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FACTORS AFFECTING EQUIPMENT PRODUCTIVITY IN COMMERCIAL THINNING

P. Meek, F.E., M.Sc.*

Abstract

FERIC studied fully mechanized cut-to-length systems during commercial thinning treatments in white spruce plantations and natural black spruce stands. The equipment's performance was assessed to better understand the effects of various organizational factors on productivity. The productivity of single-grip harvesters was little affected by variations in the trail layout and removal intensity, and by different sorting strategies. Shortwood forwarders benefited from situations in which large volumes were available for extraction on each trail. As well, it appears that precleaning treatments are not economically justifiable.

Introduction

In eastern Canada, silvicultural treatments that encompass commercial thinning will undergo considerable development over the next few years. However, the performance of various treatment options appears to be particularly sensitive to variations in operating conditions such as the terrain, stand structure, equipment used, trail network, prescription, and silvicultural objectives.

Between 1995 and 1997, FERIC worked with J.D. Irving, Limited in New Brunswick and with Matériaux Blanchet Inc. in Quebec to conduct a series of studies on the factors that were most likely to influence the performance of various cut-to-length equipment in fully mechanized commercial thinning. J.D. Irving, Limited is currently treating several hundred hectares of white spruce plantation in the Black Brook district, primarily by commercial thinning. To mechanize this work, they use small single-grip harvesters and narrow shortwood forwarders. The factors that FERIC studied at this location were the layout of the trail network, the number of products produced, and the effect of precleaning. In contrast, Matériaux Blanchet Inc. performs its thinning operations in natural black spruce or jack pine stands. They use small single-grip harvesters and forwarders to meet the silvicultural objectives defined by Quebec's Ministère des Ressources Naturelles (MRNQ) for commercial thinning on Crown land, while keeping the operating costs relatively low. Within a project conducted under the Canadian Forest Service's "Testing, experimenting and technological transfer in forestry" program, FERIC studied the effects of trail-network patterns, removal intensity, and precleaning on the productivity of the machines.

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* Philippe Meek is a Senior Researcher, Eastern Division.

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Specifically, the objectives of the studies with Matériaux Blanchet Inc. and J.D. Irving, Limited were to determine the cost differences between:

- thinning stands that had undergone precleaning and those that had not;
- treatments with the use of two ghost trails between each pair of extraction trails (30-m spacing), with a single ghost trail (18-m spacing), or with the use of the extraction trails alone (15-m spacing);
- removal intensities of 30 and 40%; and
- the production of one or two products from the commercial thinning.

Equipment Observed

The single-grip harvesters observed during this project (the Valmet 711, the Rottne 2000, and a Versatile tractor with a Pan felling head; Figure 1) were all small machines capable of working on narrow trails. Their overall widths ranged from 1.8 to 2.1 m and the ground pressures they exerted were low so as to limit the damage to root systems. Each was equipped with a fully or partially hydrostatic transmission, four-wheel drive, and an articulated chassis that permitted precise and delicate maneuvers. Each used a Pan GM728 or GM828 single-grip head capable of felling stems up to 36 or 40 cm in diameter. The machines used parallelogram booms with a reach of 6.3 to 6.5 m.

The shortwood forwarders that FERIC studied (a Timberjack 810B and a Turboforest 6100; Figure 2) had six-wheel or eight-wheel drive, a payload capacity of 8 or 10 tonnes, and loaders with an effective reach of around 6 m. The width of the forwarder (typically 2.5 m) is crucial for limiting the width of the extraction trails to less than 3.2 m.

The assumptions used for calculating the direct hourly costs of the equipment are presented in the Appendix. The cost of the Valmet 711, Rottne 2000, and Versatile/Pan single-grip harvesters ranged from $92.32 to $106.59 per PMH, versus $85.30 and $81.00 per PMH for the Timberjack 810B and Turboforest 6100 forwarders. These costs are presented only for the sake of comparison and do not necessarily represent the actual costs for the contractors. As well, the costs cover only the operating and maintenance costs of the equipment, excluding transport and supervision costs, profits, and other overhead.

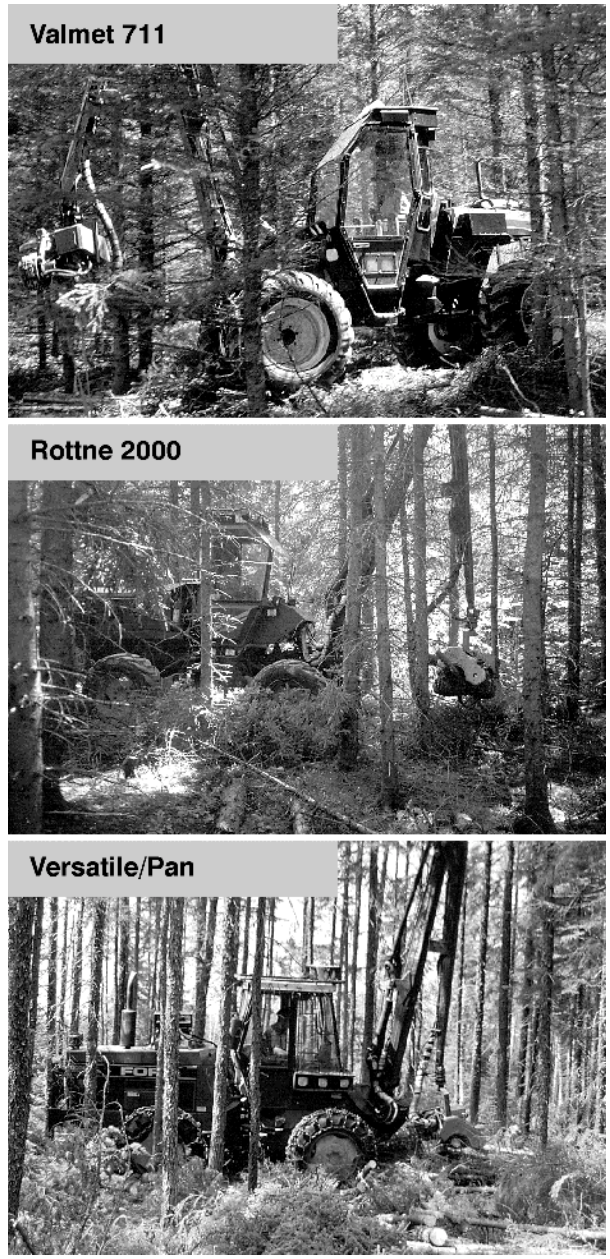

Figure 1. The harvesters that FERIC observed.

Figure 2. The shortwood forwarders that FERIC observed.

Study Methods

Before beginning the thinning work, FERIC performed a pre-treatment stand inventory using temporary sample plots in each block. After each treatment, new sample plots were established to describe the structure of the residual stand. Equipment productivity was determined through detailed short-term time studies and scale measurements of log samples. For part of the studies, the productive time was determined by shift-level measurements using a vibrational data logger.

FERIC's study of various factors compared the equipment's work in pairs of similar blocks of forest. The observations occurred at different times, but the blocks in each paired comparison were treated by the same operator, with the same machine.

The silvicultural prescription applied by J.D. Irving, Limited in the white spruce plantations was intended as a thinning from below that emphasized the removal of lower-quality and suppressed trees and aimed for a uniform basal area of 20 to 22 m^2/ha in the residual stand. Matériaux Blanchet Inc. used a prescription that accounted for provincial regulations on the percentage of basal area to remove, the proportion and density of vigorous stems capable of producing sawlogs, the uniform distribution of residual stems, and maintenance of the original stand composition and structure.

Study Conditions

Table 1 presents the stand characteristics during FERIC's studies. For the studies as a whole, some 20 blocks were used for various comparisons. The coefficients of variation for the parameters presented in Table 1 were all less than 10%, which suggests relative homogeneity between the blocks within each stand type. The natural spruce stands had the most developed structures; the trees were larger, their positions within the canopy were definitely established at the time of treatment, and natural mortality was already becoming apparent. The plantations were relatively young (25 to 30 years old), with vigorous, healthy trees, and the crowns were well developed and formed a regular canopy.

The Abitibi (Que.) spruce stands were on flat terrain, with no obstacles, and had soils with good to moderate firmness when unfrozen (CPPA class 2(3).1.1). The New Brunswick plantations were growing on firm and regular terrain with slopes of less than 10% (CPPA class 2.1.1). The humus layers were less than 10 cm thick. The single-grip harvesters and the forwarders traveled without using traction chains during the summer.

Table 1. Stand characteristics during the study

	Natural stands (Abitibi, Que.)			Plantations (N.B.)		
	Before	After	Difference (%)	Before	After	Difference (%)
Density (stems/ha)	2381	1609	–32	2491	1338	–46
Basal area (m^2/ha)	35.0	23.7	–32	33.7	20.6	–39
Volume (m^3/ha)	185	127	–31	130	82	–37
Average volume (m^3/stem)	0.078	0.079	+1	0.052	0.061	+17
Average diameter (cm)	13.7	13.7	0	13.1	14.0	+7

The treatment in the natural spruce stands differed from that in the plantations. Thinning in the natural stands (Figure 3) focused on making the distribution of residual stems more uniform and on improving their quality. The size of the harvested stems was comparable to that of the residuals, and the prescribed removal intensity was 33% of the basal area. In the plantations (Figure 3), the goal was also to make the stem distribution more uniform, but in addition, it focused on the removal of stems with poor form or small size.

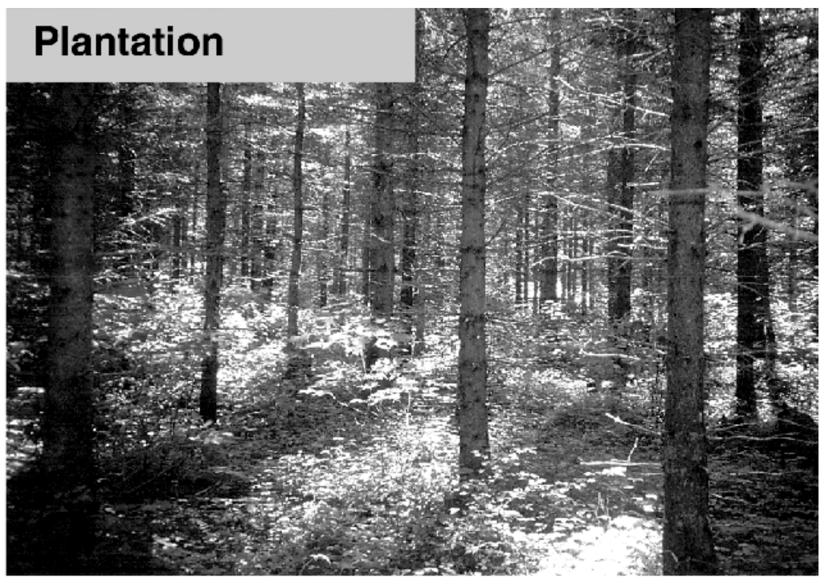

Figure 3.
Appearance of the treated stands.

Results and Discussion

Effect of Precleaning

Precleaning consists of felling unmerchantable stems with a chain saw or brushsaw before performing the thinning. The objective is to increase the productivity of the single-grip harvester by reducing interference from the trees in the stand and by improving visibility. The applicability of this practice was studied by comparing the costs of precleaning with its benefits in terms of subsequent increases in the single-grip harvester's productivity. Two pairs of blocks with comparable densities of unmerchantable stems (1200 to 1400 stems/ha) were monitored in this study: the first in the natural spruce stands and the second in the plantations.

Figure 4 indicates that the felling and processing phase was less expensive in the precleaned block of the natural spruce stand than in the control block. However, the reverse held true in the plantation blocks. It appears that other factors influenced productivity more and thereby obscured any effects of precleaning. In this case, the expense of precleaning was not justified by an offsetting increase in the productivity of the single-grip harvester.

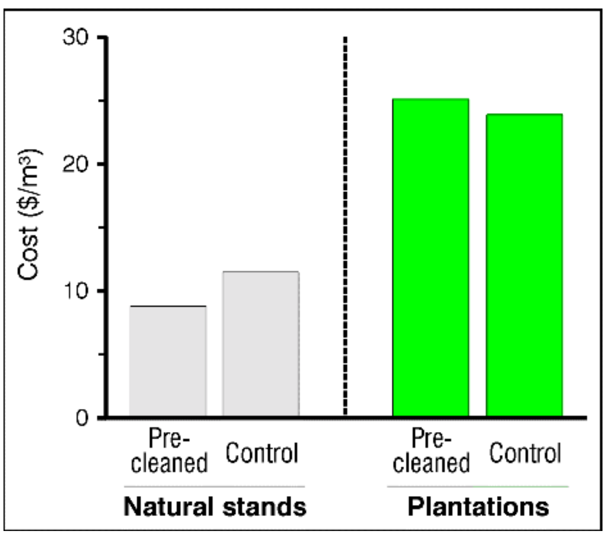

Figure 4. Felling and processing costs (precleaning not included) for the two pairs of blocks.

A detailed analysis of the work cycle showed that the 31% productivity increase that resulted from precleaning in the natural spruce stand can be explained by the reduction in time spent performing mechanized brushing (a 60% decrease). Handling the trees and maneuvering the head were also faster (times decreased by 20%).

Based on the average volume removal for the two blocks in the natural spruce stand and on the difference in the cost of felling and processing (around $2.75/m^3$), the savings attributable to precleaning were around $130/ha. Given an average time requirement of 7.8 hours per hectare for manual precleaning, this savings would permit a pay rate of $16.92 per productive hour for the worker. In many regions of eastern Canada, this would be insufficient to cover the costs of hiring such workers.

On the basis of these results, precleaning is difficult to justify under the study conditions, whether in plantations or in natural forest. A long-term study of harvester breakdowns and delays caused by the presence of unmerchantable stems could perhaps reveal more substantial savings. Where conditions favor precleaning (e.g., low labor costs, high density of unmerchantable stems), it would be opportune to perform this work the year before the thinning operation so the winter snow cover can crush the debris to the ground.

Effect of Trail Spacing

The implementation of a trail network in commercial thinning with mechanized cut-to-length systems depends on two factors: the extraction trails must be sufficiently wide to let the loaded forwarders travel at reasonable speeds, and the spacing between extraction trails must be suitable for the single-grip harvester's boom reach and size. Small single-grip harvesters can also use ghost trails, paths through the stand that are created by the passage of the harvester alone; working from these trails, the harvester places the processed logs near the main extraction trail for extraction by the forwarder. However, there is ongoing debate whether the use of ghost trails decreases the productivity of single-grip harvesters. Figure 5 illustrates different patterns based on the use of the two types of trails.

The pattern with two ghost trails between each pair of extraction trails was widely used on the sites that FERIC studied. The ghost trails must snake around residual trees to provide relatively uniform spacing among the trees of the residual stand. A variation of this pattern was also observed, in which the distance between extraction trails had been reduced to 27 m to permit a more thorough treatment than when the ghost trails were farther apart. To create extraction trails around 3 m wide every 30 m, roughly 10% of the total area must be harvested. To attain an overall removal intensity of 33% (basal area) in the thinned strips, the required level of removal between the trails is 25% with this pattern.

Where the extraction trails are closer together, the proportion of stems harvested within the extraction trails increases, and this reduces the amount that can be removed between these trails. For example, for a total removal of 33% with the extraction trails spaced 18 m apart, the removal intensity between trails must be 20%, versus only 16% if the spacing is 15 m. This makes it more difficult to achieve certain silvicultural objectives such as increasing the quality or average stem diameter of the residual stems.

The study of the effect of different trail patterns used observations of four pairs of comparable blocks. Both of the first two pairs were in natural spruce stands with homogeneous conditions. FERIC compared the use of two ghost trails (extraction trail spacing of 30 m) with that of blocks without ghost trails, in which the spacing between extraction trails was only 15 m (Figure 5). In the other pairs of blocks, which were in plantations, FERIC compared the usual work pattern based on two ghost trails (27 m) with patterns based on no use of ghost trails (extraction-trail spacing of 13.5 m) and based on a single ghost trail (18-m spacing; Figure 5).

Figure 6 compares the productivity of the single-grip harvesters in the pairs of blocks that FERIC studied. For one of the comparisons in the natural spruce stands (extreme left) and one in the plantations (extreme right), the differences were less than 4%; this can be considered insignificant. Where the productivity differences were more dramatic, the results proved to be contradictory. The narrowest spacing improved productivity in one case, and decreased it in another. It appears that other factors had more influence than the trail spacing. This suggests that, based on these results, the spacing between extraction trails and the use of ghost trails have little effect on the productivity of single-grip harvesters, all else being equal.

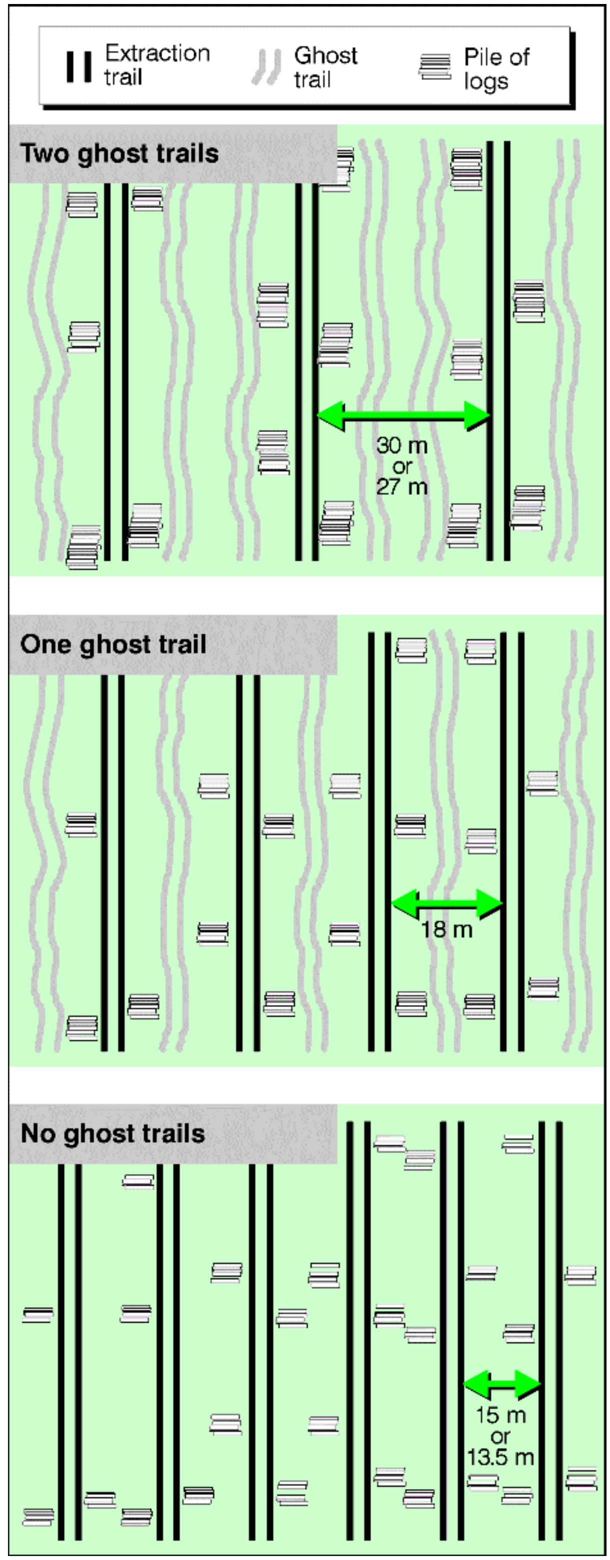

Figure 5. Illustration of the three trail patterns that FERIC observed.

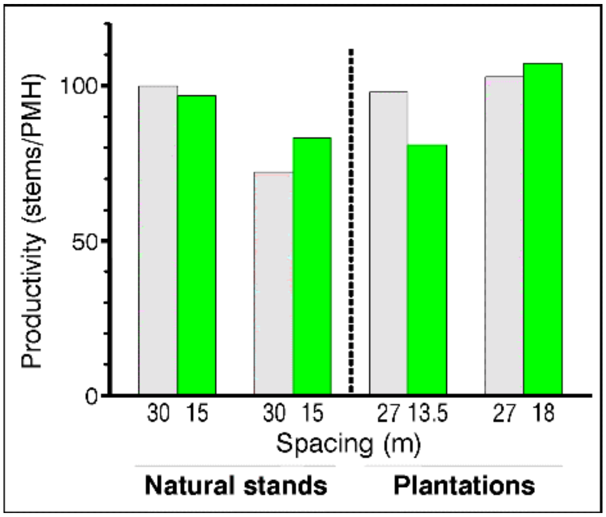

Figure 6. Productivity of the single-grip harvesters as a function of the extraction-trail patterns in four paired blocks.

The setup of the paired blocks with trail spacings of 27 and 18 m in the plantation was designed so that FERIC could replicate the time studies within the blocks. Statistical analysis suggested that the observed differences between the productivities while working from ghost trails and from extraction trails were significant, but the difference was not significant for the treatment of the block as a whole.

Figure 7 illustrates the extraction costs (for an average distance standardized at 150 m) and felling-plus-processing costs for the three treatment pairs for which FERIC observed the extraction phase. In Figure 7, it should be noted that the costs also reflect the average stem volume, and this tends to decrease or increase the magnitude of the differences displayed in Figure 6. The trail patterns with wide spacing reduced extraction costs, since FERIC's analysis revealed that the network with narrow trail spacing provided less opportunity to maximize the forwarder's load. In every case, the average load was smaller, forwarder productivity was lower, and the extraction costs were 20 to 40% higher than with wider trail spacings. It was also apparent that the loading time per m^3 was always longer with narrow trail spacings because the quantity of wood harvested per linear metre of trail was much lower. On average, 0.20 m^3 of wood was available per linear metre of trail at the wider spacings, versus only 0.10 m^3 at the narrower spacings.

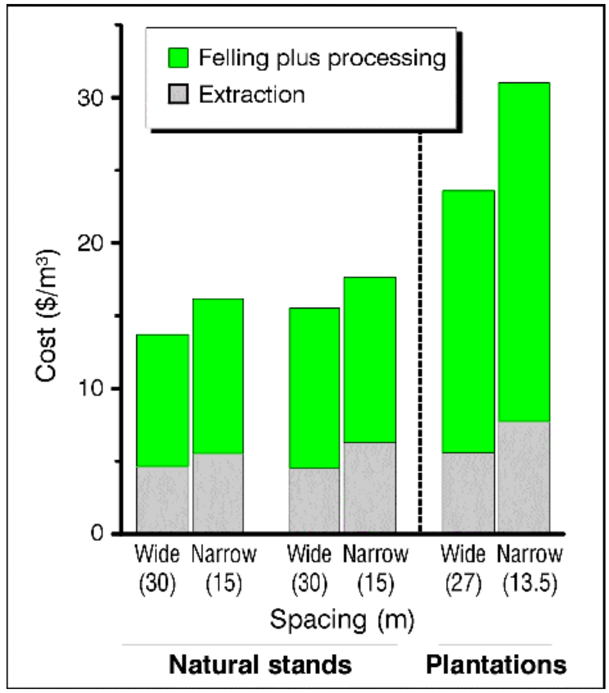

Figure 7. Extraction costs (distance standardized at 150 m) and the felling-plus-processing cost as a function of trail spacing in three pairs of blocks.

The harvesting cost (to roadside) is only one factor that managers must consider in choosing a trail pattern in commercial thinning, because different network patterns offer different possibilities for meeting the prescribed silvicultural objectives. The operator skill required to maneuver along ghost trails is greater, and the operation should be designed to let operators work on ghost trails during the day shifts; the night work should be limited to the main extraction trails, where reduced visibility is less of a problem.

In summary, the wider extraction trail spacings made possible by the use of ghost trails had little impact on the productivity of the single-grip harvesters, but significantly increased forwarder productivity because of the greater volumes available for loading on each trail.

Effect of Removal Intensity

The removal intensity within the stand can influence equipment productivity. In addition, a high removal intensity provides more flexibility in meeting the selection criteria from the same trail network. For example, an overall removal intensity of 25%, with 10% removed in the extraction trails, implies a removal intensity of 17% between the trails. An overall removal of 35% leaves 28% to be removed in the between-trail strips, which results in a 64% greater selective harvest; this permits better control of average diameter and of the proportion of higher-quality trees in the residual stand. With Matériaux Blanchet inc., these two removal levels were studied in two comparisons of paired blocks.

Figure 8 shows that the felling-plus-processing cost and the extraction cost in the natural spruce stands were comparable at these two levels of removal. For the first pair of blocks, the cost difference was only $0.27/m³, versus $1.76/m³ in the other pair. Based on the natural variations in productivity that FERIC has observed, it is likely that these differences are not significant. A detailed analysis of the work cycle did not reveal any differences between treatments.

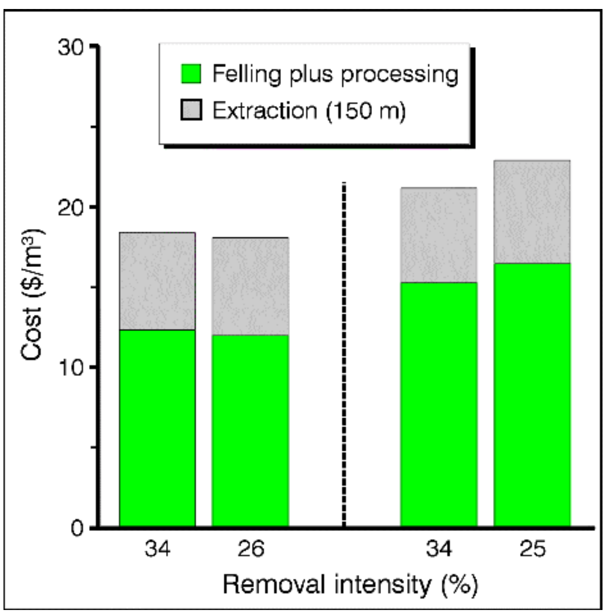

Figure 8. The costs of the two harvesting phases as a function of the removal intensity for two pairs of blocks (natural spruce stands).

Effects of Product Sorting

The production and separation of two products during processing can require additional movements of the processing head and can lead to decreased productivity because of the presence of numerous piles and interference from residual trees. To understand the effect on equipment productivity of various sorting arrangements for the processed products, FERIC studied the treatment of two pairs of comparable blocks on the operations of J.D. Irving, Limited. Sorting involved the processing and separation of 3.2-m sawlogs and 2.54-m pulpwood. In the first pair of blocks, the operator created two products in two piles versus a single product in one pile; in the second pair of blocks, the operator produced two products and placed them in two piles in one block, versus in a single pile in the second block, with separation at the mill.

As shown in Figure 9, there were no significant differences in the total cost of producing or separating one or two products. The felling-plus-processing costs were lower for the methods with two piles, and in one case, extraction costs improved slightly with separation of products. The opportunities for the forwarder to maximize its load differed between the two approaches, but in each case, the extraction was efficient. In summary, product separation under the study conditions did not decrease productivity. However, the quantity of sawlogs produced was clearly smaller when two piles were formed. The operator's tendency to produce sawlogs was greater when fewer maneuvers were required.

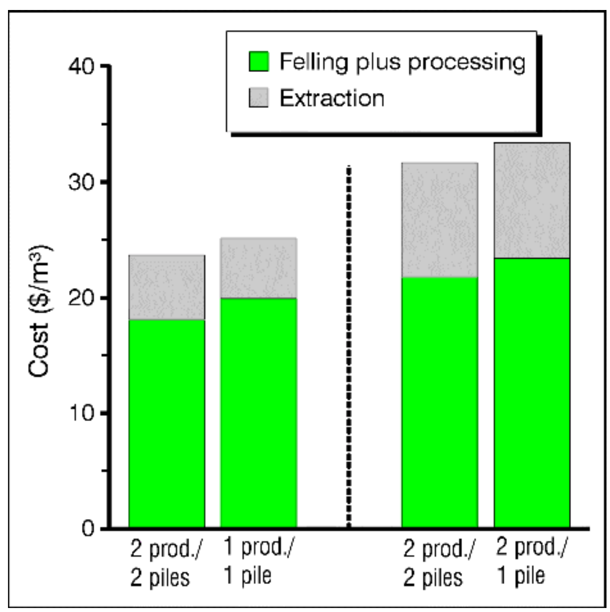

Figure 9. Costs of the two thinning phases as a function of product sorting for two pairs of blocks (plantations).

Conclusions

The studies performed with Matériaux Blanchet Inc. and J.D. Irving, Limited, two leaders in commercial thinning, let FERIC analyze the influence of four factors capable of influencing the cost of the harvesting component of commercial thinning. Under the study conditions, precleaning proved difficult to justify based solely on increased productivity for the single-grip harvester. The productivity of small single-grip harvesters travelling on widely spaced trail networks with ghost trails appeared little different from that on trail networks without ghost trails, but the productivity of shortwood forwarders improved at wider trail spacings. Two levels of removal intensity had little impact on the harvesting costs under the study conditions. Finally, the need to separate an additional product did not significantly affect the productivity of the shortwood forwarder or the single-grip harvester under the study conditions.

Several factors influence the productivity of small single-grip harvesters and shortwood forwarders during a commercial thinning operation. Among those that were not part of the current study, average stem volume is key. The conditions under which the equipment must travel, as well as the need to minimize wounding of the residual stems, are also crucial. The stand structure also has some influence because unmerchantable stems and chicots interfere with the machines, advance regeneration reduces visibility, and an irregular stand requires additional planning and maneuvering. It is thus essential to select the stands to be treated judiciously, with an emphasis on those that have a closed canopy and favorable terrain. The costs of the pretreatment planning can be easily recovered if planners avoid conditions that will reduce equipment productivity.

Recommendations for implementing a fully mechanized, cut-to-length commercial thinning operation:

- The use of small single-grip harvesters in commercial thinning lets operators meet the usual criteria for thinning at an acceptable cost.
- Precleaning, in which unmerchantable stems are felled, is not always justified by a corresponding increase in the productivity of the single-grip harvester.
- The productivity of single-grip harvesters was not influenced by changes in trail spacing or removal intensity, or the need to separate an additional product.
- The shortwood forwarders are more productive in a thinning operation that concentrates larger piles at the sides of the extraction trails.

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Appendix
Assumptions Used for the Calculation of Direct Hourly Costs for the Equipment Studied

	Single-grip harvester			Shortwood forwarder	
	Valmet 711	Versatile/ Pan 728	Rottne 2000	Timberjack 810B	Turboforest 6100
Assumptions					
Machine life (years)	5	5	5	5	5
Scheduled machine hours (SMH)/year	4 000	4 000	4 000	4 000	4 000
Purchase price ($)	360 000	340 000	430 000	340 000	310 000
Resale value ($)	36 000	34 000	43 000	34 000	31 000
Licensing ($/year)	500	500	500	500	500
Insurance ($/year)	14 400	13 600	17 200	13 600	12 400
Interest rate (%)	10	10	10	10	10
Utilization rate (%)	80	80	80	85	85
Lifetime repair costs ($)	396 000	374 000	473 000	340 000	310 000
Fuel consumption (L/PMH)	12	12	12	12	12
Fuel cost ($/L)	0.50	0.50	0.50	0.50	0.50
Oil and lubricants cost ($/PMH)	1.00	1.00	1.00	1.00	1.00
Operator cost ($/SMH)	25.00	25.00	25.00	25.00	25.00
Fixed cost					
Cost ($/PMH)	32.49	30.69	38.78	28.89	26.35
Cost ($/SMH)	25.99	24.56	31.02	24.56	22.40
Variable cost					
Cost ($/PMH)	31.75	30.38	36.56	27.00	25.24
Cost ($/SMH)	25.40	24.30	29.25	22.95	21.45
Labor cost					
Cost ($/PMH)	31.25	31.25	31.25	29.41	29.41
Cost ($/SMH)	25.00	25.00	25.00	25.00	25.00
Total cost					
Cost ($/PMH)	95.49	92.32	106.59	85.30	81.00
Cost ($/SMH)	76.39	73.86	85.27	72.51	68.85