The Effect of Single Grip Harvester's Log Bunching on Forwarder Efficiency

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Väätäinen, K., Ala-Fossi, A., Nuutinen, Y. and Röser, D. 2006. The Effect of Single Grip Harvester's Log Bunching on Forwarder Efficiency. *Baltic Forestry*, 12 (1): 64–69.

Abstract

In the CTL-harvesting method stems are bucked and cut into several timber assortments at the harvesting site by a single grip harvester. During cutting, the harvester operator can directly affect the efficiency of forwarding. Harvester and forwarder have different productivities and variations in stem size have a larger effect on the harvester than on the forwarder.

In this study one professional forwarder operator loaded logs, which were cut and bunched by six different harvester operators in the same thinning stand. The piles were measured and estimated according to size, location and accessibility *etc.* The loading stage of forwarding was measured using a manual time study.

The study revealed that the method of bunching timber assortments during cutting varied a lot among different harvester operators. The largest differences among the harvester operator's bunching results caused about 30 % difference in loading time of piles per cubic metre. The studied calculation models from the literature revealed that 40 % time savings per cubic metre in loading phase results in 20 % time savings for the whole forwarding cycle, when the forwarding distance is 300 metres. Harvesting should be understood as a processing chain in which the first step (cutting) affects the latter step (forwarding). By optimising the size of the pile the harvester operator can improve the productivity of the harvester-forwarder chain. Furthermore, the harvester operators' planning of the thinning track network in the stand can have a significant effect on the forwarding productivity, particularly in challenging terrains.

Key words: Forwarder, CTL harvesting, bunching, log pile, loading timber, productivity

Introduction

The shortwood or cut-to-length (CTL) method is the dominating harvesting method in Nordic countries. It has also become more prevalent in loggings of wood plantations and especially in thinning operations around the world. Purpose build forwarders or farm tractors with grapple-loading trailers are usually used for the forwarding of the cut shortwood.

In the CTL method the harvested trees are cross cut into different timber (or shortwood) assortments, which are then transported to different mills and utilization places for further processing. During the cutting operations the different timber assortments are processed and assorted into separate piles in the stand. As a consequence the forwarding of timber from the stand to the roadside storage will be more efficient. The forwarded shortwood is unloaded into piles of a certain assortment at the roadside storage.

In order to optimise the harvesting chain operation, the harvester work has a great effect on the forwarding and consequently on the total harvesting chain efficiency. The overall work output of a single grip harvester differs greatly depending on the harvester operator. Differences can be seen not only in productivity, but also in silvicultural, bucking and bunching results (Tynkkynen 1997, Sirén 1998, Väätäinen 1999, Ryynänen and Rönkkö 2001, Kariniemi 2003, Ala-Fossi *et al.* 2004). Timber assortment pile characteristics such as volume, distance from strip road, shape *etc.* affect the productivity of forwarding especially in the loading work phase (Kuitto *et al.* 1994, Gullberg 1997b, Väätäinen *et al.* 2005). Additionally, the loading method (multiple or single pile loading), loading conditions (remaining trees, removal per hectare, seasons *etc.*), loaded timber assortment, cutting methods and operator-machine system characteristics (grapple area, net lifting force *etc.*) affect the loading productivity (Kuitto *et al.* 1994, Gullberg 1997b).

It has been understood, in harvesting, that changing the method of bunching in different harvesting stands creates the possibility to improve the work efficiency of the harvester-forwarder chain. The aim of the study was to investigate the effect of harvester operators on the productivity of forwarder loading in terms of bunching quality and pile characteristics. The objectives of the study were divided into the following steps:

A. What characteristics of the timber assortment piles affect time consumption and productivity of loading in forwarding and,

B. How variations in the timber assortment pile characteristics affect time consumption and productivity of forwarding as a whole.

Materials and methods

Pile characteristics were measured of a total of 690 timber assortment piles (82.5 m³) cut by six different experienced harvester operators at mid winter in Eastern Finland. After the pile measurements one experienced forwarder operator loaded and forwarded the timber to the roadside storage. The time study was carried out for the loading phase of forwarding.

The six experienced harvester operators were the same than in the ProForSim-field study (Väätäinen *et al.* 2005) and carried out the cuttings with the same single-grip harvester, Timberjack 1070 C, to which harvester operators were familiarised with. In a Scots pine dominated first thinning stand each harvester operator cut two study plots. The sizes of each study plot were determined by the harvester work of one effective hour. Study plots were established in places where stand characteristics were as similar as possible among operators. In Table 1 some stand and log pile characteristics are presented.

Table 1. Stand and pile characteristics for harvester operators' study plots in the loading study

Harvester operator	Study plot	Initial basal area, m²/ha	Basal area of removal, m²/ha	%	m³/100m	Number of piles/100 m	Average pile volume, m³	Removal per loading point, m³
A	1	21.9	5.1	23.1	7.8	86	0.090	0.247
	2	22.6	6.9	30.8	5.6	57	0.098	0.257
Average		22.2	6.0	26.9	6.7	72	0.094	0.252
B	1	19.4	6.6	33.9	10.1	81	0.125	0.413
	2	25.8	10.0	38.9	6.1	63	0.096	0.257
Average		22.6	8.3	36.4	8.1	72	0.110	0.327
C	1	19.7	9.4	47.9	8.8	65	0.136	0.357
	2	22.2	8.7	39.1	10.3	74	0.139	0.485
Average		20.9	9.0	43.5	9.6	70	0.137	0.411
D	1	20.3	6.0	29.7	6.4	53	0.121	0.255
	2	23.8	6.5	27.2	7.4	51	0.144	0.344
Average		22.1	6.3	28.5	6.9	52	0.132	0.295
E	1	20.4	6.2	30.4	8.1	76	0.106	0.354
	2	26.1	8.2	31.6	6.8	54	0.126	0.281
Average		23.3	7.2	31.0	7.5	65	0.115	0.315
F	1	17.6	6.5	37.3	10.1	56	0.181	0.572
	2	22.8	8.9	38.9	6.7	56	0.119	0.287
Average		20.2	7.7	38.1	8.4	56	0.149	0.405
All in average		21.9	7.4	34.06	7.85	64	0.123	0.320

The studied forwarder operator had 11 years experience working with forwarders. The forwarder (Timberjack 1010B) in the study had the same boom system and control levers, than the operator is used to in his daily work.

After the study plot had been cut, certain timber assortment pile characteristics were measured (Figure 1). The measured characteristics were the angle of the pile in regard to the thinning track line, the distance of the pile to the thinning track and to the nearest pile, number of logs in the pile, mean diameter of logs, log assortment of pile, loading difficulty (subjective observation), shape of pile and some other variables like: are the piles on top of logging residues or are the logs of the pile inside an area determined by the longest log. Piles were numbered with A5 size paper attached to 1-metre poles.

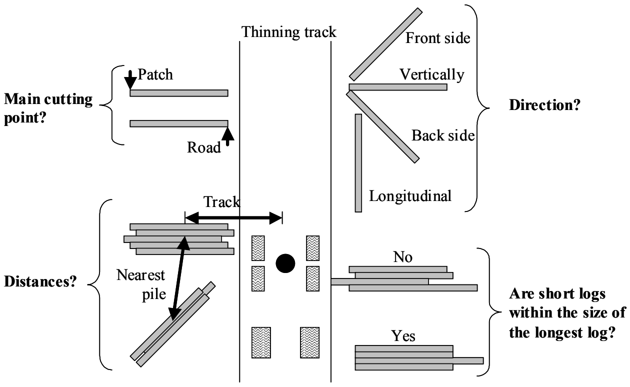

Figure 1. Some measured pile characteristics

The time study of pile loading was carried out manually by the continuous time method using a hand held computer (Rufco 900). The loading sequence of the piles was also recorded using the field computer in order to be able to link the time study material of loading and the pile characteristics. The loading work stage was divided into smaller elements, which below are defined in more detail:

Reaching pile:

starts when grapple of the boom starts to move towards the pile from the load space and ends when grapple touches next removable pile.

Lifting grapple load:

starts when the grapple with the load starts to move from the place of the last collected pile towards the load space and ends when the grapple is opened and the load is released.

Arrangement of piles:

when the grapple is used to correct the alignment of logs or when two or more piles are compiled as one grapple load.

Arrangement of load:

when the grapple is used to correct the alignment of the logs in the load space of the forwarder

Delay:

Non-productive time, not included in the analysis.

One forwarded load (average load volume 6.9 m³) was studied for each harvester operator's study plot. Forwarding was implemented using a dominating field method. All timber assortments - with a maximum of five different assortments - were loaded at the same forwarding cycle. The loading study was carried out after the cutting in artificial light during night time. Weather and lightening conditions were similar for the duration of the study.

The recorded time study data and measured data of pile characteristics were combined as a data-matrix. The SPSS-statistical application was used to conduct a regression analysis to estimate the loading productivity. Also, a calculation example for time consumption per forwarded cubic metre of all main work stages of forwarding was formulated. Previous theoretical and empirical models (Kuitto *et al.* 1994, Gullberg 1997a) were used to illustrate the effect of some forwarding factors on productivity.

Results

To some extent, logging accumulation per 100 metre along the thinning track had a positive effect on the size of an average log pile (Figure 1). Harvester operators have individual working habits and styles in bunching, which resulted in the fact that the piles were smaller or bigger than the average (Väätäinen *et al.* 2005). For example operator D and F generally made bigger piles than what was expected from the values of loading accumulation. Also, the size of the log pile had a straight effect on the size of a grapple load.

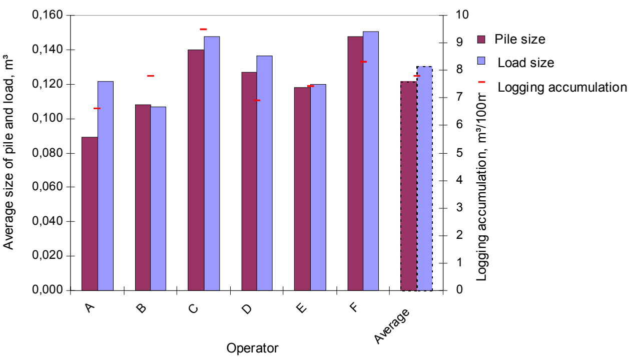

Figure 2. Relation between logging accumulation and the size of log pile and grapple load

When comparing the loading time per cubic metre, the maximum difference between loading times of the piles made by different operators was 40 seconds (Figure 3). The most time-consuming work phase in loading was lifting the load (53 % of loading time). Due to smaller pile volumes, the reaching pile -work element for example took about 10 seconds longer with piles of operators A, B and E compared to the piles of the others. Additionally, the forwarder operator had to arrange together smaller piles of operator A in order to make bigger grapple loads and also to arrange some uneven piles of operator C to better control the loading of the load space. These can be noticed as longer time consumptions in the arrangement times of piles and load in Figure 3.

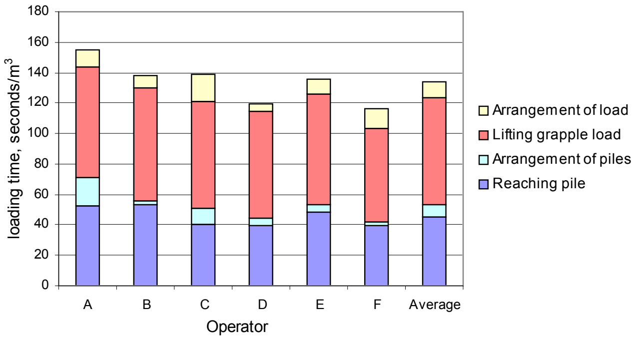

Figure 3. Loading time consumptions of the piles made by six harvester operators

Loading productivity values for each loading observation approved for analyses are presented in Figure 4. The loading method is distributed as follows; one pile in the grapple, two or more piles in the same grapple and two or more grapples from the same pile. An interesting result was, that the productivity was surprisingly low in some cases when loading bigger piles (size 0.4 – 0.6 m³). In these cases of two or more grapple loads from the same pile the first grapple load was usually close to maximum but the rest of the pile filled only a small part of the grapple capacity.

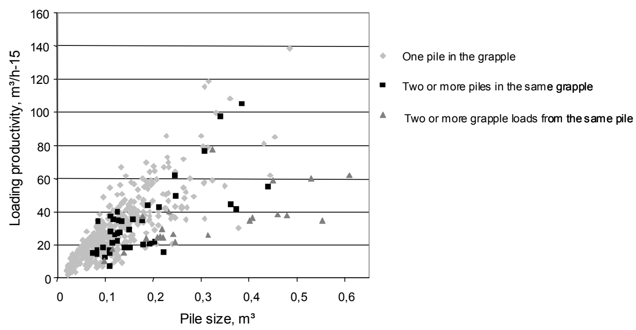

Figure 4. Loading productivity as a function of pile size and loading method

A linear regression analysis of the loading productivity was formulated from the data matrix. Variable conversions to both predictable variable and pile size -variable with natural logarithm changed the distribution of residuals close to the normal distribution. In the analysis nearly 75 % of the variation in the natural logarithm of the loading productivity was explained by the natural logarithm of the pile volume –variable in model one (Table 2). The other predicting variables and the strength of their relationship to the predictable variable are also presented in Table 2.

Table 2. Stepwise regression model summary to predict the productivity of loading. Adjusted R¸ shows the strength of the relationship between different models and the predictable variable

Model	Added independent variable to model	? Adjusted R^2	Adjusted R^2
1	Natural logarithm (LN) of pile size	0.748	0.748
2	Number of grapple loads from one pile	0.02	0.768
3	Loading difficulty	0.008	0.776
4	Timber assortment of pile	0.004	0.780
5	Number of piles in a grapple load	0.001	0.781

Model variables:
Model 1: Constant, LN(pile size)
Model 2: Constant, LN(pile size), Number of grapple loads from one pile
Model 3: Constant, LN(pile size), Number of grapple loads from one pile, Loading difficulty
Model 4: Constant, LN(pile size), Number of grapple loads from one pile, Loading difficulty, Timber assortment of pile
Model 5: Constant, LN(pile size), Number of grapple loads from one pile, Loading difficulty, Timber assortment of pile, Number of piles in a grapple load
Predictable variable: Natural logarithm (LN) of loading productivity

The formula of loading productivity model predicted only by pile size was the following:

$$LN(y) = 5.189 + 0.896*LN(x)$$

where,
y = Loading productivity, m^3/h_0
x = pile size, m^3

The curve of the inversed productivity model (inversed to min/m³) closely follows the curve of the loading time model made by Gullberg (1997a) (Figure 5). Base factors for the Gullberg model were installed similarly as it was in our study (Väätäinen and Ala-Fossi 2004). In the scale of pile size from 0.04 m³ to 0.2 m³, representing 72 % of all piles, the maximum difference between models was about 20 %.

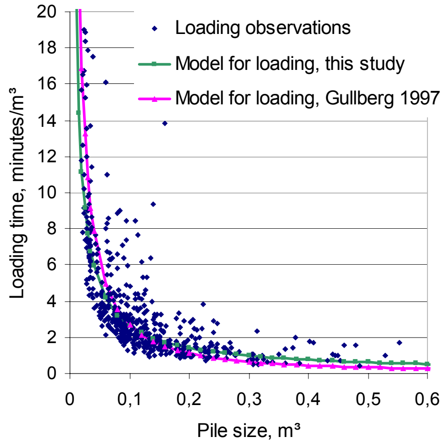

Figure 5. Curves of inversed loading productivity model of this study and Gullberg's (1997a) loading model

The following calculation of forwarding time consumption in cubic metres is based on the models made by Kuitto *et al.* (1994) and Gullberg (1997a). In the calculation, the base assumption was, that all timber assortments were loaded during the same forwarding cycle. This paper's loading study revealed close to 50 % differences in average values of log assortment pile sizes and loading accumulations by the six harvester operators. As a result of the increased pile size, also the average size of the loading points increased. The maximum differences of those operator values were taken as a comparable pair of values in the calculations. (0.1 m³ pile size - 0.25 m³ size of loading point and 0.25 m³ pile size - 0.375 m³ size of loading point) (Table 3).

Table 3. Effect of pile size, size of loading point and forwarding distance in forwarding (minutes/m³). In the calculation forwarding models of Kuitto *et al.* (1994) and Gullberg (1997a) for mid-size forwarders are used

	Time consumption for cubic metres (min/m³) and proportions (%)											
Forwarding distance, m	150				300				600			
Pile size, m³	0.1		0.15		0.1		0.15		0.1		0.15	
Loading accumulation at loading location, m³	0.25		0.375		0.25		0.375		0.25		0.375	
Work phase	min/m³	%	min/m³	%	min/m³	%	min/m³	%	min/m³	%	min/m³	%
Loading (Gullberg) [1]	2.66	*51.1*	1.60	*39.0*	2.66	*44.9*	1.60	*33.2*	2.66	*37.0*	1.60	*26.3*
Driving while loading (Kuitto) [2]	0.69	*13.2*	0.64	*15.6*	0.69	*11.6*	0.64	*13.3*	0.69	*9.6*	0.64	*10.5*
Driving empty and loaded (Kuitto)	1.01	*19.4*	1.01	*24.6*	1.73	*29.2*	1.73	*35.9*	2.99	*41.6*	2.99	*49.2*
Unloading (Kuitto)	0.85	*16.3*	0.85	*20.7*	0.85	*14.3*	0.85	*17.6*	0.85	*11.8*	0.85	*14.0*
Total time	5.21	*100*	4.10	*100*	5.93	*100*	4.82	*100*	7.19	*100*	6.08	*100*
Difference-%	*- 21.3*				*- 18.7*				*- 15.4*			
Alternative review:												
Driving while loading (Gullberg) [3]	0.92	*16.9*	0.76	*18.0*	0.92	*14.9*	0.76	*15.4*	0.92	*12.4*	0.76	*12.3*
Total time	5.44	*100*	4.22	*100*	6.16	*100*	4.94	*100*	7.42	*100*	6.20	*100*
Difference-%	*- 22.4*				*- 19.8*				*- 16.4*			

[1] gross-section area of grapple: 0.3 m² gross-section area of load space: 3.5 m²
coefficient for solid volume: 0.6 accumulation: 7.8 m³/100m average log length: 3.6 metres
[2] additional time for driving during loading: 0.04 min/change in loading points (Kuitto *et al.* 1994)
[3] 0.06 min/change in loading points (Gullberg 1997)

If the pile size and size of loading point could be increased by 50 % (see table 3), time saving of the forwarding cycle would be about 20 % per cubic metre at a 300 metres forwarding distance. The calculations have showed that depending on the forwarding distance, time savings could chance from 16 % to 22 %.

Discussion and conclusions

In similar first thinning conditions, the method of bunching timber assortments during cutting varied a lot among different harvester operators. Similar bunching differences among the same operators were observed also in other study in first thinnings (Väätäinen *et al.* 2005). The biggest differences were found especially in pile sizes and also some differences in pile locations and directions. One explanation for the variation of pile sizes was the cutting accumulation per 100 metres of thinning track. For example harvester operator A removed 27 % of the initial basal area, whereas operator F removed 44 % respectively. That has a straight effect on the accumulation per 100 metre and also the pile size.

The size of the piles explained the major part (75 %) of the variation of the formulated loading productivity model. Other statistically significant predicting variables – like number of grapple loads from one pile, loading difficulty (subjective observation), log assortment of pile, number of piles in a grapple load - explained a bit over 3 % of the variation of model. Even though the data had a good variation in pile distances to thinning track, the variable had no significant correlation to the productivity of loading. In any case, most piles were located at a suitable distance to the thinning track enabling the effective use of loading with the boom.

The greatest differences of the harvester operator's methods to bunch the log assortments caused about 30 % difference in loading time of piles per cubic metre. With similar initial values and a base assumption as in our case, Gullberg's (1997a) loading time model gave even a 40 % margin. In conclusion, the maximum variation found in pile characteristics among harvester operators' the average values resulted in about 20 % difference in forwarding productivity, when the forwarding distance was 300 metres (calculations based on models by Kuitto *et al.* (1994) and Gullberg (1997a)).

As a result of this study, some advisory points to consider when cutting with the harvester in order to improve the forwarders productivity are presented next:

• Piles should be as big as the maximum load of the forwarder's grapple

• Small piles (one small log) and also too big piles should be avoided

• Distances between the thinning track and the pile can vary a lot if there is enough free space around piles that are further away

• Working location with only one pile should be avoided

• Different productivities of the machines in different stands should be kept in mind

• Logging and forwarding should be understood as a processing chain where one step affects the latter step

• When the average diameter of stems is relatively low, the harvester operator does not need to bunch as well as when the average diameter is high (Good quality bunching takes extra time in cutting (Väätäinen *et al.* 2005)).

In addition to previously mentioned points, the logging area, amount of machines in logging, machines' working schedules, upcoming logging operations and an option to extract logging residues should be taken into consideration when changing the bunching method in order to optimise the logging productivity. For example, in thinning conditions (small trees) harvesters have a smaller productivity than forwarders and the case is opposite in clear cuttings (big trees). In loggings it should also be remembered that the harvester's unit costs are more significant than the forwarder's. In addition, the harvester operator's planning of the thinning track network can have an even more significant effect on the productivity of forwarding, especially in challenging terrains.

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Received 31 July 2005
Accepted 19 May 2006

ВЛИЯНИЕ ПАКЕТИРОВАНИЯ ОДНОМОДУЛЬНЫМ ХАРВЕСТЕРОМ НА ЭФФЕКТИВНОСТЬ РАБОТЫ ФОРВАРДЕРА

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Резюме

При использовании метода сортиментной лесозаготовки, стволы на делянке раскряжевываются и распиливаются на несколько сортиментов одномодульным харвестером. Оператор харвестера может непосредственно влиять на эффективность трелевки в погруженном состоянии. Харвестер и форвардер имеют различную производительность, также более значительное влияние на работу харвестера по сравнению с форвардером оказывает такой фактор, как размер ствола.

В ходе данного исследования профессиональный оператор форвардера грузил сортименты, распиленные и уложенные в пакеты шестью разными операторами харвестеров в одном и том же древостое, проходимом рубкой ухода. Пакеты были замерены; были оценены их размеры, положение, доступность и т.д. Этап погрузки на форвардер был оценен с помощью ручного замера времени.

Исследование показало, что методы пакетирования сортиментов, применяемые операторами харвестеров во время лесозаготовки сильно различались. Наибольшая разница по времени погрузки штабелей на кубический метр составила 30%. Использованые модели расчетов из литературы показали, что 40-процентная экономия времени на кубический метр на этапе погрузки приводит к 20% экономии по всему циклу трелевки, когда дистанция трелевки составляет 300 метров. Лесозаготовка должна рассматриваться как производственная цепь, в которой первый этап (валка) влияет на последующий этап (трелевку). Оптимизируя размер пакета, оператор харвестера может повысить продуктивность цепочки харвестер-форвардер. Более того, от избранной схемы прорубки сети волоков, составленного оператором харвестера, значительно зависит производительность трелевки при рубках ухода, в частности на сложной местности.

Ключевые слова: Форвардер, сортиментная заготовка, пакетирование, пакет сортиментов, погрузка древесины, производительность