Time Consumption Models and Parameters for Off- and On-road Transportation of Whole-tree Bundles

JUHA LAITILA[1*], KALLE KÄRHÄ[2] AND PAULA JYLHÄ[3]

[1*] *Finnish Forest Research Institute, Joensuu Unit, P.O. Box 68, FI-80101 Joensuu, Finland, Tel +358 10 2111, e-mail: juha.laitila@metla.fi*

[2] *Metsäteho Oy, P.O. Box 101, FI-00171 Helsinki, Finland, Tel. +358 20 765 8808, e-mail: kalle.karha@metsateho.fi*

[3] *Finnish Forest Research Institute, Kannus Unit, P.O. Box 44, FI-69101 Kannus, Finland, Tel. +358 10 211 3432, e-mail: paula.jylha@metla.fi*

Laitila, J., Kärhä, K. and Jylhä, P. 2009. Time Consumption Models and Parameters for Off- and On-road Transportation of Whole-tree Bundles. *Baltic Forestry*, 15 (1): 105–114.

Abstract

The absence of the empirical time study models and parameters for whole-tree bundle forwarding and truck transportation has been problematic when comparing the alternative supply systems for integrated pulpwood and energy wood procurement. In the present study, time consumption models were constructed for the forwarding of whole-tree bundles by applying regression analyses to empirical time study data. The time studies related to on-road transportation were focused on comparing the terminal time spent on the handling of whole-tree bundles and conventional 5-m pulpwood. The study showed that the forwarding productivity of whole-tree bundles is about double compared to conventional pulpwood and whole trees, when using a solid volume of 0.5 m³ for the whole-tree bundles. In on-road transportation, the mean loading and unloading time of whole-tree bundles per truck load was 46% higher compared to that of conventional 5-m pulpwood.

Key words: Integrated harvesting, bundling, forwarding, transporting, energy wood

Introduction

Background

The harvesting of industrial roundwood and energy wood from early thinnings is costly due to small stem size and low removal. Based on the pre-feasibility studies, the cost-efficiency of the harvesting of pulpwood and energy wood from early thinnings could be improved by applying a newly-developed integrated procurement system based on whole-tree bundling (Jylhä *et al*. 2007a, Kärhä 2007, Kärhä *et al.* 2007). The greatest cost reduction potential is in small-diameter ($d_{1.3}$=7-10 cm) first-thinning stands, which are relatively unprofitable sites for conventional pulpwood procurement (Kärhä *et al.* 2008a). The annual need for first thinnings in Finland is around 300,000 hectares during the next ten years (Korhonen *et al.* 2007).

In integrated harvesting of pulpwood and energy wood, increased recovery in the form of tops and branches is expected to compensate the high harvesting cost of pulpwood (*e.g.* Jylhä 2004, Jylhä and Laitila 2007, Kärhä *et al.* 2008a). In the study of Jylhä (2004), the gain in energy biomass was 150% when undelimbed Scots pine (*Pinus sylvestris*) tree sections were bundled instead of conventional cut-to-length harvesting, in which only stem bark represents the energy fraction. Based on the Finnish Energy and Climate strategy, there is a need to triple or even quadruple the production of forest chips by the year 2020 (Ryymin *et al.* 2008). The forest industries are the largest producer and consumer of wood-based energy in Finland and therefore integration of energy wood procurement into that of industrial roundwood is a rational way to organize the raw material supply. Several systems for the integrated harvesting of pulpwood and energy wood in thinnings have been developed earlier (*e.g.* Hakkila and Kalaja 1993, Rieppo *et al.* 1996, Korpilahti and Poikela 1997). However, a breakthrough has not been achieved, mainly because of the problems related to the weak cost competitiveness of the transportation of bulky undelimbed assortments.

The first prototype of the "Fixteri" whole-tree bundler was launched in 2007 by Biotukki Oy (www.biotukki.fi) (Jylhä and Laitila 2007, Jylhä *et al.* 2007a, Kärhä *et al.* 2007). The bundle harvester consists of a base machine, an accumulating harvester head and a compacting device (*e.g.* Jylhä and Laitila 2007, Jylhä *et al.* 2007a, Jylhä *et al.* 2007b, Kärhä *et al*. 2007). With the first version of the "Fixteri", trees are compacted into cylindrical bundles with a length of 2.6 m and a diameter of about 60-70 cm. Their solid volume varies between 0.3 m^3 and 0.5 m^3, depending on the bundle assortment and stand properties (Jylhä and Laitila 2007). The whole-tree bundles are transported using standard forwarders and timber trucks to the end-use facility. The pulp and energy fractions of the pulpwood bundles are separated at the debarking drum of the chemical pulp mill (Jylhä *et al.* 2007a, Jylhä *et al*. 2007b, Kärhä *et al*. 2007). The energy wood bundles composing of under-sized trees and undesirable tree species for pulp production are comminuted for combustion at heating and power plants (Jylhä *et al.* 2007a, Kärhä *et al.* 2007). Cost savings are expected especially in off-road and on-road transportation due to increase in load sizes (Kärhä *et al*. 2008a). The advantages achieved by compacting, however, have to balance the costs of compacting.

Aim of the study

Knowledge of the productivity of the machinery and the cost factors associated with transporting are crucial when designing a new procurement system. The present study was aimed at constructing time consumption models and parameters for forwarding and trucking whole-tree bundles. The parameters and models constructed in this study will be used for comparing supply systems applicable to pulpwood and energy wood procurement from young stands in a R&D project coordinated by Metsäteho Oy (Kärhä *et al.* 2008b).

Material and methods

Time studies of forwarding

The time study data were comprised of 50 forwarder loads of whole-tree bundles harvested from two first-thinning stands located in Kangasniemi (61°59'N, 26°38'E), Central Finland. The total number whole-tree bundles transported during the time study was 1113. Of them, 160 were pulpwood and 953 energy wood bundles. The bundles were harvested with the first "Fixteri" prototype bundle harvester described in Jylhä and Laitila (2007). The data were collected in winter conditions in February 2008. The terrain had gentle slopes and no obstacles and was classified as normal according to the Finnish harvesting standards (Anon. 1990). The factors affecting the productivity of forwarding whole-tree bundles are summarized in Table 1.

Table 1. The factors affecting the productivity of forwarding whole-tree bundles

	Range
Driving unloaded, m	20-880
Distance between loading stops, m	5.1-21.1
Bundle concentration on the strip road, number of bundles *per* 100 m	6.6-45.3
Size of loading stop, number of bundles	1-3
Load size, number of bundles *per* load	8-31
Average load size, number of bundles *per* load	22.3
Weight of the bundles, kg	140-390
Driving with load, m	30-770

The time study was carried out using a 6-wheeled Timberjack 1010B forwarder equipped with a Loglift 61 crane (max. reach 8.5 m) and a Loglift 25 timber grapple. The overall length of the load space was 460 cm with an external width of 256 cm. The cross sectional area of the load space was 3.5 m^2. The whole-tree bundle loads consisted of two sequential piles of bundles. The operator had 2.5 years of practice in bundle forwarding and altogether 4.5 years of working experience in timber forwarding.

The forwarding data were collected using continuous time registration with a Rufco hand-held computer with an accuracy of 0.6 seconds (1 cmin). Driving distances unloaded, during loading, and loaded were measured using a thread meter. The weights of the bundle loads were recorded with an EVOCAR-2000 vehicle scale with an accuracy of 10 kg. Each working cycle of the forwarder (clock time) was divided into effective working time (E_0h) and delay time (Haarlaa *et al.* 1984, Mäkelä 1986). Effective working time, including auxiliary time of each work phase (*e.g.* planning of work and preparations), was divided into working phases as follows:

- Driving unloaded, distance m
- Loading. The number of the bundles in the grapple and the number of the grapple loads *per* load were recorded
- Driving during loading, distance m
- Reversing and turning around in the stand
- Driving with load, distance m
- Unloading. The number of the bundles in the grapple and the number of grapple loads *per* load were recorded
- Sorting and handling of the bundle assortments in the bunk
- Moving during unloading at the roadside storage
- Cleaning of the roadside storage.

Driving unloaded began when the forwarder left the roadside landing area and ended when it stopped at the first loading stop and started to load bundles. Loading began when the operator started to move the crane from the bunk and ended when the last bundle at the loading stop was loaded and the crane with the grab was resting on the bunk. All bundles were located on the same side of the strip road, resulting from the structure of the bundle harvester (Jylhä and Laitila 2007, Kärhä *et. al.* 2007). Consequently, they were loaded from only one side of the forwarder. Driving during loading started when the bundle loading was finished and the forwarder began to move to the next loading stop, *i.e.* the working position on the strip road where the loading took place. Driving during loading ceased when the forwarder stopped at the next loading stop. Driving loaded began when the load was full and ended when the forwarder stopped at the landing area for unloading. The unloading phase started when the forwarder raised the crane for unloading and ended when the load was empty and the forwarder was ready to return to the stand or to perform another activity. When the pile at the roadside landing became high enough or all bundles of certain assortment had been unloaded, the forwarder moved to the next unloading point or to another pile at the roadside storage. Sorting and handling of the bundle assortments in the bunk was carried out at the roadside storage during unloading. Before returning to the stand, the material that had been dropped on the ground while unloading was cleaned from the roadside landing.

Time studies of truck transportation

In the truck transportation study, the loading and unloading times of whole-tree bundles were compared to those of conventional 5-m pine pulpwood. The timber was transported by a Volvo FH 16 timber truck of the 2004 model, composing of a three-axle tractor and a four-axle trailer (Weckman) with fixed length and movable load-bunk frames. The truck was equipped with a detachable Jonsered 1020 hydraulic timber crane (max. reach 9.6 m), which was not removed from the truck during the time studies. One bunch of the 5-m pulpwood was loaded on the tractor and two bunches on the trailer. The bundle loads consisted of two bunches on the tractor and three bunches on the trailer. The truck driver had 4.5 years of working experience in transporting industrial roundwood, bundles, loose logging residues and stumps.

Both loading and unloading were done using the crane of the timber truck. The empirical data comprised of five timber truck loads, of which four were whole-tree bundle loads and one was a pulpwood load (Table 2). All truck loads were unloaded directly to railway wagons. The studies were carried out in the daylight in February 2008, except for one energy wood bundle truck load, which was loaded and unloaded in artificial light in the evening. Otherwise, conditions were comparable in the case of both assortments. The volumes and payloads of the timber lots were based on the scaling at the Wisaforest pulpmill in Pietarsaari. The energy wood bundles were composed of alder (*Alnus incana* and *A. glutinosa)* and birch (*Betula pendula* and *B. pubescens*), and the pulpwood bundles contained Scots pine.

Table 2. Characteristics of the timber truck loads

Assortment	Payload, kg	Load size, m³ and pieces	Size of the bundles, m³ and kg
Energy wood bundles	26 300	30.2 and 78	0.39 and 337
Energy wood bundles	28 050	32.1 and 86	0.37 and 326
Pulpwood bundles	32 569	35.0 and 90	0.39 and 362
Pulpwood bundles	25 331	27.2 and 70	0.39 and 362
Pine pulpwood, 5 m	35 650	37.9 and -	-

The comparative time study on truck transportation was carried out by the continuous time method using a Rufco hand-held computer. Effective working time, including auxiliary time of each work phase (*e.g.* planning of work and preparations), was divided into the following work phases:

Loading

- Preparing of the crane
- Handling of the trailer and bunks
- Loading. The number of the bundles in the grapple and the number of grapple loads *per* load were recoded.
- Sorting of the logs or bundles within the piles or in the load bunk
- Moving of the truck at the roadside storage during loading
- Binding of the load
- Cleaning of the residues from the roadside storage.

Unloading

- Opening of the load binders
- Preparing of the crane
- Unloading. The number of bundles in the grapple and the number of grapple loads *per* load were recorded.
- Sorting of the logs or bundles in the load bunk
- Moving of the truck during unloading
- Handling of the trailer and bunks
- Cleaning of the delivery point.

Data analysis

The time consumption models for the work phases of the bundle forwarding described in Chapter “Time studies of forwarding” were formulated by applying a regression analysis included in the SPSS statistical package. The harvesting conditions, *i.e.* the accumulation of the bundles and forwarding distance were set as independent variables. The time consumptions of each work elements were expressed in seconds (s) *per* whole-tree bundle. The comparative time study data collected from the truck transport were arranged into a data matrix, and the comparisons on the time consumptions of the main work phases were conducted using an Excel spreadsheet. The final time consumptions were given in seconds (s) *per* truck load of whole-tree bundles or 5-m pulpwood.

Results

Time distribution of forwarding

Loading consumed 22% of the forwarder's effective working time (E_0h) in the time study while the proportion of unloading was 21% (Figure 1). Driving unloaded and with load took 21% and 17% of E_0h, respectively. Driving during loading accounted for 16%. Reversing at the stand, sorting and handling the bundle assortments in the bunk and moving during unloading and cleaning of the roadside storage represented about 1% of E_0h each. The average driving distance unloaded was 342 m, loaded 235 m, and 123 m during loading. One forwarder load contained on average 22.3 whole-tree bundles.

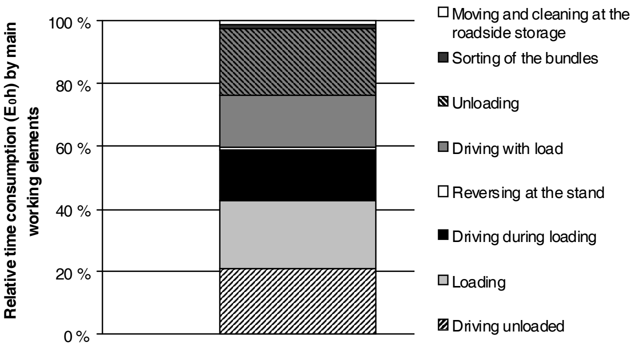

Figure 1. Division of the forwarder's effective working (E_0h) time into work phases when forwarding whole-tree bundles

Time consumption models for forwarding

Driving unloaded

The distance was set as an independent variable when modelling the time consumption function for driving unloaded. The time consumption was linearly dependent on the forwarding distance as follows:

$$T_{Empty\ load} = \frac{37.761 + 0.919 d_{empty\ load}}{n_{load}}$$

$T_{Empty\ load}$ = Time consumption on driving without load, s *per* whole-tree bundle

$d_{empty\ load}$ = Forwarding distance without load, m

n_{load} = Load size, number of whole-tree bundles *per* load

Loading of whole-tree bundles at the stand

All whole-tree bundles were loaded one by one at the stand, and the time consumption on loading was independent of bundle weight as shown in Figure 2. Therefore, the average loading time of whole-tree bundles, $T_{Loading}$, of 15.8 seconds for bundle was used.

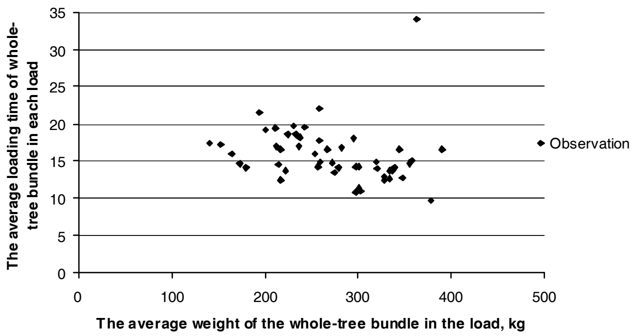

Figure 2. The loading time of whole-tree bundle according to the weight of bundle. The average loading time *per* bundle was 15.8 seconds during the time studies (std 3.8)

Driving while loading

The driving time between the loading positions was dependent on the concentration of the whole-tree bundles along the strip road, *i.e.* the number of whole-tree bundles *per* 100 m of strip road. Consequently, the number of loading stops and the driving distance during loading depended on the accumulation of the bundles beside the strip road. The moving time while loading decreased when the concentration of whole-tree bundles increased (Figure 3), and an increase in the accumulation of bundles shortened the driving distance required for a full load. The average time spent on reversing in the stand (15 s *per* load) was set as a constant value (a) in the time consumption formula.

$$T_{Moving} = 5.850 + \frac{106.904}{z} + \frac{a}{n_{load}}$$

T_{Moving} = The moving time of the forwarder during loading, s *per* a whole-tree bundle

z = The concentration of the whole-tree bundles alongside the strip road, the number of whole-tree bundles *per* 100 m of strip road

a = Constant miscellaneous time, 15 s *per* load

n_{load} = Load size, number of whole-tree bundles *per* load

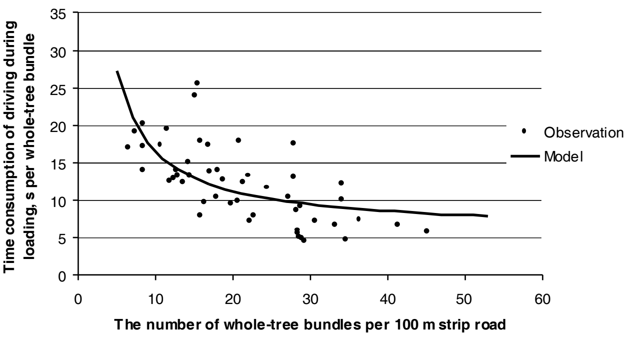

Figure 3. Moving time during loading as a function of accumulation of the whole-tree bundles beside the strip road

Driving with load

The forwarding distance was set as an independent variable for time consumption when driving loaded. With short distances the driving speed with load was equal to driving unloaded, but somewhat lower for longer distances (Figure 4).

$$T_{\text{Driving with load}} = \frac{12.173 + 1.114\, d_{\text{with load}}}{n_{\text{load}}}$$

$T_{Driving\ with\ load}$ = The time consumption of forwarding with load, s *per* a whole-tree bundle

$d_{with\ load}$ = Forwarding distance with load, m

n_{load} = Load size, the number of whole-tree bundles *per* load

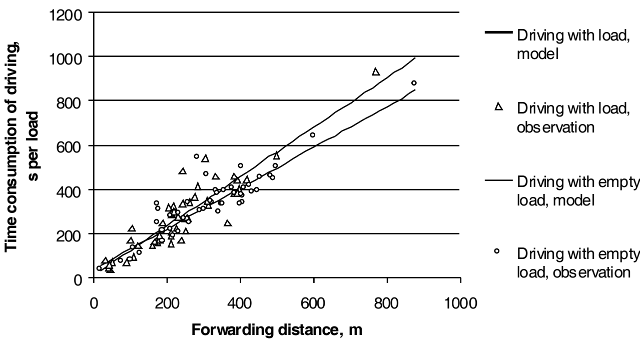

Figure 4. The time consumption of driving with empty load and with load as a function of forwarding distance

Unloading

The weight of the whole-tree bundles did not affect the unloading time (Figure 5). Hence, the unloading time was expressed using the average unloading time, $T_{Unloading}$, of 15.7 seconds. The average cleaning and moving time during or after unloading at the roadside storage was 19.0 seconds *per* load. Sorting and handling of the whole-tree bundle assortments in the bunk took 26 seconds *per* load, when forwarding both pulpwood and energy wood bundles in the same load. The mixed loads contained 28% pulpwood bundles and 72% energy wood bundles. All the whole-tree bundles were unloaded one by one at the roadside storage during the time studies.

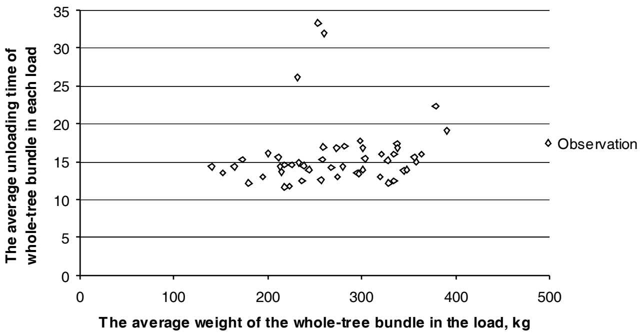

Figure 5. The effect of the bundle weight on the unloading time. The average unloading time was 15.7 seconds (std 4.3)

Review of the models

The effective forwarding time (E_0h) of whole-tree bundle by the forwarder, $T_{Forwarding}$, (s *per* whole-tree bundle) was obtained by summing up the main working elements as follows:

$$T_{Forwarding} = T_{Empty\ load} + T_{Loading} + T_{Moving} + T_{Driving\ with\ load} + T_{Unloading}$$

The time consumption *per* forwarder load, T_{Load}, was calculated by multiplying the time consumption *per* whole-tree bundle ($T_{Forwarding}$) by number of bundles in the load (n_{load}).

$$T_{Load} = T_{Forwarding} * n_{load}$$

The forwarding productivity of whole-tree bundles can be expressed in solid volume *per* effective time (m^3/E_0h) by dividing the time consumption *per* load (T_{Load}) by the solid content of the whole-tree bundles, v_{bundle} (*cf.* Jylhä and Laitila 2007).

$$m^3/E_0h = \frac{T_{Load}}{v_{bundle}}$$

Compacting of whole trees into dense bundles markedly improves the efficiency of forwarding wood from young stands (Figure 6). The forwarding productivity of whole-tree bundles is about double compared to conventional pulpwood and whole trees when the forwarding distance is 300 meters and the solid volume of the bundle is 0.5 m^3. Even if the solid volume of the whole-tree bundle was reduced to 0.3 m^3, the forwarding productivity would still be 20-40% higher compared to conventional pulpwood or whole trees. In the comparisons, the cutting removal was assumed to be 60 m³/ha and the load size 6.5 m³ for whole trees, 11.0 m³ for pulpwood and 24 pieces for whole-tree bundles. The forwarding productivity of whole trees (m³/E_0h) was computed using the models of Laitila *et al.* (2007). In the case of forwarding pulpwood, the models of Kärhä *et al.* (2006a) were used.

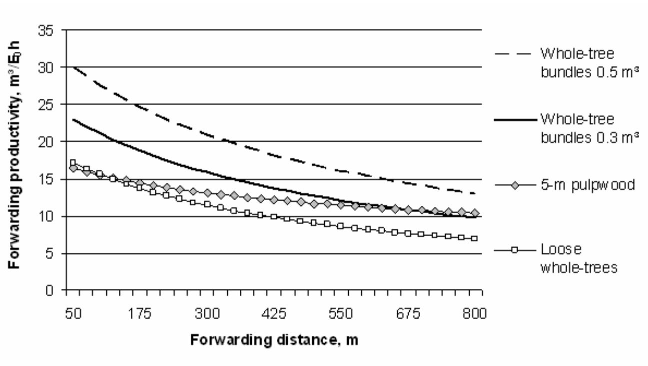

Figure 6. Effect of forwarding distance on the productivity of forwarding loose whole trees, 5-m pulpwood and whole-tree bundles (cutting removal 60 m³/ha)

The statistical analyses were conducted for each regression model of bundle forwarding in order to examine the suitability of the regression models and to test the significance of coefficients. The results of the analyses are summarised in Table 3. The F-values of the models with $p < 0.001$ indicate that the models fit well with the data. The independent variables are very significant, excluding model for driving with load, which had higher *p*-value (0.548) (Table 3).

29%, respectively. The binding of the load accounted for 13% for both assortments, and opening of the load binders took 4% and 9% of the E_0h. Cleaning of the working site after the loading and unloading of the whole-tree bundles accounted for 4% and 3% of the E_0h. The conventional delimbed pulpwood was free of slash and thus there was no need for cleaning either after loading or unloading (Figure 7).

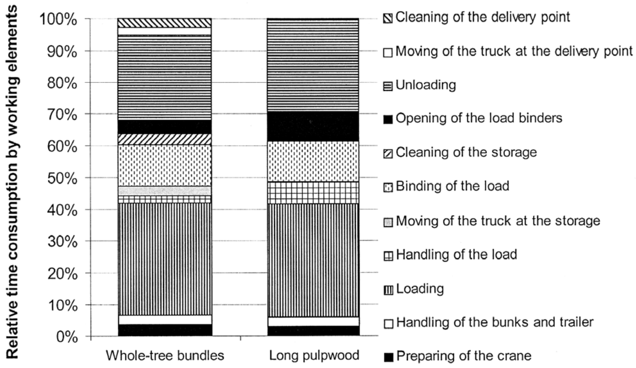

Figure 7. The relative time consumption of working elements in the loading and unloading of whole-tree bundles and 5-m pulpwood with the timber crane of the truck

In this study, one bunch of the 5-m pulpwood was loaded on the tractor and two bunches on the trailer whereas the bundle loads consisted of two bunches on the tractor and three bunches on the trailer. Consequently, the driver had to move the timber truck while loading and unloading of the bundles in order to get the load full or empty within the crane reach. With 5-m pulpwood, the driver was able to load and unload from one working point without a need for relocation at a

Table 3. Statistical characteristics of regression models of whole-tree bundle forwarding

Work phase model	Dependent variable	R^2	F-test F-value p	N	Term	Constant/Coefficient Estimate	Std. error	t-test t-value	p
Driving	$T_{Empty\ load}$	0.84	252.767	48	Constant	37.761	20.098	1.879	0.066
unloaded			<0.001		$l_{empty\ load}$	0.919	0.058	15.899	<0.001
Driving	T_{Moving}	0.39	30.764	47	Constant	106.904	19.274	5.547	<0.001
while loading			<0.001		z^{-1}	5.850	1.246	4.694	<0.001
Driving	$T_{Driving\ with\ load}$	0.83	230.495	48	Constant	12.173	0.073	15.182	<0.001
with load			<0.001		$l_{with\ load}$	1.114	20.093	0.606	0.548

Time consumption of loading and unloading in on-road transportation

Based on the comparative time study on trucking, the structures of the time consumptions in bundle and pulpwood transport were similar (Figure 7). Loading and unloading accounted for 36% and 27% of the total effective working time (E_0h) in the case of whole-tree bundles. With pulpwood, the proportions were 36% and

storage pile or a railway wagon. The relative handling time of the bunks and the preparing time of the crane were about 3-4% for both timber assortments (Figure 7). The relative handling time of the pulpwood at the load bunk was 7% and the handling time of the whole-tree bundles was 2% of the total effective working time.

The average loading time of a whole-tree bundle was 3.8 seconds higher than its average unloading time

(16.3 s *vs.* 12.5 s). The loading and unloading times ranged from 13.4 to 20.5 seconds and from 10.2 to 15.1 seconds, respectively (Figure 8). The average number of whole-tree bundles in the grapple load when loading was 1.8 bundles and 1.9 bundles during unloading. The number of bundles in a grapple load varied between 1.7 and 1.9 bundles when loading and between 1.6 and 2.1 bundles when unloading (Figure 8). The number of grapple loads *per* load during loading was about equal compared to unloading both in the case of whole-tree bundles and pulpwood (Figure 9).

The mean time consumption of the work elements in the comparative time study are shown in Table 4. The preparation time of the crane, the handling time of the bunks and the trailer, the handling time of the load, translocation time during loading and unloading, the binding and opening time of the load, and the cleaning time of the storage and delivery sites were given as the mean value *per* whole-tree bundle load. The loading and unloading time of whole-tree bundles were calculated using a load size of 90 bundles. The

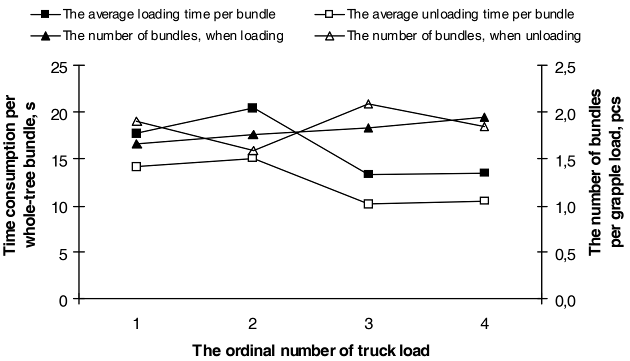

Figure 8. The average time consumption *per* bundle and the size of grapple load when loading and unloading whole-tree bundles

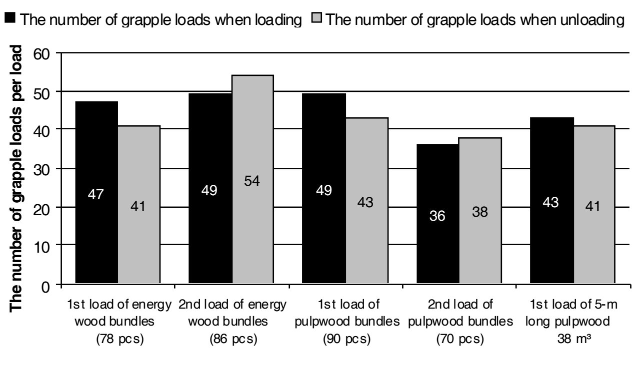

Figure 9. The number of grapple loads *per* load when loading and unloading whole-tree bundles and conventional 5-m pulpwood

load size of the 5-m pulpwood as well as the time consumption of working elements were derived from the results of the comparative time study. The relative time distribution of the above mentioned work elements between the loading and unloading are detailed in Table 5. Following the procedure described above resulted in a total effective handling time of the whole-tree bundles of 3,958 seconds and 2,724 seconds for the 5-m pulpwood (Table 4).

Table 4. The mean time consumption (E_0h) of work elements *per* timber truck load of whole-tree bundles and pulpwood in seconds

Work element:	Whole-tree bundles, 90 pieces *per* load	5-m long pulpwood, 38 m³ *per* load
Preparing of the crane, s	134	83
Handling of the bunks and trailer, s	112	84
Loading, s	1464	969
Handling of the load, s	90	192
Translocations, s	196	0
Binding and opening the load, s	626	593
Unloading, s	1125	803
Cleaning, s	238	0
Total time *per* load, s	3985	2724

Table 5. The division of the E_0h of the work elements into loading and unloading phases

Work element:	Whole-tree bundles		5-m pulpwood	
	Proportion of the loading	Proportion of the unloading	Proportion of the loading	Proportion of the unloading
	%			
Preparing of the crane	42	58	46	54
Translocations	56	44	0	0
Cleaning	57	43	0	0
Binding and opening of the load	77	23	58	42
Handling of the bunks and trailer	53	47	62	38

Discussion and conclusions

Bundling increases the size of the handling unit in loading and unloading, as well as the load size, thereby increasing the output of forwarding. The effect of the size of handling is well known from the earlier studies related to the forwarding of roundwood and whole trees (Gullberg 1997, Väätäinen *et al.* 2005, Nurminen *et al*. 2006, Laitila *et al.* 2007). The pile and grapple load volume is of great importance especially in thinnings, where removal of timber per areal unit is low and the piles are sparsely scattered alongside the strip road (Nurminen *et al.* 2006). In the study of

Nurminen *et al.* (2006) the average pulpwood grapple load volume was 0.16 m^3 in thinnings. When loading loose whole trees, the average grapple load volume was estimated to be 0.22 m^3 after mechanized cutting (Laitila *et al.* 2007). The load size also has a substantial impact on productivity, especially when forwarding loose whole trees from long transporting distances (Kärhä 2006b, Laitila *et al.* 2007).

The unloading productivity of whole trees and whole-tree bundles were about equal in the present study. When unloading loose whole trees, the grapple load volume was 0.53 m^3 and the average time of unloading cycle 21 seconds in the study of Kärhä *et al.* (2006b). In the study of Laitila *et al.* (2007), the load volume of loose whole trees was 0.63 m^3 *per* grapple load when unloading, and the mean duration of the loading cycle was 23.5 seconds. Nurminen *et al.* (2006) have reported of a mean time consumption of 0.56 min/m^3 when unloading conventional pulpwood. In the study of Kärhä *et al.* (2006a), the time consumption of unloading pulpwood was 0.91 min/m^3.

In the truck transportation, the handling time of whole-tree bundles *per* load was 46% higher compared to conventional 5-m pulpwood (Table 4), resulting from the need for cleaning the working site from slash after loading and unloading of the bundles. Furthermore, it was not possible to load and unload the bundle stacks within the crane reach without relocating the truck. Also an extra preparation of the crane was needed after translocation. The bundle loads consisted of two bunches on the tractor and three bunches on the trailer, which also increased the time needed for the handling of the bunks and trailer compared to pulpwood.

Korpilahti (2004) found that the time consumption of loading logging residue bundles and pulpwood are almost equal; the mean time consumption ratio *per* load was no more than 1.02. However, the variation in the ratios between the drivers was large, ranging from 0.82 to 1.37. The data comprised 29 loads of logging residue bundles and 16 loads of pulpwood, with six truck drivers involved in the study. In the present study, the average load volume of 38 m^3 of the 5-m pulpwood was rather low compared to the volumes of 47.4 m^3 and 48.2 m^3 reported by Korpilahti (2004) and Nurminen and Heinonen (2007), respectively. The low mean volume of the pulpwood loads of the present study might be a partial explanation for the high handling time ratio between whole-tree bundles and 5-m pulpwood.

In this study, all assortments were unloaded directly to the railway wagons and the work was done using the crane of the timber truck. In Finland, 77% of the domestic roundwood was transported straight to the mills by trucks and only 19% by trains from intermediate storage to the end-use facility (Finnish Statistical Yearbook…2007). The unloading methods of the timber trucks at the mill vary both among and within the mill yards, but the work is done frequently by log stackers or wheeled loaders (Nurminen and Heinonen 2007).

From the methodological point of view, the present forwarding study was a relationship study, while the truck transportation study was a comparative time study with very limited data, aimed at comparing the handling times of pulpwood and whole-tree bundles, thereby generalizing and making the results more comparable with the earlier studies. The results reported in this paper were based on the output of only one forwarder operator and one timber truck driver, and therefore they do not cover the whole range of productivity. However, it is evident that the number of experienced operators available for the study is limited. The study was focused on the effective time (E_0h), which is only a part of the total working time. Nevertheless, the results give new estimates for the performance in terrain and road transportation of the whole-tree bundles. The workers involved in the studies were skilled, utilizing machinery representative of current machines in use.

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Received 17 March 2009
Accepted 19 May 2009

ПРОИЗВОДИТЕЛЬНОСТЬ ТРАНСПОРТИРОВКИ ПАЧЕК ХЛЫСТОВ В ЛЕСУ И ПО ДОРОГЕ

Ю. Лайтила, К. Кярхя и П. Юлхя

Резюме

Отсутствие эмпирической модели, основанной на хронометражных наблюдениях для перевозки пачек хлыстов форвардерами и лесовозами представляло собой проблему при сравнении альтернативных схем в интегрированной цепи поставок балансов и энергетической древесины. В данном исследовании путём применения метода регрессивного анализа к данным эмпирического хронометрирования были построены модели временных затрат на форвардерную перевозку пачек хлыстов. Изучение временных затрат при транспортировке по дорогам было сфокусировано на сравнении расхода времени при работе с пачками хлыстов и традиционного 5-метрового баланса. Исследование показало, что продуктивность перевозки на форвардере, загруженном пачками хлыстов (0,5 плотн. м3) примерно в два раза выше, чем перевозки на форвардере, загруженном традиционным балансом или целыми деревьями. При транспортировке по дороге средний показатель времени погрузки и разгрузки одной машины для пачек хлыстов был на 46 % выше, чем для традиционного 5-метрового баланса.

Ключевые слова: интегрированные заготовки, пакетирование, перевозка на форвардере, транспортировка, хлысты