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Contents

Effect of log length and number of products on the productivity of cut-to-length harvesting in the boreal forest

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Abstract

With the increasing number of products that must be separated in the forest, it's becoming increasingly important to carefully evaluate the impact of sorting on the productivity of forestry machines. As well, the assortment of log products is becoming increasingly diverse, with log lengths ranging from 2.5 m (8 ft) to 7.3 m (24 ft). This report summarizes the results obtained thus far by FERIC in terms of the impact of log lengths and of the number of products to separate on the productivity of cut-to-length harvesting machines. We developed a productivity model for single-grip harvesters as a function of mean stem volume (m^3), the number of products to separate, the use of multi-stem processing, and the mean log length, and another model for forwarders as a function of the payload per trip, the travel speed, the number of products to separate, the mean log length, and the extraction trail length. A cost analysis is also presented that demonstrates, among other things, that the production of short logs has a significant negative impact on costs.

Keywords:

Harvest, Cut-to-length, Log length, Sorting, Single-grip harvester, Forwarder.

Introduction

There is an increasing demand for sorting products in the forest, particularly in the current industry context of value-added products and of multiple clients for the resource. It's thus becoming increasingly important to carefully evaluate the impact of sorting (by species, length, quality class, or destination) on the productivity of forestry machines. As well, the assortment of log products is becoming increasingly diverse to meet the needs and constraints of the destination mills, with log lengths ranging from 2.5 m (8 ft) to 7.3 m (24 ft), and including a range of intermediate lengths (3.0, 3.6, 4.3, 5.0, and 5.5 m), as well as random lengths, which are commonly referred to as « random length ».

The cut-to-length system is well adapted to the separation of multiple products and random lengths. This process, which uses a single-grip harvester teamed with a forwarder, has been the subject of many FERIC publications, including Gingras and Godin (1997), Favreau (2001), and Gingras and Favreau (2002). In 2004, other studies conducted in partnership with Tembec Industries Inc. (La Sarre division, Quebec) and Barrette-Chapais ltée (Chapais division, Quebec) were used to enhance our database. The present report summarizes the results obtained thus far in terms of the impact of log length and number of products to separate on the productivity of cut-to-length harvesting machines (i.e., the single-grip harvester and forwarder).

Results

Single-grip harvester

The productivity of single-grip harvesters is often expressed as a function of stem volume. For example, FERIC's *Interface 2003* software uses a production function based on the mean stem volume, adjusted based on correction factors that account for the harvesting conditions. In addition, the production of shorter or longer logs can affect productivity, since the duration of the head's processing cycle changes. In effect, for a given length of stem, there will be more or fewer accelerations, decelerations, and stopping of the feed rollers and more or less bucking with the saw, depending on the target log length. Similarly, the need to create piles of distinct products can decrease the operator's productivity. Several past studies have proposed productivity corrections as a function of the number of products to separate (Brunberg and Arlinger 2001, Gingras and Favreau 2002, Gingras and Godin 1997).

The results of the recent studies performed with Tembec at La Sarre and with Barrette-Chapais at Chapais confirmed the influence of log length and the number of products on the productivity of single-grip harvesters. In Lasarre, complete harvesting strips were cut using different processing patterns that involved various combinations of logs: 2.5 m (pulp), 5.0 m (lumber), 5.5 m (large-diameter lumber), and random length logs (pulp). In Chapais, the processing of 5.0-m logs was compared with the production of 7.3-m logs. The objective of this latter study was to determine whether the production of longer logs would better fit with the mean merchantable length of the stems available in the study area, thereby decreasing fiber losses. For each length, the slashing pattern was completed by producing random length (RL) pulp logs from the top end of the stem.

Analysis of results from Parent (Gingras and Favreau 2002), and those from Tembec at La Sarre and Barrette-Chapais at Chapais, let us re-examine the influence of the following variables on the felling and processing productivity: mean stem volume (m^3), number of products to separate, use (or not) of multi-stem processing (expressed as the mean number of stems per cycle), and the mean length of the processed logs. Seven product assortments were used for this analysis (Table 1).

Statistical analysis confirmed that all the abovementioned variables explained part of the variation in the felling and processing productivity. We developed a productivity equation based on this analysis (Appendix 1). This equation was used to produce Figure 1, which illustrates the effect of the log lengths produced using five bucking patterns on the

Table 1. Processing patterns in the operations studied, in order of mean length

Logs produced	Mean lengths (m)
2.5 m (8 ft)	2.5
2.5 m and 5.5 m (8 and 18 ft)	2.6 – 2.7
2.5 m and 3.6 m (8 and 12 ft)	3.1 – 3.2
2.5 m and 5.0 m (8 and 16 ft)	3.1 – 3.8
5.0 and random lengths (16 ft and RL)	4.8 - 5.0
5.0 and 5.5 m and random lengths (16 and 18 ft and RL)	4.8 – 4.9
7.3 m and random lengths (24 ft and RL)	7.1

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mean productivity of the single-grip harvesters that we studied. All curves in Figure 1 were calculated with the separation of two products, with the exception of the curve labeled "2.5", which was calculated for a single product.

It's clear that the mean productivity increased with increasing length of the processed logs. This suggests that any difficulties encountered while handling or processing the longer logs were more than compensated for by the gains that resulted from decreasing the number of times the feed rollers were stopped to permit slashing of the stem for a given length of stem. For example, the production of 5.0-m and random length logs from stems with a volume of 0.10 m³ per stem increased the single-grip harvester's productivity by around 16% compared with the production of shorter 2.5-m logs; conversely, the single-grip harvester was around 13% less productive than when processing logs to 7.3-m lengths plus random lengths.

Using the same equation, Figure 2 illustrates the effect of the number of products on the single-grip harvester's productivity for the combined production of 5-m logs and random lengths. The productivity illustrated by the four curves increases with increasing mean stem volume, but decreases with an increasing number of products to separate for a given stem volume. This graph also suggests that the difference in productivity between one and four products, on the same cutover, was around 12%, for a decrease of around 4% per additional product. The effect on productivity was also greater when comparing the curves for **1 product** and **2 products** than when comparing the curves for **3 products** and **4 products**.

The productivity adjustments obtained here are greater than the results reported in Sweden (0 to 2% per product), but are comparable to those obtained in past FERIC studies of the separation of two and three products (Gingras and Favreau 2002), which also predicted a productivity decrease of 4% per additional product. In the latter case, the

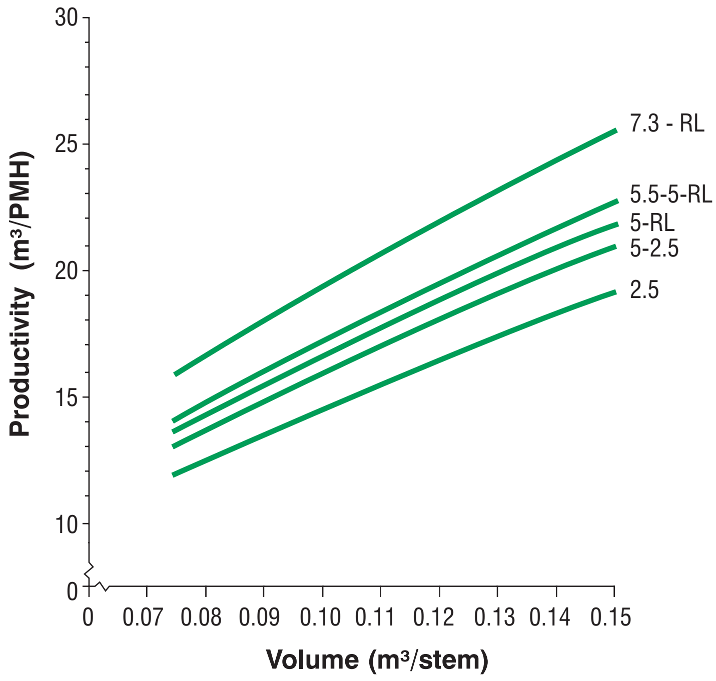


Figure 1. Effect of log length on the productivity of single-grip harvesters.

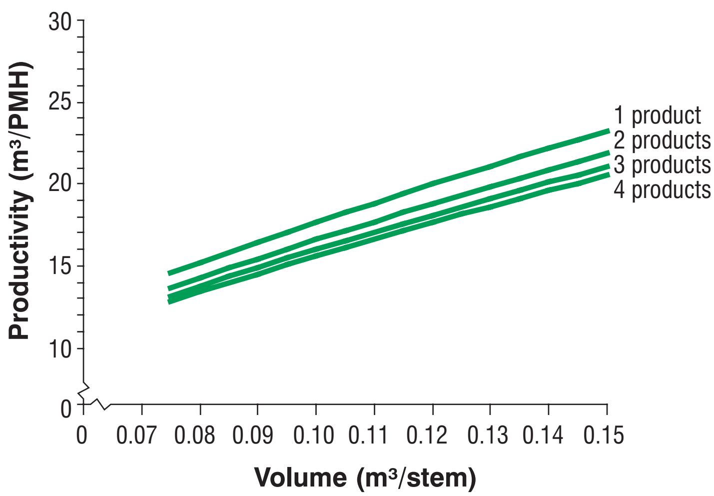


Figure 2. Effect of number of products on felling and processing productivity (production of 5.0-m logs and random lengths).

results were produced in a trial with a single machine and a single operator. Also note that the overall productivity levels observed in the more recent studies were greater than the mean levels obtained in previous studies.

Forwarder

Our study of the forwarder's work cycle let us predict its productivity by accounting for several key operational factors. In this summary, we calculated the forwarder's productivity based on the results of our studies by developing mathematical relationships for loading, travel, and unloading of cut-to-length wood. The following factors were used: the payload per trip, the mean travel speed, the number of products to separate per extraction trail, the mean log length, and the extraction trail length.

The loading time depends on several operational factors, as well as on the characteristics of the forwarder, such as the size of the load bunk and of the grapple. Our summary of different studies revealed that the loading productivity depends primarily on the volume of wood extracted per trip and on the mean length of the logs placed in the load bunk. Our model predicts a loading time of 2.9 minutes per m^3 for 2.5-m logs, 0.77 minutes per m^3 for 5-m logs, and 1.75 minutes per m^3 for 7.3-m logs. In contrast, the model did not reveal an impact of unfavorable terrain conditions on the payload or the loading time. Favreau (2001) also noted that the separation of products by the single-grip harvester reduced the mean pile volume and that in this context, the forwarder operator could no longer consistently use the full loading capacity of the grapple. We would thus expect longer loading times per cubic meter, but the consolidated results did not reveal any influence of the number of products on loading productivity.

The travel time required to totally clear a trail depends on terrain conditions as well as on the number and distribution of products along the trail. Our review of the forwarder studies indicated that travel speeds averaged 51 m/minute and could reach 84 m/minute under very favorable conditions—but could also decrease to 20 m/minute with a loaded forwarder on a slope greater than 30%. An increased number of products also requires the operator to return more often to the back of the block when all the products are uniformly distributed along the trails, even if the operator takes advantage of trips with mixed loads to clear the back of the block first. An increased number of products thus increases the distance that must be traveled by the forwarder to clear a trail of a given length.

Unloading of products by the forwarder is the last step in completing a trip. The unloading time depends on the payload and on the mean log length that must be unloaded. Our model predicts an unloading time of 1.41 min/m^3 for 2.5-m logs, 0.53 min/m^3 for 5.0-m logs, and 0.70 minute per m^3 for 7.3-m logs. The average payload in the studies used to create our model was 10 m^3, but some trips over short distances hauled as little as 1 m^3, versus more than 17 m^3 over long distances. Note that the productivity of the forwarder must be calculated with an average load that is compatible with the dimensions of the load bunk and with the log lengths that will be loaded. The number of products to unload can also increase unloading times when the piles of distinct products are far apart (Favreau 2001). Despite our consolidation of the results of several studies, the number of products did not have a statistically significant impact on the productivity of unloading.

Adding the times for the various phases of the forwarder's work cycle let us develop a model based on our collection of studies and that uses the average payload per trip and average travel speed (Appendix 1). Figure 3 illustrates the influence of the mean log length produced by the single-grip harvester on the productivity of the forwarder to clear a 200-m trail of a single product. The forwarder's productivity increases with increasing log length up until 5 m, then decreases as log length increases beyond 5.5 m. The slower handling of logs longer than

5.5 m increases loading and unloading times sufficiently that productivity decreases despite the larger volume per grapple load. Productivity reductions of 50 and 34%, respectively, are expected when the operator fills the load bunk with 2.5-m and 7.3-m logs rather than with a load of 5-m logs.

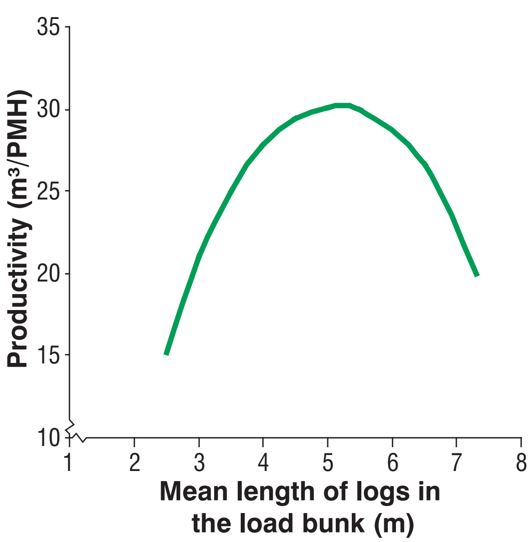
Figure 4 illustrates the impact of two factors on the forwarder's productivity (the number of products and the total length of trail to be cleared) using two curves based on trips with 5-m logs.

The productivity decrease that accompanies increasing extraction trail length is 27% for the first 200 m of trail length (from 100 to 300 m), then decreases by 21, 18, and 15% for each additional 200 m. The productivity of a forwarder working along a trail where there are four products to extract (dashed curve) is always lower than that for a trail with a single product (solid curve); the difference between the two curves increases with increasing length of trail to clear, from 8% for a 200-m trail to 16% for a 800-m trail, for a difference of around 5% per additional product in this case. In this model, the impact of the number of products on the forwarder's productivity is again comparable to that predicted based on the studies of Favreau (2001) and of Gingras and Favreau (2002), where decreases on the order of 4 to 6% per additional product were observed along trails where products were uniformly distributed. Combining the study results suggests that the products are not always evenly distributed along the trail. Other factors, such as unfavorable terrain conditions, also explain the distance traveled to clear a trail. In unfavorable terrain, the operator tends to reduce the distance traveled with a full load, which forces him to return more often to the back of the block.

Relative harvesting costs

Adding the harvesting cost to the forwarding cost lets us compare the direct production cost for delivering cut-to-length logs to roadside in different production scenarios. The cost per m³ is obtained by dividing the hourly cost ($150/PMH for the single-grip harvester and $110/PMH for the forwarder) by the productivity (m³/PMH) estimated using the models developed earlier in this report. Table 2 presents four scenarios with different log lengths and different product separation for stems with a mean volume of 0.10 m³, two species groups to separate, and no multi-stem processing:

- 2.5-m logs
- 5.0-m and 2.5-m logs (60:40 proportion)
- 5.0-m logs and random lengths
- 7.3-m logs and random lengths



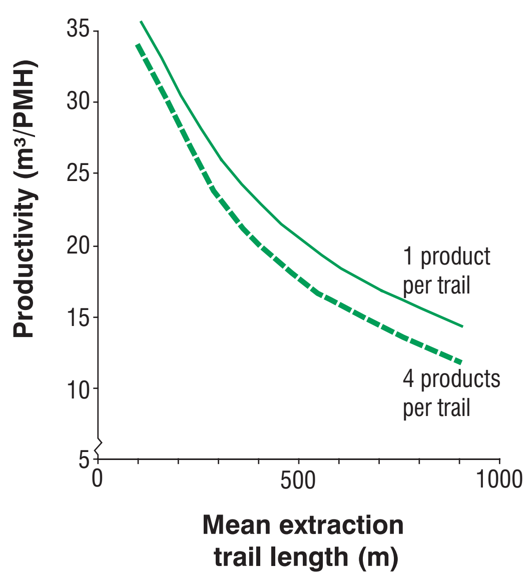


Figure 3. (*left*) Influence of mean log length on the forwarder's productivity (mean extraction distance of 100 m).

Figure 4. (*right*) Effect of number of products and of the extraction distance on the productivity of forwarder (5-m logs).

Table 2. Costs of the cut-to-length system at roadside

Scenario	Number of products	Mean length (m)	Cost ($/m³) Harvesting	Forwarding (300-m trail length)	Total
2.5-m logs	2	2.5	11.05	8.10	19.15
5.0-m and 2.5-m logs	4	4.0	10.00	5.05	15.05
5.0-m logs and RL	4	4.9	9.35	4.75	14.10
7.3-m logs and RL	4	7.1	8.20	6.05	14.25

Clearly, the production of short logs has a very large negative impact on the cost. In addition, the production of 5-m logs and of random lengths is the least expensive of the four scenarios. With very long logs (7.3 m), the gains from improved harvesting productivity are offset by productivity losses during forwarding.

Other parameters

Long logs

Two operations produced logs longer than the typical maximum length of 5.0 m (16 ft): 5.5 m (18 ft) and 7.3 m (24 ft). The results demonstrate that the processing of these logs posed no technical difficulties and even improved the productivity of the single-grip harvester. For the forwarder, however, the difficulty of handling these longer logs, and particularly the 7.3-m logs (Figure 5), increased handling times. These results are reflected in the models developed during this study and have the impact on costs described in Table 2.

Figure 5. A forwarder loading 7.3-m logs.

Other points should also be considered before choosing to produce very long logs: the configuration of the loads on haul trucks, additional slashing of these logs at the mill, and the length-measurement accuracy, among others. We expect that measurement errors will increase when processing longer logs. However, in the La Sarre operation, where 5.5-m logs were processed, 94% of the logs were within the acceptable range of target lengths (547 ± 5 cm), contradicting our assumption. Conversely, the proportion of 7.3-m logs within ±5 cm of the target length in the Barrette-Chapais operation was only 29%, compared with a value of 60% for the 5.0-m logs. In this operation, the contractor paid little attention to the quality of his work and instead tried to maximize his productivity by frequently processing several stems simultaneously, to the detriment of the length-measurement quality.

Bucking window

In the La Sarre operation, a trial was conducted to determine how changing the allowable range of bucking lengths tolerated by the onboard computer (“the bucking window”) affected the single-grip harvester’s productivity. A smaller bucking window can significantly slow processing, since it becomes more difficult to position the saw within the allowed limits. Table 3 summarizes the results of this trial with two slashing patterns and two bucking windows (±5 cm and ±8 cm).

As expected, productivity improved when the bucking window was larger, but the proportion of logs that met the target length decreased. These results demonstrate that it’s necessary to find the optimal bucking window that will provide the best possible productivity without excessively compromising the proportion of logs of acceptable length.

Multi-stem processing

Previous reports have demonstrated the benefits of multi-stem processing, particularly in stands with small-diameter stems and with a head specifically designed for such

Table 3. Effects of the bucking window on the productivity of the single-grip harvester and on the proportion of log lengths that met the target

	5.5-m and 2.5-m logs		5.5-m, 5.0-m and random-length logs	
	Bucking window			
	± 5 cm	± 8 cm	± 5 cm	± 8 cm
Productivity (m³/PMH)[a]	14.2	14.7	15.2	18.0
Productivity difference	+4%		+18%	
Proportion of logs ± 5 cm of the target length (%)	91	88	90	84

[a] Adjusted to 0.095 m³/stem.

operations (Gingras 1999, 2001). The harvesting equation in Appendix 1 predicts that using multi-stem processing, thereby increasing the average number of stems per cycle to 1.5 for example, would increase productivity by 9% compared with cycles that handled only individual stems (i.e., 1.0 stems/cycle). This result is lower than those reported in the two previous reports (20 to 40%), primarily because the studies reported here did not use heads designed to process multiple stems (Figure 6).

Fiber recovery

The bucking pattern can have a significant impact on fiber recovery because the last log processed in a stem must meet the mill's minimum length and diameter criteria. For example, if the minimum acceptable length is 2.5 m for a minimum diameter of 7 cm, it's relatively easy to recover a large proportion of the available fiber. In contrast, if the minimum length is 3.0 m (as is often the case with random lengths that must be placed in the same piles as the 5.0-m logs), it can be more difficult to produce a final log from each stem. An inventory of the fiber left on the cutover after the La Sarre operation confirmed this assumption (Table 4). In the two trails harvested with random-length slashing patterns (trails T2 and T5), the quantities of merchantable fiber left in the forest were clearly greater than in the corridors harvested with 2.5-m logs.

Figure 6. Multi-stem processing with a Logmax 7000 head (not specifically designed to handle multiple stems).

Table 4. Fiber loss as a function of the slashing pattern

	Trails				
	T1	T2	T3	T4	T5
Last log (random lengths = RL)	2.5 m	RL	2.5 m	2.5 m	RL
Total volume left behind (>7 cm diam., > 50 cm long) (m³/ha)	4.2	6.8	6.4	6.6	7.4
Merchantable volume left behind (>9 cm diam., > 1 m long) (m³/ha)	0.0	3.2	0.0	1.6	3.9

Implementation

The results presented in this report suggest the following key findings:

- Processing of longer logs improves the harvesting productivity, even with unusually long logs (7.3 m = 24 ft).
- The maximum forwarder productivity occurs with 5.0-m logs, since shorter or

longer logs increase the mean loading and unloading times.

- The risk of unacceptable length-measurement accuracy can increase with increasing log length, particularly when the head is poorly calibrated or when the operator processes several stems simultaneously.
- Widening the bucking window used by the onboard computer can increase productivity, but at the expense of a decrease in the proportion of the logs that meet the target length specifications.
- Multi-stem processing can increase productivity; but it requires highly skilled operators if the harvester head is not designed specifically for this purpose.
- Producing 2.5-m logs decreases the productivity of the cut-to-length system, but provides the maximum fiber recovery.
- The production of several products on each cutover is expensive (4% per sort with the harvester, 4-6% per sort with the forwarder) and should be carefully analyzed in terms of the finished products that will provide the maximum income during each period of the year. In general, if the operational constraints can be ignored, it's often said that performing product diversification further downstream in the supply chain will increase the revenue opportunities.

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Appendix 1 – Productivity equations

Single-grip harvester

$$\text{Productivity (m}^3\text{/PMH)} = 50.2 \times \text{m}^3\text{/stem}^{0.68} \times \text{no. of products}^{-0.09} \times \text{stems/cycle}^{0.22} \times \text{mean log length}^{0.34}$$

To exclude the effects of multi-stem processing, use a value of 1.0 for the term that represents the number of stems per cycle.

Forwarder

$$\text{Productivity (m}^3\text{/PMH)} = 60 \times (\text{m}^3 \text{ per trip}) / (\text{Loading} + \text{Travel} + \text{Unloading})$$

Where:

$$\text{Loading (minutes)} = (\text{m}^3 \text{ per trip}) / (-0.1163 \times (\text{mean log length, m})^2 + 1.162 \times (\text{mean log length, m}) - 1.683)$$

$$\text{Travel (minutes)} = 1.11 \times (\text{travel speed, m/min})^{-0.935} \times (\text{no. products per trail})^{0.19} \times (\text{trail length})^{1.016}$$

$$\text{Unloading (minutes)} = (\text{m}^3 \text{ per trip}) / (-0.1243 \times (\text{mean log length, m})^2 + 1.3484 \times (\text{mean log length, m}) - 1.8446)$$