar information for *partial cut* scenarios.

Harvesters

General Description

Harvesters (also called feller-processors) are designed for felling, delimbing and bucking stems to length in the stand. They are referred to as "single-grip" (grapple) or "double-grip" (bed or bunk) depending on how many times a stem is handled by the machine. Single-grip harvesters are more popular than the double-grip type because they are faster, more versatile and often cheaper. However, double-grip harvesters are generally more robust and often more suitable for working with large trees and removing larger branches. Because the current trend is towards single-grip harvesters, both in North America and in Europe, the text will concentrate on the single-grip configuration.

Single-grip harvesters are sold either as integrated machines or as harvester heads sold as attachments to be mounted on a carrier, usually a tracked excavator in North America. Small heads can be mounted on small excavators or wheeled carriers such as the Ford Versatile bidirectional tractor for use in woodlots.

Integrated harvesters consist of a base machine, often adapted from a forwarder design and thus having parts that are interchangeable with forwarders from the same manufacturer. Their booms may be articulated or telescopic. Many have leveling tables under the boom's mast.

To avoid the high cost of integrated harvesters, many contractors are mounting harvester heads on excavator carriers. However, matching problems can occur because the hydraulic systems on excavators are not specifically designed for harvester heads. They may have insufficient flow capacity, inadequate filters, small reservoirs or an inadequate cooling system. Also, with articulated boom configurations, the stick boom often must be extended to allow operation close to the machine.

Factors Affecting Harvester Productivity and Performance

Various factors influence harvester productivity. Data from 46 different harvester studies conducted by FERIC were used to generate a relationship between productivity in m^3 per productive machine hour (PMH) and three significant variables: tree size, the ratio of unmerchantable stems[1] to merchantable stems, and the number of years of operator experience:

$$P = 42.46 \times Vol.^{0.6683} \times (\frac{Um}{M})^{-0.1211} \times Oper.^{0.1351}$$

where:

P = productivity (m^3/PMH)

Vol. = average tree size (m^3)

$\frac{Um}{M}$ = the number of unmerchantable stems per hectare divided by the number of merchantable stems per hectare

Oper. = number of years of operator experience

These factors explain 61% of the variation in productivity (adjusted r^2 = 0.61).

Tree Volume

Tree volume is the most important measurable variable that affects harvester productivity. Harvesters are very sensitive to tree size because they generally handle only one stem at a time, and since the cycle time to process one small tree is quite similar to that for a large tree, the volumetric productivity is proportional to average tree volume. The observed productivities of single-grip harvesters as a function of tree size are presented in Figure 1. The curve therein was developed from the earlier regression equation with the unmerchantable to merchantable ratio and operator experience held constant at their average values (0.59, and 0.78 years, respectively).

Unmerchantable Stems

The proportion of unmerchantable stems in a stand can affect productivity. Harvesters must maneuver around large unmerchantables left standing. Small unmerchantable stems in the understory reduce visibility. The frequencies of minor breakage and repairs to saw chains, bars and hydraulic hoses generally increase in stands with a large unmerchantable component.

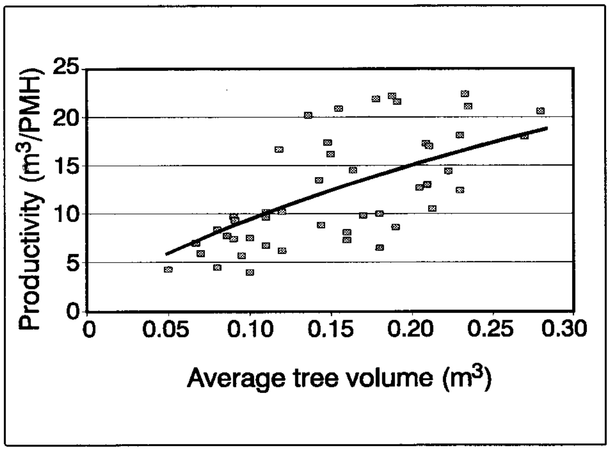

Figure 1. Effect of tree size on harvester productivity.

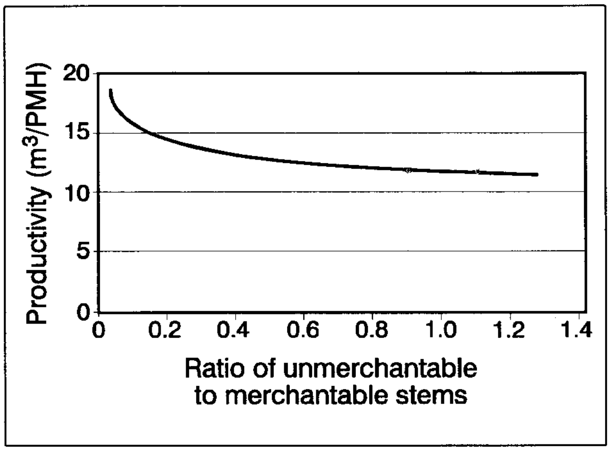

Figure 2. Effect of the unmerchantable-merchantable ratio on harvester productivity.

[1] Unmerchantable stems were defined as all stems with a DBH between 4 and 8 cm, or unmerchantable species with a DBH greater than 8 cm.

Figure 2 presents the productivity of single-grip harvesters as affected by the ratio of the number of unmerchantable stems to the number of merchantable stems in a stand (keeping volume per tree and operator experience constant at 0.15 m^3/tree and 0.78 years, respectively). The figure indicates that there is a rapid increase in productivity as the ratio drops below 0.2.

In two earlier studies, harvester productivity was increased by 22 and 37% over the control values when the unmerchantable stems were manually felled prior to the final harvest (Richardson 1992, 1993).

Operator Skill

The operator has an important influence on machine productivity. Harvesters have a complex work cycle and operators must make thousands of decisions each day. The literature and comments collected in the field indicate that operators may need up to 2 years to reach 100% of their potential productivity (Anon. 1990; Cottell et al. 1976; Hall et al. 1972; Lehtonen 1975). A regression analysis (with the volume held constant at 0.15 m^3 per tree and the unmerchantable to merchantable ratio set at 0.59) showed that the greatest productivity gains occur during the first 6 months of operator experience (Figure 3). Operator skill, however, depends not only on experience, but also to a great extent on operator motivation, dexterity, judgment, aptitude and depth perception.

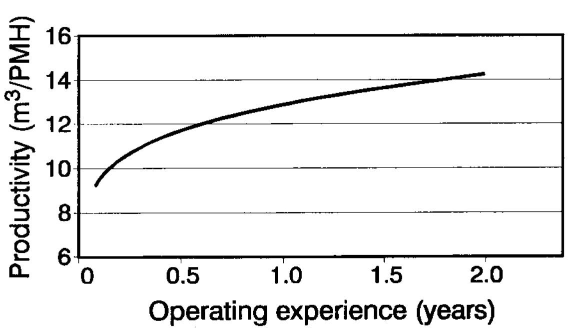

Figure 3. Effect of operator experience on harvester productivity.

Other Factors

For the reader's convenience, the combined effect of tree volume, unmerchantable stems and operator skill is presented in the form of a nomogram (Figure 4), which provides a graphical representation of the regression equation presented earlier.

Other factors that influence productivity, but for which no statistically significant relationship could be established from the studies, include tree branchiness and form, multiple-stem handling, length accuracy requirements, and the specific technical characteristics of the harvesters.

Single-grip harvesters often have difficulty removing large branches. The effect of branchiness was assessed during one FERIC study of a medium-sized harvester, in which trees were rated before harvest as having most branches less than 4 cm in diameter and, therefore, easily delimbed (class 1); having some branches larger than 4 cm (class 2); or having stems of poor form (class 3). Classes 2 and 3 are known to cause delimbing problems. During the study, the average productivity of the harvester was 34% lower with stems in classes 2 and 3 than with stems in class 1 for the same tree size. This is comparable to results in New Zealand (Raymond et al. 1988), where the productivity for stems with large branches or poor form decreased by from 35 to 57% compared with productivities for stems that presented no such difficulties.

A few studies suggest that multiple-tree handling is feasible when trees are small, homogeneous in size, close to one another and not too limby (Brunberg et al. 1989; Lilleberg 1990; Sluss 1991). Handling more than one tree at a time can increase productivity. However, length-measuring accuracy and delimbing quality may suffer. The productivity increase depends on the percentage of cycles in which multiple stems are processed. Multiple-tree handling did not occur to any significant extent in any of the FERIC harvester studies, but other studies indicate that a productivity increase of 5 to 25% is possible under favorable conditions (Brunberg et al. 1989; Lilleberg 1990, 1994).

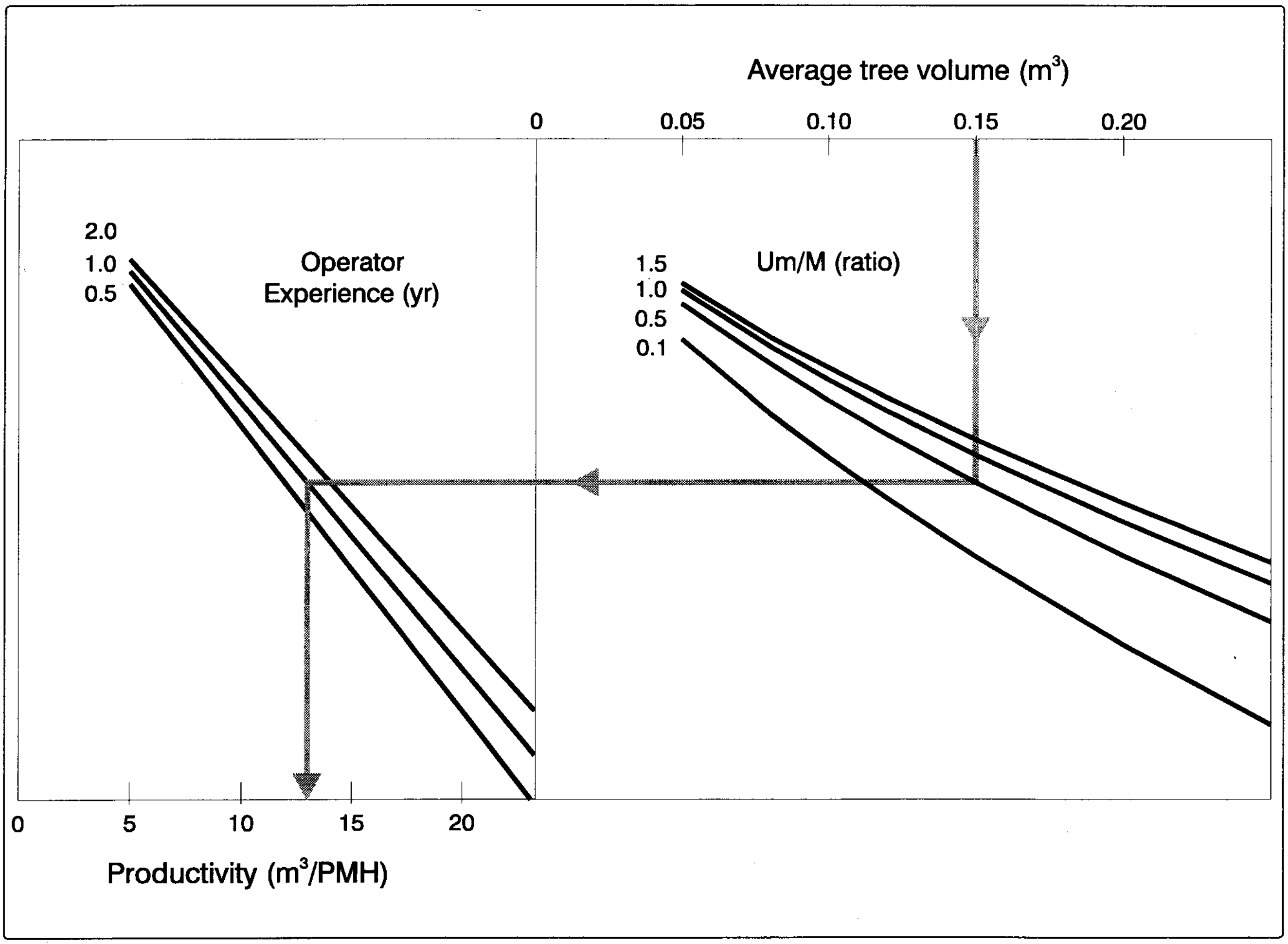

Figure 4. Productivity nomogram. (The grey line shows an example calculation with an average tree volume of 0.15 m³, a Um/M (unmerchantable to merchantable) ratio of 0.5 and 1.0 year of operator experience. The resultant productivity is 13.0 m³/PMH.)

A strict requirement for precise log lengths can also adversely affect productivity because the operators may spend more time jockeying the stem back and forth to reach the target length. Measurement accuracy varies with make and model, automatic or manual functioning, and the attention paid by the user to regular calibration. Users claim that producing random and longer lengths is 35 to 50% more productive than producing 8-foot lengths because of reduced stopping, jockeying and slashing times (B. Chisholm, personal communication). A short test recently conducted by FERIC found a 20% increase in productivity when producing tree lengths or long lengths versus 16-foot lengths.

Processors

General Description

Processors are designed to delimb and buck to length either in the stand or at the roadside. Processors may be single-grip, with the processing head mounted on the boom, or double-grip, with a grapple on the boom and a processing unit mounted on the chassis. Larger models can be mounted on wheeled or tracked carriers, whereas smaller units can be mounted on farm tractors of suitable size. Much of the componentry in European models is similar to that of harvesters and is described in more detail in Richardson (1988).

Factors Affecting Processor Productivity and Performance

Processors are not as sensitive as harvesters to adverse operating conditions because they work in an environment where the trees have already been felled and often bunched together, and where the visibility has been improved. However, productivity is still affected by many of the same factors.

Tree Size

A regression analysis on data from 17 FERIC processor studies showed that tree volume was the most important variable affecting processor productivity under the conditions studied. The best equation for predicting processor productivity, as measured in the FERIC studies, is as follows:

$$P = 41.16 \times Vol.^{0.4902}$$

where:

P = productivity (m^3/PMH)

Vol. = average tree size (m^3)

The equation explains 31% of the variation in observed productivity (adjusted $r^2 = 0.31$). The observed and calculated processor productivities as a function of tree size are illustrated in Figure 5. Other factors account for the rest of the variation; however, none were statistically significant, probably because of the small sample size.

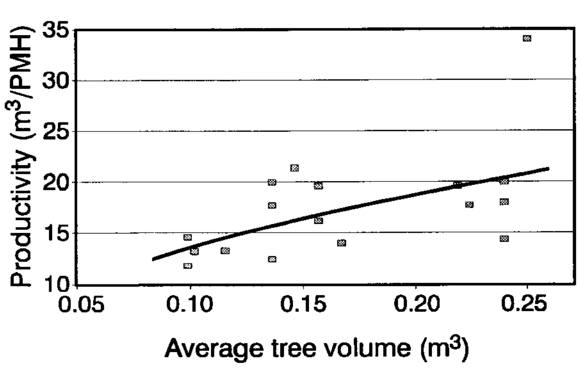

Figure 5. Effect of tree size on processor productivity.

Other Factors

Because they work from bunched or windrowed trees, processors are often able to handle multiple stems. The number of trees per cycle as well as the proportion of cycles in which multiple stems are handled influence productivity. FERIC's processor studies have recorded cycles with up to five stems processed at the same time. More typically, two or three smaller stems can be delimbed together whereas larger stems are processed individually. The average processing time per tree as a function of tree size and the number of trees processed per cycle for a double-grip machine is shown in Figure 6. The curves are similar to those determined by Brunberg et al. (1991) for a single-grip machine, but the results will vary depending on the machine and the conditions encountered. They do, however, show the relative effect of handling multiple trees on productivity.

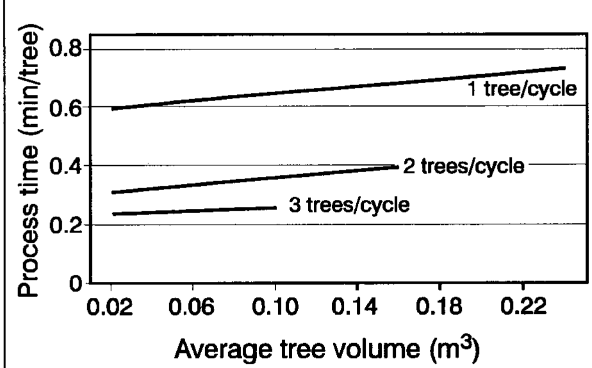

Figure 6. Processing time for a double-grip machine as affected by the number of trees per cycle and tree volume.

Processors are easier to operate than harvesters because there is one less function to perform and fewer decisions to make. Nevertheless, processors are complex machines, whose production rates are greatly affected by operator skill levels. Branchiness, log length, and accuracy requirements can also influence productivity in a manner similar to that with harvesters.

Whether the processor is following a feller-buncher or is working in manually felled and windrowed stems can influence productivity (Meek 1993). A small, low-powered machine may be better off with windrowed stems as it may lack the required power to break stems out of large piles. Conversely, large machines may benefit from large piles, which reduce the number of moves and setups.

Forwarders

General Description

Forwarders are designed to carry shortwood from the stand to the roadside or landing. Their load capacities vary from 4 000 to 20 000 kg, and the engine output varies between 54 and 160 kW, with many at 85 kW. Forwarders may have four, six or eight wheels (front and rear bogies) and are sometimes equipped with tracks or wide tires.

Factors Affecting Forwarder Productivity and Performance

A large proportion of a forwarder cycle is accounted for by terminal time (loading and unloading). Many of the factors influencing terminal time, discussed hereafter under "Other Factors", are not controllable by block layout. One factor that is controllable is forwarding distance.

Forwarding Distance

Regression calculations using data from 10 FERIC studies with various machine types and different operators found that forwarding distance had a significant impact on productivity.

Since few studies were conducted where distances exceeded 300 m, the productivity equation is based on the regression curve for the first 300 m and mathematical modeling for longer distances, as follows:

$$P = 57.09 \times \text{Dist.}^{-0.2286}$$

where:

P = productivity (m^3/PMH)

Dist. = one-way travel distance (m).

The regression explained only 12% of the observed variation in forwarder productivity at up to 300 m distance (adjusted $r^2 = 0.12$). Since terminal time is not influenced by distance and has the greatest proportional effect on productivity at relatively short distances, this low correlation is expected. The observed and calculated productivities as a function of travel distance are presented in Figure 7.

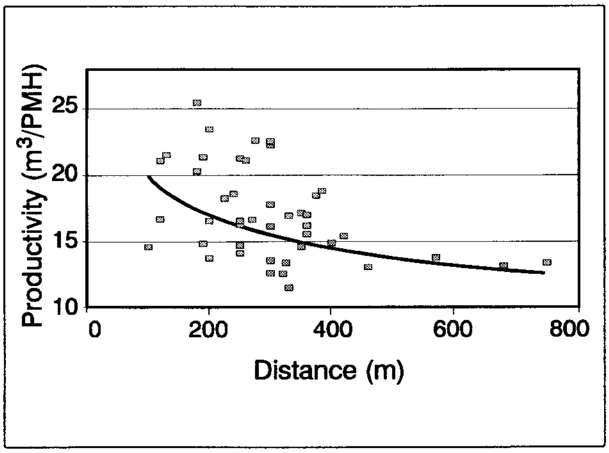

Figure 7. Effect of one-way travel distance on forwarder productivity.

Other Factors

Operating a forwarder is not as demanding as operating a harvester or a processor. Fewer decisions are required and operators get relief from operating the loader while they drive. Nonetheless, as for all machines, operator skill level makes a difference. This is most evident in the rate of unloading. Information extracted from several studies showed that the best operators unloaded up to 75% faster than the worst operators (Figure 8). The best operators also drove faster than the others. Under difficult conditions, experienced operators typically adjusted their load size to avoid problems during travel.

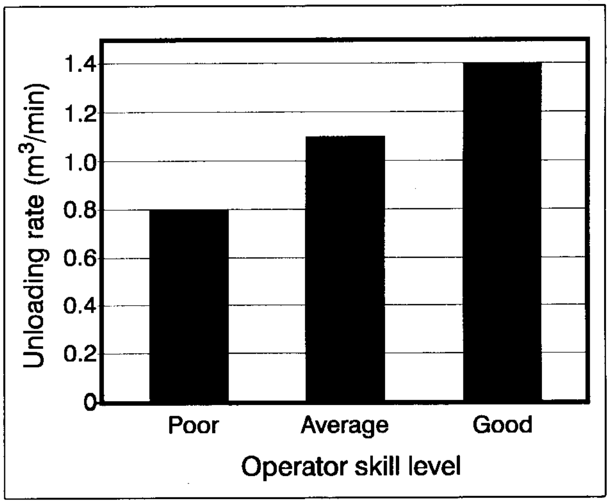

Figure 8. Average rate of unloading for different levels of operator skill.

The rate of loading is influenced by the volume of the logs, the size and quality of the pile, operator skill, and the size and power of the loader. Larger logs are faster to load and unload. Where a large amount of branches, moss or debris is present under a pile, the rate of loading may decrease considerably as the operator tries to shake out the debris. The number of sorts required of the operator will also affect productivity, as both the rate of loading and the rate of unloading will decrease as the number of sorts increases.

FERIC's forwarder studies were conducted under mainly good ground conditions. A reduction in productivity could be expected for rough ground, steep slopes, high stumps, deep snow or soft ground. Good tractive effort and differential locks are especially important on steep slopes or in rough terrain.

Systems Comparison

Annual Production Levels

In a harvester-based system, a contractor can expect to fell and process about 35 000 m^3/year under good conditions in wood averaging about 0.15 m^3/tree with a harvester working two shifts per day (4000 scheduled machine hours (SMH)/yr). Depending on forwarding distance, a forwarder can be operated for somewhat less time than a harvester to match the production of the two machines. Thus, a contractor can provide delimbed and bucked wood to the roadside with only two machines.

Under the same conditions, a processor could be expected to produce around 50 000 m^3/year. Yearly feller-buncher production is much higher, reaching around 80 000 to 90 000 m^3/year. In this case, matching machine schedules is more difficult and depends on whether there is other work in the area for the feller-buncher. Often, a processor and a forwarder are matched with a feller-buncher that is working part of the year in another operation.

The approximate production capabilities of harvesters, processors and forwarders, based on 4000 SMH per year in trees of various sizes, are presented in Table 1. Utilization rates (PMH divided by SMH) were assumed to be 70% for harvesters and 75% for processors and forwarders.

The productivities of machinery used in full-tree systems have been studied extensively and thus, are not presented here. Recent studies include Favreau (1992), Gingras (1994a), Mellgren (1990), and Richardson et al. (1991).

Table 1. Approximate annual production capabilities (m^3) of cut-to-length machines in clearcuts

Average tree volume (m^3)	0.10	0.15	0.20	0.25
Production (m^3/year)				
Harvester	26 000	35 000	42 000	49 000
Processor	39 000	49 000	56 000	62 000
Forwarder				
- at 100 m[a]	51 000	60 000	75 000	84 000
- at 400 m[a]	38 000	45 000	51 000	59 000

[a] Average extraction distance.

System Costs

System costs are based on the hourly costs of owning and operating the machines, their productivities, and their degrees of utilization.

The purchase price of harvesters varies from $125 000 for a small head on a small North American or Japanese carrier to $550 000 for the most expensive six-wheeled Nordic harvester. Processors tend to be priced 5 to 10% lower. Installing harvester or processor heads on excavators can reduce the price by more than $100 000 but may also reduce performance and operator comfort slightly. Four-wheeled North American forwarders can be purchased for around $150 000 and six-wheeled Nordic forwarders for about $250 000.

Figure 9 presents the variation in direct hourly costs for harvesters, processors and forwarders of different purchase prices using the standard FERIC costing formula. These costs are based on a 12 000-SMH working life (approximately 8 400 PMH) for harvesters and 15 000 SMH (approximately 11 250 PMH) for processors and forwarders. Resale value for used machines, insurance, and lifetime repair costs were assumed to be 20%, 3% and 100% of purchase price, respectively. An interest rate of 10% and a $20/SMH cost for operator wages and fringe benefits were used, but taxes, credits, profits and the cost of overhead were not included.

The system costs for the two cut-to-length options and for a full-tree system are compared in Figure 10. Curves were based on a $400 000 harvester, a $240 000 forwarder with a 400-m average extraction distance, and a $375 000 processor. The full-tree system costs were derived using baseline productivities from Mellgren (1990). Purchase prices were assumed to be $170 000 for a grapple skidder with a 100-m average extraction distance, $300 000 for a delimber, $375 000 for a feller-buncher and $200 000 for a slasher. The purchase prices used represent generic values for the different machine types considered, and are not specific to any particular make or model. Thus, the curves would change depending on the original purchase price of the machinery. However, in most scenarios, cut-to-length systems are more expensive than mechanical full-tree operations with roadside slashing when considering only direct owning and operating costs and assuming that the average forwarding distance is greater than the average skidding distance. The cost difference between cut-to-length systems and the full-tree system is reduced as average tree sizes increase up to the maximum rated size for harvesters or processors.

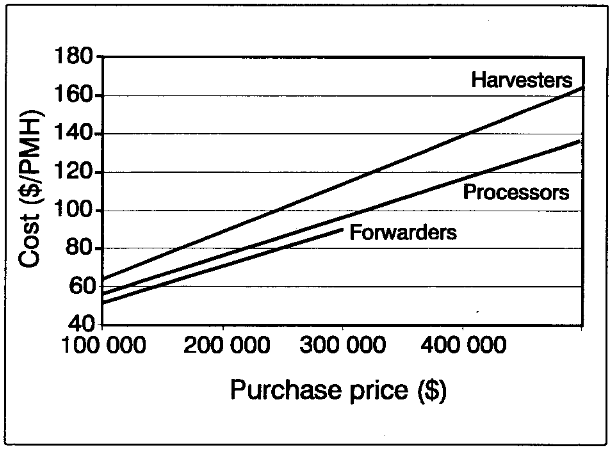

Figure 9. Hourly costs for harvesters, processors and forwarders based on purchase price.

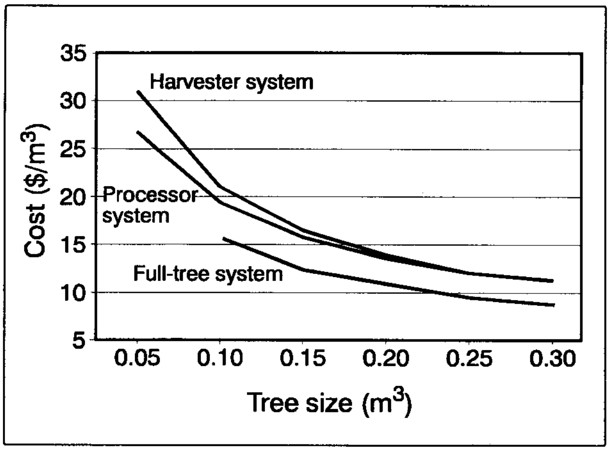

Figure 10. Costs of a harvester-based system and a processor-based system, both with a forwarding distance of 400 m, and a full-tree system with a skidding distance of 100 m.

Although forwarders are generally used for longer extraction distances than skidders, for comparison purposes, the curves were recalculated at an extraction distance of 100 m for both the forwarders and skidders and are presented in Figure 11. In this case processor-based systems have a similar direct cost to full-tree systems while harvester-based systems are more expensive at the smaller tree sizes.

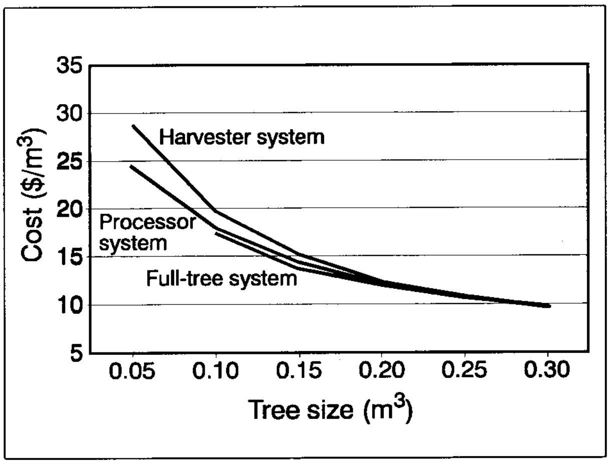

Figure 11. Costs of a harvester-based system, a processor-based system and a full-tree system at extraction distances of 100 m.

In stands with small stems or a high density of unmerchantable stems, systems composed of feller-bunchers with accumulator heads followed through the cutover by processors and forwarders have higher production and lower costs than harvester-based systems. Harvester-based systems become cost-competitive at tree sizes of around 0.15 m^3 and up when considering only owning and operating costs.

When considering alternative harvesting systems, the savings in roads, infrastructure, reforestation or slash treatment costs must also be considered. It is possible that cut-to-length systems may be more economical overall than conventional full-tree harvesting systems under certain conditions. A further savings may be realized if the harvester's or processor's volume measurement device can replace manual scaling. Cut-to-length systems, especially harvester-based systems, are more mobile and are thus better suited than conventional mechanized full-tree systems to smaller cut blocks, where frequent moves are required. Also, because they are lower-capacity systems than full-tree systems, they may be more cost-effective for contractors working primarily with smaller contract allotments.

Table 2 shows the relative difference between systems in terms of capital investment, machinery and labor requirements for producing 100 000 m^3 per year of shortwood to roadside and the approximate cost per m^3. The assumptions used in this table are tree sizes averaging 0.1 and 0.2 m^3; planning, supervisory and administrative personnel, vehicles, and roads are not included; all machines operate two shifts per day; and original purchase prices are the same as were assumed for Figure 10 and 11. Forwarders are also used more commonly with longer extraction distances than grapple skidders. Much can be done through adjusting operating techniques, maintenance schedules, shift lengths and operating days per year to balance the use of the machines, but this may influence costs.

Discussion

The studies that FERIC has conducted since 1987 have shown that there are both advantages and disadvantages to using cut-to-length systems when considering operational aspects, wood utilization, environmental compatibility, and machine transport. Some of these aspects have already been discussed by Gingras (1992a), Richardson (1988), and Wakelin (1992), and are summarized on page 11.

Table 2. Machine, labor and capital requirements for producing 100 000 m³ per year of shortwood to roadside, and the approximate cost per m³

System	Harvester-based			Processor-based			Full-tree		
Avg tree size (m^3)		0.1	0.2		0.1	0.2		0.1	0.2
Extraction distance 100 m									
Machines (no.)	harvesters	3.8	2.3	feller-bunchers	1.3	0.8	feller-bunchers	1.3	0.8
	forwarders	2.1	1.3	processors	2.5	1.8	grapple skidders	1.0	0.8
				forwarders	2.1	1.3	delimbers	1.3	0.8
							slashers	1.8	1.4
		5.9	3.6		5.9	3.9		5.4	3.8
Capital cost ($)		2 024 000	1 232 000		1 929 000	1 287 000		1 408 000	956 000
Labor (no. of operators)		11.8	7.2		11.8	7.8		10.8	7.6
Approx. cost per m³ ($)[a]		20	12		18	12		17	12
Extraction distance 200 m									
Machines (no.)	harvesters	3.8	2.3	feller-bunchers	1.3	0.8	feller-bunchers	1.3	0.8
	forwarders	2.3	1.8	processors	2.5	1.8	grapple skidders	1.4	1.1
				forwarders	2.3	1.8	delimbers	1.3	0.8
							slashers	1.8	1.4
		6.1	4.1		6.1	4.4		5.8	4.1
Capital cost ($)		2 072 000	1 352 000		1 977 000	1 407 000		1 480 000	1 007 000
Labor (no. of operators)		12.2	8.2		12.2	8.8		11.6	8.2
Approx. cost per m³ ($)[a]		20	14		19	13		18	13
Extraction distance 400 m									
Machines (no.)	harvesters	3.8	2.3	feller-bunchers	1.3	0.8	feller-bunchers	1.3	0.8
	forwarders	2.7	2.0	processors	2.5	1.8	grapple skidders	2.4	1.8
				forwarders	2.7	2.0	delimbers	1.3	0.8
							slashers	1.8	1.4
		6.5	4.3		6.5	4.6		6.8	4.8
Capital cost ($)		2 168 000	1 400 000		2 073 000	1 455 000		1 645 000	1 126 000
Labor (no. of operators)		13.0	8.6		13.0	9.2		13.6	9.6
Approx. cost per m³ ($)[a]		21	14		19	14		21	15

[a] Rounded to the nearest $.

Operational Assessment of Cut-to-length Systems

Advantages:

- Single-grip harvester/forwarder systems are versatile. Often, the same machinery can be used effectively in partial cuts as well as in clearcuts. The cut-to-length system is well suited to stands where understory damage or damage to residual trees must be minimized.
- Forwarders can economically forward over longer distances than skidders and can deck higher. Thus, less landing space is required. Roadside disturbance is reduced and road networks need not be as dense, reducing road construction costs.
- It is possible for the forwarded wood to be directly unloaded onto trailers, thereby reducing wood handling costs.
- Wood is forwarded, not skidded, resulting in cleaner fiber.
- The cut-to-length equipment performs well in wet areas and on sensitive sites because of increased flotation from the slash mat produced.
- It is less costly to move two machines (in the case of a harvester/forwarder system) than three or more (in the case of a mechanized full-tree/slasher system). This is particularly important in areas with small cut blocks, where machines must be moved regularly.
- In small trees, fiber recovery may be 13% (Gingras 1992c) to 25% (Wakelin 1992) more than would be recovered with mechanized full-tree systems, as there is less stem breakage caused by rough handling and there are reduced stem losses during extraction.
- In-stand merchandising for increased value can be accomplished easily with harvesters and processors. On-board computers can be reprogrammed after any market change to indicate the desired products.
- Rot can be removed on the cutover, thus decreasing the amount of waste hauled to roadside.
- Products can easily be sorted into two or three categories by the harvesters or forwarders.
- Because processing occurs at the stump, slash disposal is unnecessary. Tops, branches, needles, leaves and cones are left on site, thereby minimizing nutrient exports. The debris also serves as a seed source and as shelter and shade for natural regeneration.
- These systems may be easier to supervise because the machines tend to work together rather than in completely separate phases.
- The two-machine system is viable with lower annual volumes than the mechanized full-tree system.
- Wood delivered to the mill is generally fresher as there are fewer phases and less delay.

Disadvantages:

- Cut-to-length systems are more affected by changes in stand conditions, especially tree size, than full-tree systems.
- Intensive operator training is desirable for shortwood operations and operators take longer to reach their full production capabilities because of the complexity of the machinery.
- Productivity is strongly dependent on operator skill and motivation.
- Capital cost for the equipment may be higher than for most full-tree equipment, especially considering yearly production capabilities.
- In general, operating cost is also higher because the mechanical availability is lower (the machines are more complex to repair and to operate).
- The forwarder may be underutilized in small operations.
- Cut-to-length equipment is best suited to stands of medium-sized trees (DBH between 18 and 45 cm).
- Hauling shortwood may require a change in trailer configuration from traditional tree-length setups.
- Trailer loading and unloading times for shortwood may be longer than for tree lengths. There are also more concerns about load security (tie-downs).
- Heads with metal feed rollers or tracks with aggressive spikes may penetrate the stem surface, which can affect the suitability of the wood for lumber or veneer, create openings for fungal attack, and push bark into the stem, where it cannot be removed easily.
- For phase contractors, the individual machine costs are higher in the cut-to-length system than the individual machine costs in the mechanized full-tree system.

Conclusions

Although mechanized cut-to-length systems are not the answer for every condition (e.g., they are less well suited to large or extremely branchy wood), there are many places where they can be applied successfully:

1. In midsized wood, where a variety of products is desired (e.g., sawlogs, veneer logs and pulpwood) and the merchandising ability of the harvester or processor can be used to its full potential.
2. On sensitive or wet sites where high-flotation machinery is necessary and stems must be carried rather than skidded to minimize soil disturbance.
3. In stands where there is a good stocking level and damage to existing natural regeneration should be minimized.
4. In partial-cutting operations.
5. Where wood must be merchandised, sorted and shipped to different mills, but operation of a satellite sort yard is not possible.
6. Where the stands are patchy or small and the equipment must be moved often.
7. When considering overall costs, including those associated with roads, environmental protection and stand re-establishment.
8. For contractors working on private land and/or small allotments.

Mechanized cut-to-length harvesting systems are versatile and have a more discreet impact on the environment. Their popularity is growing across the country despite generally higher harvesting costs than other harvesting systems. Already well established in the east, the systems are now making inroads in central and western Canada, and this trend will likely continue.

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APPENDIX
FERIC Studies of Cut-to-length Machines

HARVESTERS

Study no.	Machine	Place	Date (d/m/y)	Avg volume (m^3/tree)	Terrain classification[a]	Timing (min)	Productivity trees/PMH	Productivity m^3/PMH
1	Bruun	N.S.	07/88	0.08	1.2.1	396	111	8.3
2	Bruun	N.S.	07/88	0.09	1.1.1	138	84	7.4
3	Bruun	N.S.	07/87	0.09	1.1.1	408	111	9.7
4	Case 888/Tapio 550R	N.S.	28/06/90	0.21	1.1.1	120	62	12.7
5	Case 888/Tapio 550R	N.S.	05/89	0.19	1.1.1	344	45	8.6
6	Cat EL200/FMG762	Que.	26/09/90	0.15	1.1.1	46	108	16.2
7	FMG 990	Que.	20/06/91	0.21	1.1.1	21	80	17.0
8	FMG 990	Que.	20/06/91	0.28	1.2.2	129	73	20.6
9	FMG 990	Que.	19/06/91	0.15	1.1.1	19	118	17.4
10	FMG 990	Que.	19/06/91	0.23	1.1.1	12	97	22.4
11	FMG 990	Que.	18/06/91	0.23	1.1.1	18	54	12.4
12	FMG 990	Que.	18/06/91	0.12	1.1.1	13	83	10.2
13	FMG 990	Que.	21/11/90	0.23	1.2.1	289	80	18.1
14	FMG 990	Que.	20/11/90	0.27	1.2.3	336	68	18.0
15	FMG 990	Que.	11/07/90	0.12	1.2.1	16	142	16.7
16	FMG 990	Que.	11/07/90	0.14	1.2.1	31	149	20.2
17	FMG 990	Que.	11/07/90	0.18	1.2.1	16	122	21.9
18	FMG 990	Que.	11/07/90	0.16	1.2.1	18	135	20.9
19	FMG 990	Que.	10/07/90	0.19	1.1.1	18	113	21.6
20	FMG 990	Que.	10/07/90	0.16	1.1.1	11	88	14.5
21	FMG 990	Que.	09/07/90	0.19	1.1.1	7	118	22.2
22	FMG 990	Que.	09/07/90	0.14	1.1.1	13	94	13.5
23	FMG 990	Nfld.	25/10/89	0.09	1.2.1	60	98	9.3
24	FMG 990	Que.	11/10/89	0.14	1.2.1	50	61	8.8
25	FMG 990	Que.	11/10/89	0.21	1.2.1	77	83	17.3
26	FMG 990	Que.	10/10/89	0.16	1.2.1	21	51	8.1
27	FMG 990	Que.	10/10/89	0.10	1.2.1	71	60	5.7
28	FMG 990	Que.	10/10/89	0.22	1.2.1	103	65	14.4
29	FMG 990	Que.	10/10/89	0.21	1.2.1	127	49	10.5
30	FMG 990	Nfld.	10/88	0.07	4.2.1	1032	77	5.9
31	Ford Versatile/Tufab	N.S.	03/89	0.09	1.1.1	73	88	7.7
32	Keto 150/Kobelco 905	N.B.	12/91	0.24	1.1.1	152	90	21.1
33	Koehring 6612/Silverstreak	N.S.	05/90	0.16	2.2.2	405	46	7.3

HARVESTERS (continued)

Study no.	Machine	Place	Date (d/m/y)	Avg volume (m³/tree)	Terrain classification[a]	Timing (min)	Productivity trees/PMH	Productivity m³/PMH
34	Komatsu/Tapio 400	N.S.	04/89	0.11	1.1.1	288	62	6.7
35	Komatsu/Tapio 400	N.S.	01/89	0.18	1.1.1	663	36	6.5
36	Rottne	Nfld.	10/88	0.10	2.2.2	894	75	7.5
37	Rottne	N.S.	07/88	0.11	2.2.2	462	91	10.2
38	Rottne	N.S.	07/88	0.11	2.2.2	216	86	9.6
39	Silverstreak	N.S	05/90	0.12	2.1.1	405	53	6.2
40	Silverstreak	MI	11/89	0.18	1.1.1	180	54	10.0
41	Silverstreak	MI	11/89	0.21	1.1.1	180	61	13.0
42	TJ230/Tapio 400	P.E.I.	03/89	0.10	1.1.1	220	41	4.0
43	TJ230/Tapio 400	P.E.I.	03/89	0.08	1.1.1	100	57	4.5
44	Valmet 901	N.S.	26-29/08/91	0.07	1.1.1	796	104	7.0
45	Valmet 901	N.S.	13-14/09/89	0.17	1.1.1	312	57	9.8
46	Valmet 901	N.S.	11-12/09/89	0.05	1.1.1	312	90	4.3

PROCESSORS

Study no.	Machine	Place	Date (d/m/y)	Avg volume (m³/tree)	Terrain classification[a]	Timing (min)	Productivity trees/PMH	Productivity m³/PMH
1	Koehring 762/Kobelco	Que.	08/92	0.22	2.1.2	765	89	19.6
2	Komatsu PC200/Steyr KP40	N.B.	22-24/06/92	0.16	2.1.1	744	126	19.6
3	Komatsu PC200/Steyr KP40	Ont.	06/87	0.24	1.2.1	246	84	20.0
4	Komatsu PC200/Steyr KP40	Ont.	06/87	0.24	1.2.1	156	76	18.0
5	Rottne 2-grip	Nfld.	04/93	0.17	2.2.1	546	110	14.0
6	Rottne 2-grip	Que.	09/03/93	0.15	1.1.1	184	160	21.4
7	Rottne 2-grip	Que.	08/03/93	0.25	1.1.1	52	134	34.0
8	Rottne 2-grip	Que.	08/03/93	0.14	1.1.1	164	127	17.7
9	Rottne 2-grip	N.B.	06/92	0.14	2.1.2	66	142	20.0
10	Rottne 2-grip	N.B.	06/92	0.24	2.1.3	186	59	14.4
11	Rottne 2-grip	N.S.	01/08/91	0.10	1.1.1	195	141	14.6
12	Rottne 2-grip	N.S.	31/07/91	0.10	1.1.1	267	114	11.8
13	Rottne 2-grip	N.S.	20/10/89	0.22	2.2.2	169	79	17.7
14	Rottne 1-grip	N.S.	19/10/89	0.11	2.2.2	62	123	13.2
15	Rottne 2-grip	N.B.	07/87	0.16	1.1.1	414	101	16.2
16	Steyr KP40	Nfld.	9-10/07/92	0.14	2.3.4	453	91	12.5
17	Steyr KP40	Nfld.	21/11/91	0.12	2.1.1	45	111	13.3

FORWARDERS

Study no.	Machine	Place	Avg forwarding distance (m)	Terrain classification[a]	Number of cycles timed	Productivity (m^3/PMH)
1	TF C6D	Nfld.	380	1.2.1	9	18.2
2	TF C6D	Nfld.	281	1.2.1	6	13.9
3	TJ230	N.S.	287	2.2.1	8	13.9
4	TJ230	N.S.	258	1.1.1	6	24.9
5	TJ230	N.S.	102	1.1.1	8	15.7
6	TJ230	N.S.	74	1.1.1	6	31.3
7	TJ520	Que.	390	1.1.1	13	16.3
8	TJ/FMG 1010	Ont.	185	2.2.2	16	19.1
9	TJ/FMG 910	Nfld.	1294	1.1.1	4	12.1
10	Valmet 836	N.S.	167	1.1.1	3	14.5

[a] Mellgren (1986).