Advantage

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Contents

Effects of operational factors on the productivity of shortwood forwarders

Abstract

A shortwood forwarder was studied to obtain a better understanding of the effect of various operational factors on productivity. The study demonstrated, among other things, that the forwarder's productivity was affected by the number of products carried, the length of the logs, the average slope of the terrain, and the size of the log piles to be loaded.

Keywords:

Forwarders, Cut-to-length operations, Operational factors, Productivity.

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Introduction

In the past, FERIC developed productivity curves for shortwood forwarders as a function of extraction distance (Mellgren 1990; Plamondon and Favreau 1994). Corrections were then applied to the productivity values to account for the number of products, the transport of short logs (3.1 m and shorter), and difficult terrain conditions. FERIC's *Interface 2000* software still uses the 1994 results, but today, a growing number of forestry contractors must face the reality of harvesting operations that produce several products for forwarding. FERIC thus decided to re-evaluate the productivity of shortwood forwarders.

Study methods

FERIC studied the productivity of a shortwood forwarder in July 2000 on the operations of Bowater Pulp and Paper Canada Inc. (Boiestown, N.B.). Six products were sorted by a single-grip harvester working in a clearcutting operation. FERIC used a Trimble Pro-XR GPS system while scaling the wood piles to locate the positions of these products along three extraction trails. The area covered by the three trails totaled 1.25 ha, and the six products were uniformly distributed along each 270-m-long trail, as shown in Figure 1. A Fabtek 546B shortwood forwarder was timed while gathering all the wood from

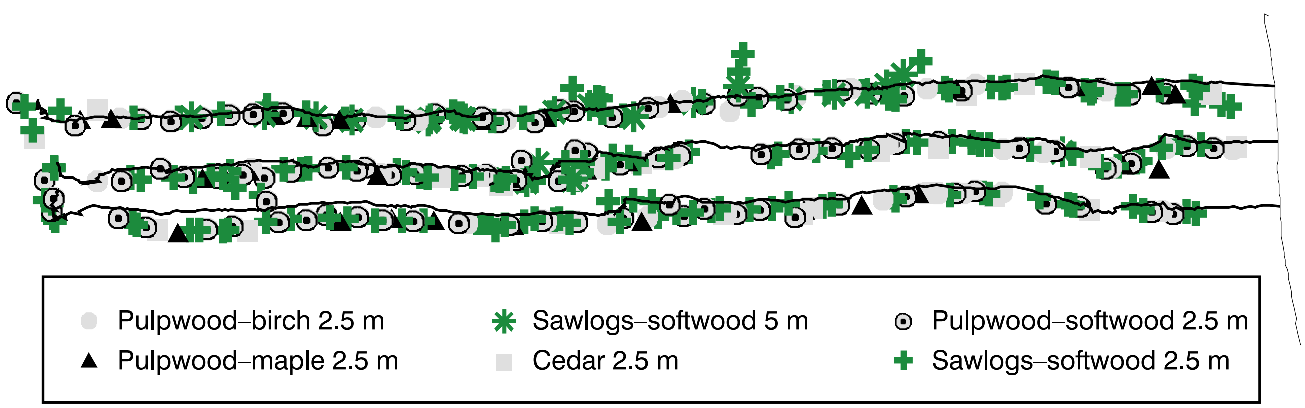

Figure 1. Distribution of the six products on the three trails observed during FERIC's study.

the three trails. The forwarder unloaded the six products in separate piles at roadside, and performed additional sorting of the 5-m logs by diameter at roadside. The terrain conditions were very favorable for the forwarder's work during the study (CPPA class 1.1.1).

Results

Sixteen trips were required to extract 165 m³ of wood from the three trails. Figure 2 presents the number of products extracted per trip and the arrangement of the products in the load bunk. Softwoods represented 91% of the volume extracted. The volume per log averaged 0.12 m³, and ranged from 0.03 m³ for 2.5-m-long softwood pulp logs to 0.27 m³ for 5.0-m-long softwood sawlogs. The forwarder's work sequence and load sizes appear in Figure 3.

Loading

The time required to load the forwarder's bunk depends on several operational factors in addition to the forwarder's characteristics (e.g., bunk dimensions, grapple capacity). FERIC's study estimated the effects of some of these factors on the loading time. The time required depended primarily on the volume of wood extracted per trip. The work sequence chosen by the operator during the study and the number of products to extract created large variations in the load extracted per trip, as shown in Figure 3.

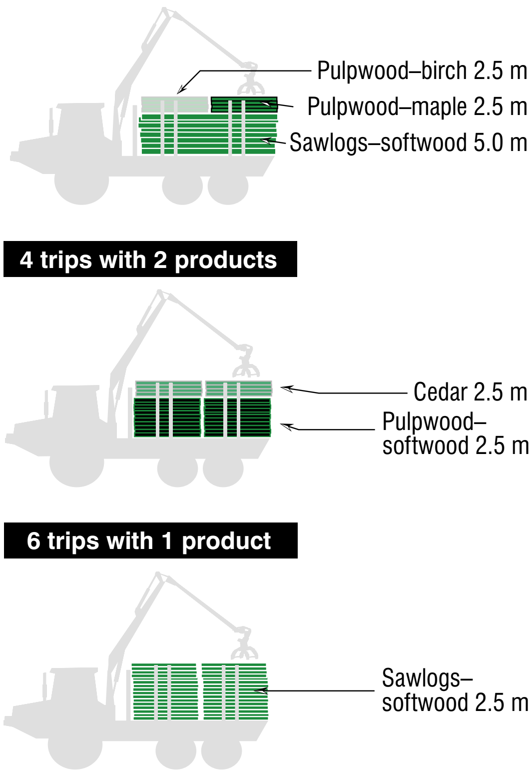

Figure 2. Number of products extracted per trip.

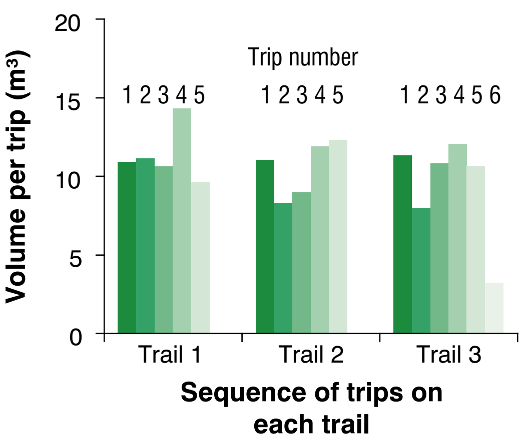

Figure 3. Variations in the volume extracted per trip and per trail.

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Product separation during felling and processing inevitably reduces the average volume per pile. When the forwarder operator must load from such small piles of wood, it becomes impossible to consistently take advantage of the grapple's full capacity, and this increases the number of grapple loads required to fill the bunk. Based on the results from our study, Figure 4 presents the times required to load 1 m^3 of wood as a function of the volume per pile for 2.5-m and 5-m logs. The figure indicates that the loading time was around 2 min/m^3 with 2.5-m logs and piles as small as 0.2 m^3. However, loading time decreased with the 5-m logs. Once the grapple's maximum capacity is reached (around 0.2 m^3), loading times decrease as the number of grapple loads required to completely load the bunk decreases. The favorable terrain conditions during the study did not permit an estimation of the effect of unfavorable conditions (e.g., soft soils, ground roughness, slope) on the size of the load and on loading times. The study also did not let us determine whether the mean log diameter affected loading productivity.

Travel

The second aspect of the forwarder's work cycle consists of travel. The travel time required per trip depends on the trail length and on terrain conditions, among other factors. The study also identified that increasing the number of products increased the distance the forwarder had to travel to load all the wood from a given length of trail. Figure 5 presents the distances traveled on the first trail for the six log types produced in the study, and compares these distances with a situation in which the forwarder would only be required to extract a single product. With six products, the operator was required to return to the back end of the block during the first three trips. The distance traveled was around 2300 m to extract all six products from the trail, which represented an additional 675 m of travel compared with the distance when only a single product was forwarded.

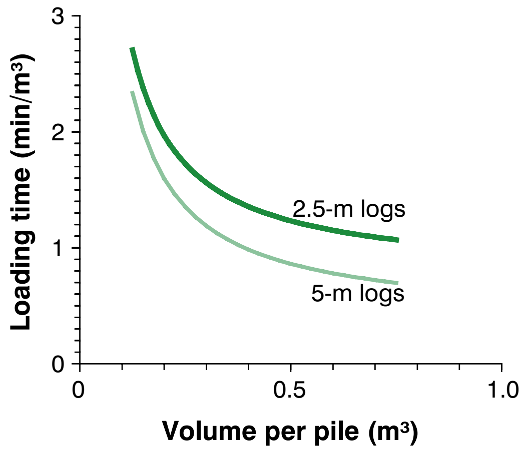


Figure 4. Time required to load 1 m^3 of 5-m and 2.5-m logs as a function of pile volume.

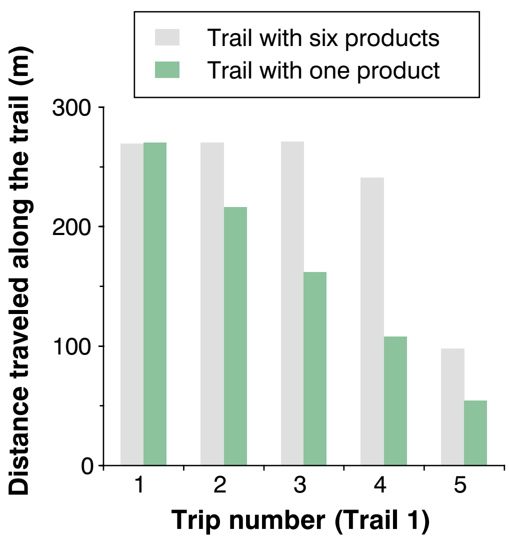


Figure 5. Trail length (one direction) traveled per trip (data for Trail 1).

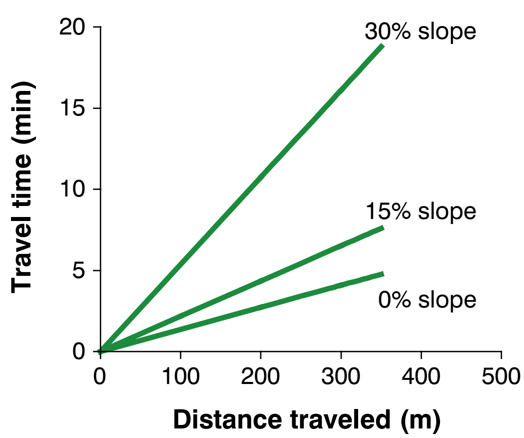
The three trails in FERIC's study favored rapid travel by the forwarder. FERIC thus decided to observe the forwarder in another cut block with steep slopes [CPPA class 1.1.4(3)] in an effort to determine the effect of slope on the forwarder's travel speed. Figure 6 presents the travel time required for various distances on flat terrain and on terrain with average slopes of 15% and 30%. The results indicate that travel speed decreased with increasing slope and that the forwarder was affected in the same manner whether it was climbing or descending a slope. The forwarder did not haul less wood in its bunk while working on a slope, and the study revealed no difference in travel speed for the forwarder working loaded or unloaded on a slope. Figure 6 indicates that travel speed remained constant at 73.5 m/min on flat terrain, but decreased to 18.6 m/min on a 30% slope. In addition, the travel speed was no higher on the haul road than on flat extraction trails. However, the presence of soft soils or rough terrain would probably decrease the forwarder's travel speed in the forest.

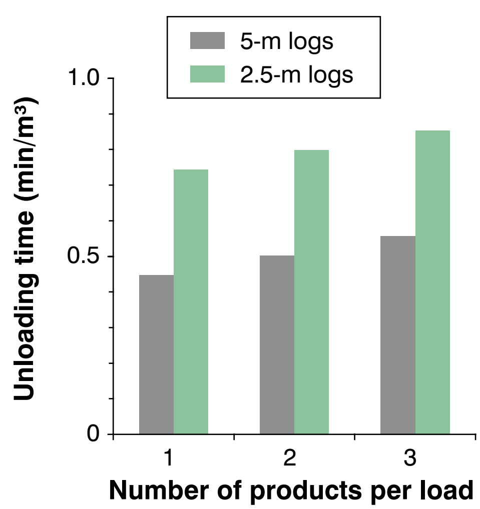
Unloading

Unloading of products by the forwarder to complete a trip represents the final stage of the work cycle. During the study, FERIC was able to estimate the unloading time as a function of the number of products in the forwarder's bunk and of log length. Figure 7 shows the time needed to unload the forwarder, excluding travel between the piles, when the forwarder had to unload more than one product. Unloading 5-m logs was faster than unloading 2.5-m logs. For example, the time required to unload 1 m^3 of 5-m logs with a single product in the bunk was around 0.45 min, compared with more than 0.74 min for 2.5-m logs. The time to unload 5-m logs would have been even shorter if the operator had not been required to perform an additional size separation of the 5-m logs during unloading. Increasing the number of products also increased the unloading time. A load (11 m^3) of three 5-m products took around 1.2 min longer to unload than was the case with only a single product. In addition to the travel between the

Figure 6. (*left*) Travel time as a function of the distance traveled and the slope.

Figure 7. (*right*) Unloading time per m^3 of 2.5-m and 5-m logs as a function of the number of products.





piles that is required when unloading multiple products, it is more difficult for the forwarder to use the grapple's full load capacity when unloading those areas of the bunk where two products touch within mixed loads.

Productivity of the shortwood forwarder

Our study of the phases of the work cycle lets us predict the forwarder's average productivity as a function of several operational factors such as the load per trip, the size of the piles, the number of products per trip, the distance traveled (along the trail, on the haul road, or both), the travel speed, the average slope of the terrain, and log length. The forwarder's productivity was calculated by combining the information reported in the previous sections (see the sidebar entitled "Calculation of forwarder productivity").

For the 2.5-m logs, Figure 8 presents two productivity curves for travel on flat

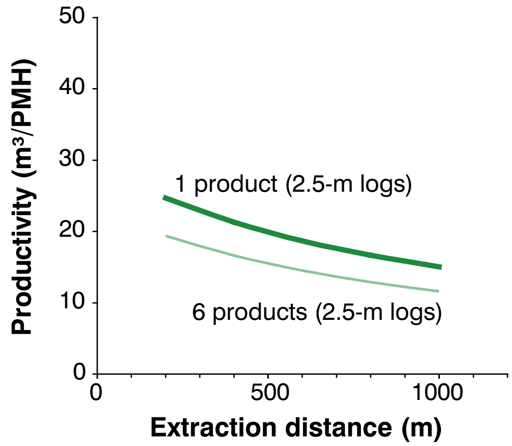


Figure 8. Impact of the number of products and extraction distance (flat terrain) on the forwarder's productivity.

Calculation of forwarder productivity

Work phase	Equation
Loading (min)	$T_l = 1.855L/S + 0.245L/V_p$
Travel (min)	$T_r = D/(S_t - 1.830G_a)$
Unloading (min)	$T_u = 3.233 + 0.599N_p - 3.255S_{16} + 0.395L$
Forwarder's productivity (m^3/PMH)	$P = 60L/(T_l + T_r + T_u)$

Where:

T_l = loading time (min), L = load per trip (m^3), S = log length (m), V_p = average pile volume (m^3)

T_r = total travel time for a return trip (min), D = total distance for a return trip (m), S_t = forwarder's travel speed on flat terrain (m/min), G_a = average slope (uphill or downhill, in %)

T_u = unloading time (min), N_p = number of products to unload, S_{16} = 0 for short logs (≤ 3.1 m) and 1 for the longer logs (5 m), L = load per trip (m^3)

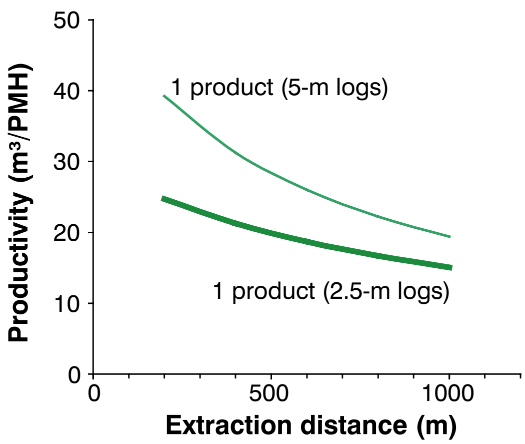
P = productivity of the forwarder (m^3/PMH), L = load per trip (m^3) (log length can limit the load), T_l = loading time (min), T_r = travel time in the forest and on the bush road (return trip, in min), T_u = unloading time (min)

Note: The estimated forwarder productivity includes 5% operational delays in the productive time obtained during the study.

terrain as a function of trail length and the number of products: the upper curve illustrates the forwarder's productivity on a trail with a single product, whereas the lower curve shows the productivity with six products to be extracted. The forwarder's productivity decreases by around 20% when it extracts six products rather than one.

Figure 9 presents two productivity curves on flat terrain as a function of trail length and log length: the upper curve illustrates the forwarder's productivity with 5-m logs and the lower curve shows the productivity with 2.5-m logs. The forwarder is more productive with 5-m logs than with 2.5-m logs because the loading and unloading times are shorter. The productivity difference in favor of the 5-m logs (which reaches 60% at a distance of 200 m) tends to decrease with increasing trail length.

Figure 9. Impact of log length and extraction distance (flat terrain) on the forwarder's productivity.



Potential of GPS in cut-to-length harvesting

The Bowater study also had the objective of evaluating the potential use of a GPS system in cut-to-length harvesting. In this approach, the single-grip harvester would be equipped with a GPS unit linked to the harvester head's measuring system. A map of the felling trails and wood piles by product, volume, and species would then be provided to the forwarder operator, who could use this information to better plan the machine's travel and the loading sequences in a new cut block. The forwarder, also equipped with a GPS system, could record the progress of the work completed and the positions of the piles of each product at roadside. Such a system would have several potential advantages:

- It would provide wood inventories for each phase of the work. Among other things, the map of volumes per product at roadside would help to improve the logistics of the haul operation. Knowledge of the in-woods inventories is particularly important in a "just in time" supply system.
- Georeferencing the piled wood with a GPS position would help the forwarder operator locate isolated or difficult-to-find piles under bad terrain conditions or when visibility is reduced (e.g., at night, under snow, on soft ground, in rough terrain).
- The map of pile locations would help the operator to plan the work sequence in cut blocks that produce several products.

- It would optimize the forwarder's work by recording travel speeds and by knowing the spatial distribution of products and volumes. A simulation of a theoretical optimized extraction from one of the trails in the study showed that it would have been possible to increase productivity by 5%. The potential optimization is even greater over long forwarding distances or when several trails provide access to wood piles. In addition, the optimization could help identify the best positions for wood piles at the landing as a function of the trail network and the volume of each product. For example, optimization of the extraction sequence for products along a 1000-m trail could increase forwarding productivity by around 12% by helping to maximize the payload and minimize the travel required to obtain this maximum load. In addition to decreasing the forwarder's production cost, the optimization would also reduce fuel consumption and thus the amount of pollution generated by the operation.

Ongoing research is attempting to find effective optimization models (Carlsson and al. 1998). FERIC will continue to evaluate solutions relevant to the Canadian context, including software for simulating road layout. Other research will be required to develop an operational system for measuring and positioning log piles. Among other things, we must test the relative pertinence and feasibility of producing a map on which all the piles are located versus a map that illustrates the volumes and products for each trail section.

Implementation

The Bowater study permits predictions of the productivity of shortwood forwarders as a function of various operational factors. To minimize the productivity losses observed during the study:

- Choose the locations where product separation occurs judiciously, since this separation creates productivity losses that vary with the machines used and the number of products separated. The transport of six products that had been sorted beforehand by the single-grip harvester caused a 20% productivity decrease for the forwarder. The travel distance increased by more than 40% because the forwarder had to carry six products rather than just one. Loading and unloading times also increased.
- Where possible, produce longer logs, such as the 5-m logs in the present study, to improve productivity. Loading and unloading 2.5-m logs rather than 5-m logs would reduce productivity by around 37% on a 200-m trail and by 23% on a 1000-m trail.
- Lengthen extraction trails rather than forcing the forwarder to travel on steep slopes. A forwarder working on a slope travels considerably more slowly than on flat terrain; on a 30% slope, for example, the productivity decrease was 41% over a 200-m distance and reached 63% over a 1000-m distance.
- Choose the position of the wood piles at roadside carefully so as to minimize the travel time between piles, particularly when there are several products.
- Avoid extracting an overly small average payload so as not to reduce the forwarder's productivity. Several factors can

decrease payload, especially the terrain conditions, the compatibility of the mix of product lengths with the dimensions of the forwarder's bunk, and the work sequence chosen by the operator. When the average load decreases from 11 m^3 to 9 m^3 per trip, productivity per PMH decreases by from 7 to 13% over extraction distances of 200 and 1000 m, respectively. It is thus very important to plan the loading sequences for multiple products carefully in an effort to maximize payloads.

The work sequence selected by the operator was not optimal, and calculations showed that it would have been possible to improve forwarding productivity by around 5% for an average trail length of 270 m. Optimization of the work sequence with several products to be extracted could prove particularly beneficial over long extraction distances. For example, with a forwarder that costs $110/PMH to operate and six products to extract over a distance of 1000 m, the savings could be more than $1.20/$m^3$.

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