Energy Wood Logging from Early Thinnings by Harwarder Method

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Abstract

During the last decade harwarders have been developed for both industrial roundwood and energy wood harvesting. This article looks into the productivity results obtained by a conventional forwarder equipped with the Moipu 400 E energy wood harwarder grip in thinning a young stand. Productivity functions for the harwarder logging were formulated by applying a regression analysis in which the harvesting conditions (tree volume, cutting removal, forwarding distance etc.) were independent variables. The logging productivity of small trees with branches using the harwarder method, was 3.3 m^3/E_0-h (effective working hour), when the tree volume was 25 dm^3, accumulation of energy wood 50 m^3 per hectare, load volume 6.2 m^3 and forwarding distance 250 m. Felling and bunching represented 45 % of the energy wood harwarders effective working time. Making a strip road took 18 % of the total time consumption and loading of felled trees 17 %. Time consumption of forwarding was 6 % loaded and 5 % unloaded. Moving during cutting and loading and unloading at landing represented both 5 % of the effective working time.

Key words: young stand thinning, harwarder, energy wood, productivity functions, logging

Introduction

In Finland the target for the use of forest chips is set at 5 million m^3 (solid) by 2010. At present the level is 2.7 million m^3 per year and the main resource of forest chips is logging residues from final fellings (Ylitalo 2005). Plans to increase the use of forest chips require expanding the raw material base with biomass from young forests. This will help to reduce the transport distance and ensure reliable fuel supply. The recovery of logging residues from clearcut areas is more cost-competive than harvesting small trees from young stands because the slashes are a by-product of timber harvesting (Hakkila 2004). The difference in the production cost is caused by the high cost of felling bunching of small-sized trees, whereas in the other phases of the procurement chain cost differences are rather small.

Handling of small trees limits the productivity and increases logging costs. The cutting of small diameter trees for energy in Finland is traditionally carried out manually by chain saw. However, mechanical thinning is becoming more common particularly since small-tree operations and new equipment has been developed to make it cost effective and less sensitive to tree size. Feller-bunchers and harwarders using the multi-stem processing technique represent the cutting edge of this technology.

Multi-tree handling creates opportunities to reduce the time per tree and thereby make it profitable to harvest trees instead of leaving them in the forest. Multiple tree-handling is achieved by felling more than one tree in one cut or by felling one tree per cut and accumulating trees on the felling head, thereby handling several trees during one crane cycle (Johansson and Gullberg 2002). According to Bergkvist (2003) productivity rose by 18 % from 7.9 m^3 per productive hour (E_{15}) in single-tree handling to 9.3 m^3 per hour in multi-tree handling in roundwood harvesting.

The harwarder is a machine for all logging phases (Asikainen 2004). Compared to the normal harvester-forwarder chain translocation of machinery is cheaper when only one machine is moved. The harwarder method also provides more diverse work for the operator, when the cutting and forwarding tasks are integrated into one machine (Rieppo and Pekkola 2001, Sirén 2003, Sirén and Aaltio 2003). A dual-purpose machine diminishes organisational costs and need for management, when two tasks can be accomplished with a machine and a single pass at the site (Talbot *et.al* 2003). It also enables better employment of machinery and a higher degree of capacity utilization, when two tasks are done with a single machine (Laitila *et.al* 2005).

However, the harwarder is a compromise machine; it is designed both for harvesting and loading, and it is thus a little bit clumsy compared to special machines (Björheden and Dahlin 1999, Rieppo and Pekkola 2001). The harwarder is also an expensive machine, because it is a combination of a forwarder and harvester. Its hourly cost is about 30 - 40 % more than that of forwarder and it does not load more or drive faster than a forwarder (Wester and Eliasson 2003). Therefore harwarder operations with long forwarding distances are not economical (Sirén 2003, Sirén and Aaltio 2003). During the last decade harwarders have been developed for both industrial roundwood and energy wood logging.

This article looked into the use and productivity of the Moipu 400 E energy wood harwarder grip in energy wood thinnings. Findings are based on the results of "Cost factors and supply logistics of fuel chips from young forests" project (Laitila *et al*. 2004). The project was a part of the National Wood Energy Technology Programme (Hakkila 2004). A number of studies have been carried out with the harwarder technology in energy thinnings (Lilleberg 1995, Hämäläinen and Lilleberg 1996, Eriksson and Rytter 2000, Hämäläinen and Rieppo 2000), but productivity functions have not been published earlier.

The objectives of the study were:

1. To describe the work pattern of the Moipu 400 E energy wood harwarder.

2.Create productivity models for the energy wood harvesting when using harwarder method.

3. To estimate the productivity of the machine.

Material and methods

Technical data of the machine and operation principle

The base machine of the energy wood harwarder was 8-wheeled Valmet 840 forwarder (Figure 1). The forwarders year model was 1997 and the cabin was not turnable. The weight of the standard forwarder was 10 600 kg and the load rating was 10 000 kg. The diesel engine was a 4-cylinder turbo charged Valmet 420 DW with a power output of 86 kW (Anon. 1995). The crane model was the Loglift 71 F and its reach was 10 m and the gross lifting torque 99 kNm. The forwarders loading area was modified so that stanchions can be pulled close to the front frame, when the harwarder drives backwards into the stand and makes a strip road. The front frame was also reclining which enables a good view for the cutting work. The harwarders loading space was not turnable.

The Moipu 400 E felling-loading head was mounted on the forwarders hydraulic loader. The Moipu 400E performs cutting and loading so that one machine can fell and forward energy wood. In cuttings the combi grip is capable to handle several trees at the same time, which reduces the movements of the crane and improves the productivity. The Moipu 400E uses a guillotine knife for cutting and the biggest cutting diameter for single trees is 30 cm and 50 cm for bunches. The opening diameter of the combi-head is 120 cm and it weighs 540 kg (Moisio Forest 2005). The harwarder was not equipped with a load scale.

Figure 1. Moipu 400 E harwarder grip and Valmet 840 forwarder

The work cycle of a harwarder can roughly be divided into cutting and forwarding operations. The Moipu 400 E energy wood harwarder, having a forwarder as a base machine, uses the following logging method: First the harwarder drives backwards into the stands and makes a strip road. Trees on the strip road are felled and piled alongside the trail. The driver estimates the length of the trail so that there is enough timber for one load. After opening the strip road, on the way out of the stand, the harwarder thins both sides of the strip road and loads processed trees into the load space. A fully loaded harwarder drives to the roadside storage and starts unloading. After unloading the harwarder drives back to the stand and continues the thinning.

Time study

Time studies were carried out 23.9.2002 - 27.9.2002 in Posio, in the North-West part of Finland. The trial was carried out on 14 different kinds of time study plots (Table 1). In the field studies, the time study plot was equal to the strip where the harwarder harvested a full load of energy wood. The mean height of the removed trees varied from 8 to 12 metres, stand density of cutting removal varied from 800 to 4500 trees/ha, tree volume varied from 17 to 48 dm^3 and harvested volume per hectare varied between 24 – 95 m^3/ha. Trees were harvested with branches (whole tree method) and time study sites were either birch or pine dominated. The nature and slope of the ground surface was normal and an experienced operator was driving the machine. The distance between strip roads on average was 20 metres and the width of the strip road was 3.9 meters.

Table 1. Harvesting conditions of the time study sites

Time study plot no.	Average density of removal, stems/ha	Average height of removal, m	Average size of removal, dm³	Accumulation of energy wood, m³/ha	Load volume/cutting removal of time study plot, m³
1	2150	8.0	17	35.6	4.8
2	1000	10.3	42	41.6	8.3
3	1800	8.3	17	30.7	3.3
4	1333	9.8	38	51.3	8.2
5	1300	9.5	48	61.9	8.7
6	726	9.5	33	24.1	5.5
7	1400	10.2	47	65.2	7.3
8	4400	8.5	18	80.4	6.1
9	4500	8.3	17	74.5	6.9
10	2200	7.9	18	40.1	6.9
11	800	11.7	36	29.0	5.5
12	1000	9.7	40	40.4	9.5
13	1000	9.5	33	33.1	7.2
14	2950	11.5	32	95.4	8.2

The time study was carried out manually by the continuous time method using a field computer and driving distances were measured using a thread meter. The work of the energy wood harwarder (clock time) was divided into effective working time and delay time. If work elements were performed simultaneously, during the time studies, the time with highest priority was recorded. Effective working time was divided into the following work phases:

Driving unloaded (driving with empty load from roadside storage to the stand)

Felling and bunching when opening strip road (cutting over the load space)

Moving when opening strip road (driving backwards during cutting)

Felling and bunching (harwarder thins both sides of the strip road)

Loading (harwarder loads processed trees into the loading area)

Moving (harwarder drives forward during cutting and loading)

Driving with load (driving with load from stand to the roadside storage)

The volume of removals from the time study plot was estimated using the stump diameter. In each time study plot, sample plots with a radius of 3.99 meter were systematically set up (Figure 2). The stump diameters of the removed trees by tree species were measured at each sample plot. Breast height and height of removed trees (stumps) were derived by sample tree data and linear regression. The stem volume of harvested trees was calculated using the breast height diameter and height (Laasasenaho 1982). The volume of tree branches and needles was determined using biomass models of Hakkila (1991) and the basic densities produced by Hakkila (1978). The time study plots volume of removal was the average of the sample plots removal. The harwarders productivity (m^3/E_0-h) was calculated dividing volume of removal by effective working time in the time study plot. The length of the time study plot was measured with a thread metre.

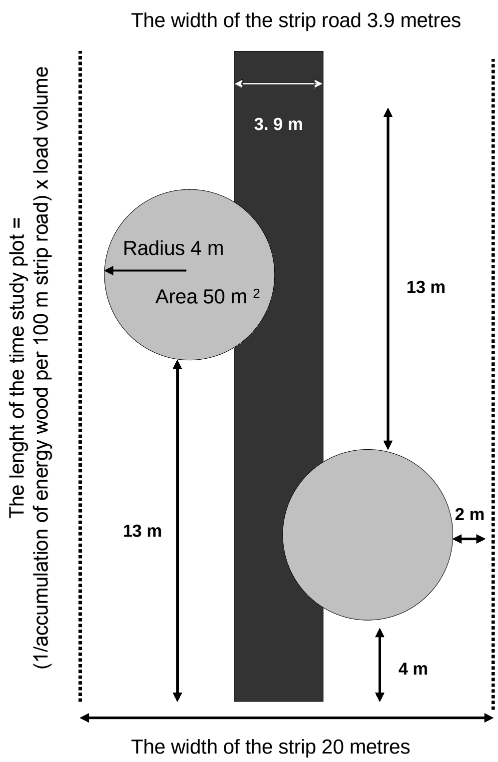

Figure 2. Principle of the time study plot

Data analysis

The time consumption of the work phases in the harwarder logging was formulated by applying a regression analysis, in which the harvesting conditions (tree volume, cutting removal, forwarding distance *etc*) were independent variables. The final calculation unit for time consumptions in every work elements was second (s) per solid cubic meter (m³). The SPSS-statistical application was used to carry out a regression analysis to estimate the harvesting productivity.

Results

Distribution of time consumption

Felling and bunching represented 45 % of the energy wood harwarder's effective working time in a stand having forwarding distance of 250 m, volume of removed trees 25 dm³ and accumulation of energy wood 50 m³/ha (Figure 3). Load volume was 6.2 m³. Opening strip roads took 18 % of the total time consumption and loading of felled trees 17 %. Time consumption of forwarding was 6 % with load and 5 % with empty load. Moving during cutting and loading and unloading at landing were both 5 % of the effective working time.

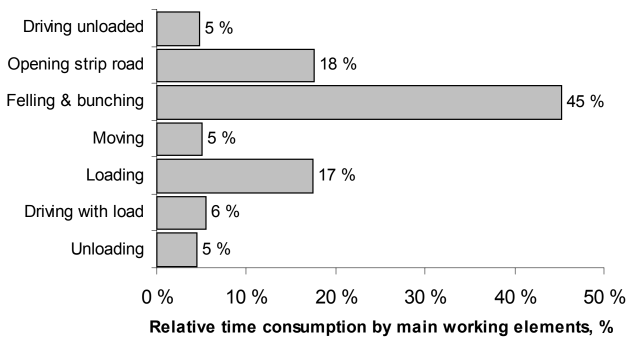

Figure 3. Main elements of the energy wood harwarders effective working time

Time consumption equations for the main working elements

Logging cycle of the harwarder was divided in cutting and forwarding operations, and further into work elements. The determined productivity functions for the main working elements were: 1. *Opening strip road*, 2. *Felling and bunching*, 3. *Moving*, 4. *Loading,* 5. *Forwarding to landing and driving back empty to the stand,* 6. *Unloading*. The calculation unit for effective time (E_0) consumptions for each work element was seconds per m³ (solid) or seconds per tree. The whole time consumption of the harwarder loggings load cycle was calculated by summarizing the time needed for each stage of the cutting and forwarding work.

1. Opening of strip road

Density of the cutting removal (stems per ha) and stem volume with branches (dm³) were independent variables, when modelling the time consumption of the strip road opening. The length of the strip road by load was dependent on the size of the load space and the energy wood concentration per strip road.

1.1. Time consumption when opening strip road, s per m³

$$T_{Strip\ road} = \frac{T_{Opening\ road}\ x\ L}{v_l}$$

$T_{Strip\ road}$ = Time consumption when opening strip road, s per m³

$T_{Opening\ road}$ = Opening of strip road, s per m

L = The length of the strip road, needed to fill the load space, m

v_l = Size of load space, m³

1.2. Opening of strip road, s per m

$$T_{Opening\ road} = -10.474 + 0.46v_s + 0.007534y$$

$T_{Opening\ road}$ = Time consumption when opening strip road, s per m

v_s = Stem volume with branches, dm³

y = Density of the cutting removal, stems per ha

r^2 = 0.58

1.3. The length of the strip road, m

$$L = \frac{1}{z}v_l$$

L = The length of the strip road, needed to fill the load space, m

z = Energy wood concentration, m³ per 100 m strip road

v_l = Load volume, m³

2. Felling and bunching

The most important productivity factors in the multiple tree handling are stem volume and number of trees per accumulation. The number of trees per crane cycle was modelled by the density of the cutting removal and the stem volume. Felling and bunching time per tree when using accumulation was calculated by the tree volume and number of trees per crane cycle.

2.1. Processing time per tree when using accumulation, s per tree

$$T_{Processing} = 17.848 + 0.07304v_s - 1.883x$$

$T_{Processing}$ = Processing time per tree when using accumulation, s per tree

v_s = Tree volume with branches, dm³

x = Number of trees per crane cycle

r^2 = 0.60

2.2. Number of trees per crane cycle

$$x = 4.616 - 0.0467v_s + 0.0001987y$$

x = Number of trees per crane cycle

v_s = Tree volume with branches, dm³

y = Density of the cutting removal, trees per ha

r^2 = 0.47

3. Moving

Time consumption of driving during cutting and loading were modelled by the density of tree removals. Moving time per tree decreased when the cutting removal of stems increased (Figure 4).

$$T_{Moving} = 0.373 + \frac{1990.103}{y}$$

T_{Moving} = Moving time during cutting and loading, s per tree

y = Density of the cutting removal, trees per ha

r^2 = 0.90

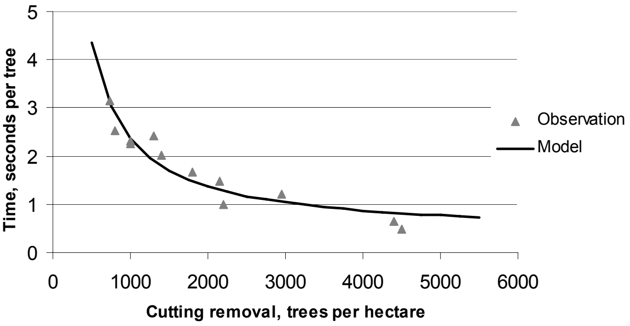

Figure 4. Moving time per tree as a function of the cutting removal

4. Loading

The grapple load volume was the main independent variable of the time consumption in the loading time (Figure 5). The larger the piles in the stand the easier and faster it was to grab larger load sizes. The grapple load volume was calculated by the size of cutting and loading stop (Figure 6). The size of cutting and loading stop was determined by the energy wood concentration, m³ per 100 m strip road (Figure 7). The relationship between grapple load volume and size of cutting and loading stop and also the relationship between size of cutting and loading stop and energy wood concentration was assumed to be linear.

4.1. Time consumption of loading, s per m³

$$T_{Loading} = 36{,}981 + \frac{22{,}962}{v_{Grapple}}$$

$T_{Loading}$ = Time consumption of loading, s per m³

$v_{Grapple}$ = Grapple load volume, m³

r^2 = 0.88

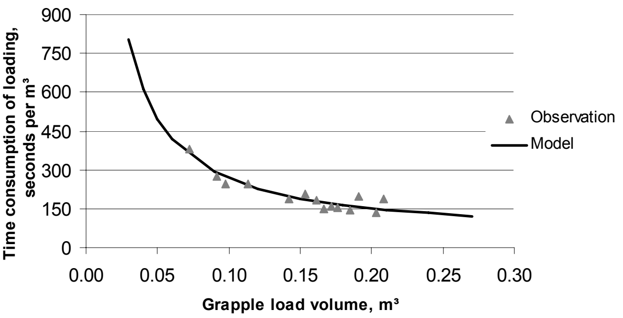

Figure 5. Time consumption of loading as a function of grapple load volume

4.2. The grapple load volume, m³

$$v_{Grapple} = 0.01935 + 0.524 v_{C\,\&\,L\ Stop}$$

$v_{Grapple}$ = Grapple load volume, m³

$v_{C\ andL\ Stop}$ = Size of cutting and loading stop, m³

r^2 = 0.68

4.3. Size of cutting and loading stop, m³

$$v_{C\,\&\,L\ Stop} = 0.0724 + 0.02095z$$

$v_{C\ andL\ Stop}$ = Size of cutting and loading stop, m³

z = Energy wood concentration, m³ per 100 m strip road

r^2 = 0.55

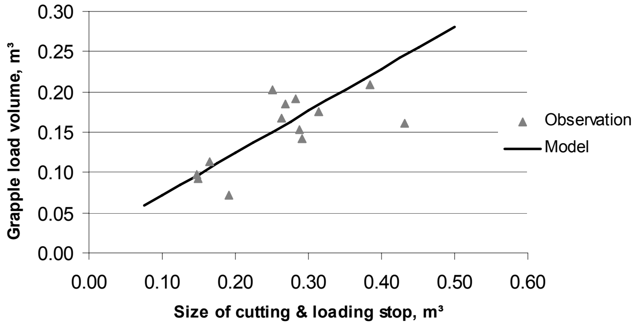

Figure 6. The grapple load volume according to size of cutting and loading stop

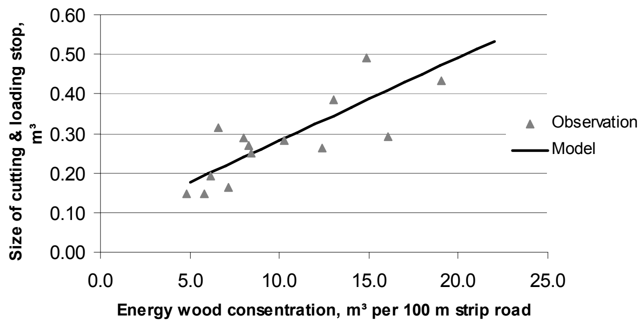

Figure 7. The size of cutting and loading stop as a function of the energy wood concentration

5. Forwarding to landing and driving back to the stand empty

The forwarding distance was the independent variable for the time consumption when driving with load or empty load with the forwarder (Figure 8). The driving speed was somewhat higher when driving unloaded than driving with load. Regression models for forwarding to landing and driving back empty to the stand have been published earlier in Metla's Working Paper 3 (Laitila *et al.* 2004). The time study data consisted of 97 loads of small sized thinning wood and it was noted that the driving speed of a forwarder based harwarder doesn't differ from normal forwarders driving speed.

5.1. Driving with load

$$T_{Driving\ L} = \frac{3.99 + 1.493 l_l}{v_l}$$

$T_{Driving\ L}$ = Time consumption of forwarding with load, s per m³
l_l = Forwarding distance with load, m
v_l = Size of load space, m³
r^2 = 0.94

5.2. Driving unloaded

$$T_{Empty\ load} = \frac{10.868 + 1.241 l_e}{v_l}$$

$T_{Empty\ load}$ = Time consumption of empty driving, s per m³
l_e = Forwarding distance with empty load, m
v_l = Size of load space, m³
r^2 = 0.96

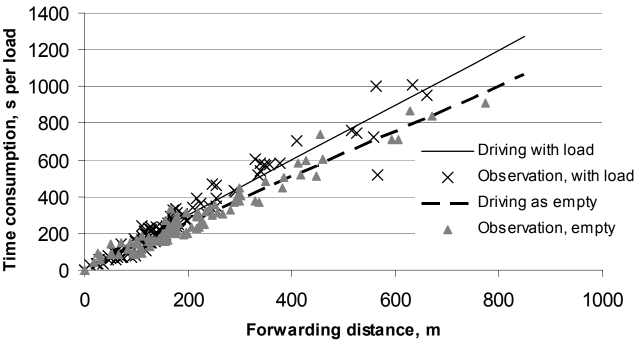

Figure 8. Time consumption when driving unloaded and with load as a function of forwarding distance

6. Unloading

The grapple load size was the independent variable for time consumption in unloading (Figure 9). The grapple load volume for unloading was almost double compared to grapple load volume for loading (Figure 5). In the time studies the grapple load volume for unloading was 0.3 m³ on average.

$$T_{Unloading} = 14.367 + \frac{12.009}{v_{U\text{-}Grapple}}$$

$T_{Unloading}$ = Time consumption for unloading, s per m³
$v_{U\text{-}Grapple}$ = Grapple load volume for unloading, m³
r^2 = 0.71

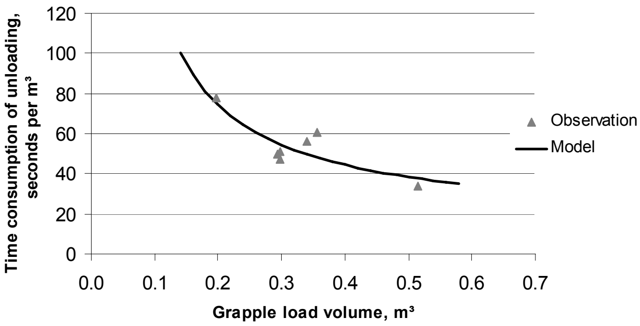

Figure 9. Time consumption of unloading as a function of grapple load volume

Review of results

The effective logging time consumption T_{Tot} , s/m³, by the harwarder method is the sum of the main working elements.

$$T_{Tot} = T_{Strip\ road} + \frac{T_{Processing} + T_{Moving}}{Stem\ volume, m^3} + T_{Loading} + T_{Driving\ L} + T_{Unloading} + T_{Empty\ load}$$

The time consumption per harwarder load, T_{Load} , is calculated multiplying the time consumption per cubic meter (T_{Tot}) by the harwarders load volume (v_l).

$$T_{Load} = T_{Tot} \ x \ v_l$$

The logging productivity of small trees with the harwarder method was 3.3 m³/E_0-h (effective working hour), when the tree volume was 25 dm³, accumulation of energy wood 50 m³ per hectare, load volume 6.2 m³ and forwarding distance 250 m (Figure 10).

The tree volume of the removals has the greatest effect on harwarder loggings productivity. The increase of tree volume from 10 dm³ to 50 dm³ increased harwarder loggings effective hour productivity from 2.2 m³/h to 3.7 m³/h (Figure 10). The lengthening in the forwarding distance from 50 m to 500 m, decreased logging productivity by 0.6 m³ per effective working hour (Figure 11). The increase in the cutting removals from 25 m³/ha to 75 m³/ha, improved the harwarder loggings productivity by 0.5 m³/ha per effective working hour (Figure 12).

Discussion

At the time when the research was carried out, the Moipu 400E grip was still under development. Originally, the harwarder grip model (Moipu 400) was designed for roundwood logging. It was modified for energy wood logging by taking away feeding rolls and delimbing knives and replacing the chain saw with a guillotine knife. After the Moipu 400 E was launched, several manufactures have developed their own energy wood harwarder grips in Finland (Naarva 1500-40E,

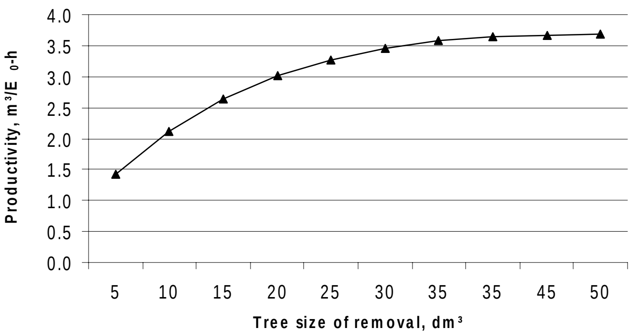

Figure 10. The effective hour productivity of energy wood logging with harwarder as a function of tree volume. Forwarding distance 250 m and accumulation of energy wood 50 m³ per hectare

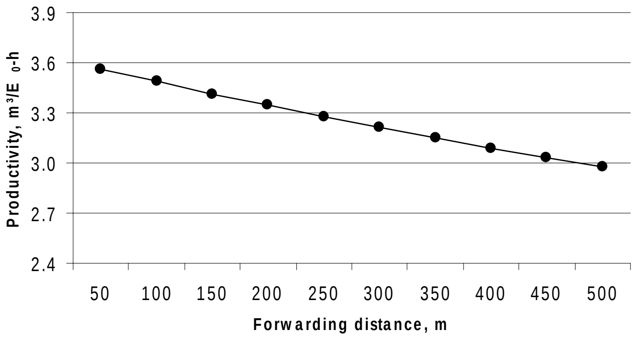

Figure 11. The effective hour productivity of energy wood logging with harwarder as a function of forwarding distance. Tree volume of removal is 25 dm³ and accumulation of energy wood 50 m³ per hectare

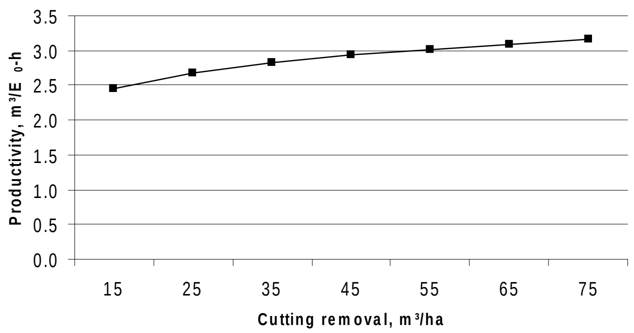

Figure 12. The effective hour productivity of energy wood logging with harwarder as a function of cutting removal. Tree volume of removal is 25 dm³ and forwarding distance 250 m

Ponsse EH 25, Pinox 220, Nisula 280E). Compared to earlier studies, the Moipu 400 E proved to be efficient and competitive (Hämäläinen and Lilleberg 1996, Hämäläinen and Rieppo 2000). It seems that the harwarder's productivity in energy wood thinnings is slightly higher than 3 m³/h.

The potential to further improve the harwarder work is considerable. In the time studies the harwarders logging work phases were not integrated, but harwarder was operating either as a forwarder or as a feller buncher. For example, the energy wood bunch, which had been collected, was laid on the ground instead to be lifted straight onto the load space. The operator used this working method, because the cranes lifting height was not adequate. It is obvious, that if most of the bunches are loaded directly onto the load space of the harwarder, it improves the productivity and diminishes the risk to get stones and mineral soil into the roadside storage pile.

There is a great demand to develop a reliable and real time method to estimate the harvested energy wood volumes. In this research, evaluation of cutting removal was carried out using sample plots and mathematical equations, which is very laborious, complicated and a somewhat inaccurate method to measure harvested volumes. In practical energy wood procurement, measurement of the harvested trees is performed a few months later when the trees are chipped. This delay is a big problem, since the contractor needs to get salary for his work earlier (Lindblad *et al*. 2005).

Measuring methods, which are based on load scale, are at the moment, obviously the most reliable and real time methods. The load scale is installed to the forwarders or harwarders crane and the measurement is carried out during unloading. The biggest problem with the load scale system is the fluctuation of the raw material's moisture content. The weight and moisture content of the energy wood cubic metre, which is seasoned a couple of summer weeks in the forest is clearly lower compared to the fresh wood after cutting. When using the harwarder method, there is not this kind of "drying" problem, because cutting and forwarding are linked together and the moisture content of the fresh wood is quite stable (Hakkila 1962).

State subsidies in Finland play a very important role in the procurement of bioenergy and they enable harvesting activities for fuel in early thinnings (Anon. 1996, Tanttu and Sirén 2004). Thus, there is a certain political and economical risk to invest into a business, which is based on state subsidies. The energy wood contractor can diminish this risk by buying a energy wood harwarder instead of a energy wood harvester and forwarder chain. According to Björheden and Dahlin (1999) the harwarder investment in roundwood logging compared to the harvester and forwarder chain amounts to around two thirds of the investment represented by the two machine system.

The energy wood harwarder is also a secure choice for starters in the business. Later he can expand the business flexibly by installing the felling-loading head to a separate felling machine and using the harwarders base machine as a conventional forwarder. The dual-purpose machine method enables better employment of machinery, because it is easier to find work for one machine than two machines and keep machine capacities in balance. The capacity balance is a big problem especially in energy thinning since the felling machine's productivity is roughly one third of forwarder's productivity (Laitila *et al*. 2004). In order to find the most economical machine mix, in terms of capital costs, a regional study to examine machine performance, seasonal fluctuations of employment and stand structure is needed (Imponen and Poikela 2005).

The regression models, which are published in this article, enable to carry out cost comparison and sensitivity analysis of the one machine system in different type of working conditions. It is valuable, when planning small-sized thinning wood procurement activities and allocating machine resources. Regression models are also needed, when developing and analyzing machines and working methods.

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ЗАГОТОВКА ЭНЕРГЕТИЧЕСКОЙОЙ ДРЕВЕСИНЫ В ХОДЕ РАННИХ РУБОК УХОДА ХОРВАРДЕРОМ

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Резюме

За последнее десятилетие хорвардеры развивались для заготовки как делового круглого леса, так и топливной древесины. Данная статья рассматривает продуктивность использования традиционного форвардера, оснащенного манипулятором Moipu 400 E, для заготовки топливной древесины в ходе рубок ухода в молодняках. Функции продуктивности лесозаготовок хорвардером были сформулированы с помощью регрессивного анализа, в котором за независимые переменные были взяты условия заготовки (объем стволов, объем заготовки, дистанция трелевки и т.д.). Производительность заготовки небольших деревьев с ветками хорвардером составила 3.3 m^3/E0-h (эффективный рабочий час), где объем дерева был 25 dm^3, содержание топливной древесины 50 m^3 на гектар, нагрузка 6.2 m^3 и дистанция трелевки 250 м. Валка и пакетирование занимали 45% эффективного рабочего времени хорвардера при заготовке топливной древесины. Прокладка волоков заняла 18% от общего времени, а погрузка поваленных деревьев – 17%. Расход времени на трелевку был 6% с грузом и 5% без груза. Передвижение во время заготовки, погрузки и разгрузки на нижнем складе заняло 5% эффективного рабочего времени.

Ключевые слова: рубки ухода в молодняках, хорвардер, топливная древесина, функции продуктивности, заготовка