PRODUCTIVITY AND COST OF LOGBEAR F4000 FORWARDER IN THINNING DEPENDING ON DRIVING CONDITIONS

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Abstract. According to earlier studies, Logbear F4000 forwarder is suitable for extreme and bad forwarding conditions in pre-commercial and commercial thinning, but it can be also used in salvage loggings and, when necessary, in final felling; however, larger machines are recommended for the conventional final felling. The aim of the study is to test performance of the tracked forwarder Logbear F4000 in thinning in forest stands with moderate or bad forwarding conditions (on wet and drained mineral and organic soils), including productivity, fuel consumption, load capacity and forwarding costs. Trials were conducted in 2016 and 2017 by forwarding logs in thinning, where harvesting was done by Vimek 404 T5 (bad conditions) and John Deere 1070 harvester and chainsaws (moderate conditions). No significant difference was found in forwarding productivity, when logging was done with a chainsaw or a harvester. In moderate forwarding conditions the average load was 3.4 m^3 and the average driving speed was 77.5 $m \cdot min^{-1}$, but in bad forwarding conditions the average load was 3.6 m^3 and the average driving speed was 45.0 $m \cdot min^{-1}$. According to the study, the productivity is significantly influenced by both, increase of the forwarding distance and the load size. The average fuel consumption of Logbear F4000 is 4.93 ± 0.26 (standard deviation) l per hour (1.14 ± 0.14 (standard deviation) $l\ m^{-3}$). Prime cost of roundwood forwarding in bad forwarding conditions is 6.8 $EUR \cdot m^{-3}$, in moderate conditions 7.9 $EUR \cdot m^{-3}$, accordingly, and is significantly influenced by increase of the forwarding distance and reduction of payload.

Keywords: Logbear F4000 forwarder**,** forwarding conditions, productivity, forwarding costs.

Introduction

Several studies concluded that forwarding conditions have a significant impact on the productivity and cost of the forwarding operation [1-5]. Productivity of forwarding can be increased through the use of machinery suitable for specific forwarding conditions [6]. As shown by several studies, forwarding of maximal payload is time and cost-effective [7].

Bearing capacity of soil closely relates to the forest site type and significantly affects the forwarder movement [3; 8; 9]. According to the classification, which is used by Joint Stock Company "Latvia State Forest" (hereinafter LSF), forwarding conditions, according to the forest type, are classified as good (sufficient bearing capacity of soil, forwarding can be done during all seasons, no need to use tracks), average or moderate (soil bearing capacity is moderate, trucked forwarders are recommended, if forwarding is done throughout the whole year), bad (bearing capacity of soil is low, moist areas should be crossed, it is necessary to strengthen strip roads with harvesting residues and low grade roundwood, forwarding is possible only by using tracks), extreme (very low bearing capacity of soil, forwarding can be done only when forwarders are equipped with tracks on the rear and front axle or soil is frozen or dried out) [3; 8; 10].

The increase of fuel consumption in forwarding is associated with the same factors that cause reduction of productivity [3; 9; 11].

The aim of this study is to evaluate the productivity and costs of the Logbear F4000 forwarder in thinning depending on the forwarding conditions and to determine the fuel consumption, load capacity and the driving speed.

Materials and methods

The trials were done in two forest stand areas managed by LSF. The first trial object was located in the northern part of Latvia in Piejūras forest district near Salacgrīva. The total area of the experimental site was 1.3 ha, stand type *Myrtilloso-sphagnosa*, the average tree height 8 m, average tree diameter 8 cm, growing stock 135 $m^3 \cdot ha^{-1}$, stand age 44 years, dominant tree species spruce (*Picea abies*). Thinning was done using the Vimek 404 T5 harvester. The second trial object was located in the central part of Latvia in Zemgale (Kandava forest district near Kandava). The total area of the experimental site was 9.8 ha (*Dryopteriosa)*, the average tree hight 11 m, average tree diameter 9 cm, growing stock 142 $m^3 \cdot ha^{-1}$, average stand age 46 years, dominant tree species birch (*Betula pendula*). Thinning was done using the chainsaw and John Deere 1070 harvester.

In this study forwarding productivity data were obtained in stands with moderate (*Myrtilloso-sphagnosa)* and bad (*Dryopteriosa)* forwarding conditions.

Forwarding was done using the Logbear F4000 forwarder, which had worked 1 187 engine hours before start of the trial. The main technical specifications of the forwarder are given in Table 1.

Table 1

Technical specifications of Logbear F4000 forwarder

Nr.	Indicators	Numerical values
1.	Engine	Perkins 804 TD – 33 T Turbodiese, 62 kW or 84 hp at 2 600 rpm.
2.	Transmission	Working speed 6 km h^{-1}, transport speed 12 km h^{-1}, tracks with pendulous bogie levers and tip wheel drive front.
3.	Chassis	Tracks with pendulous bogie levers and tip wheel drive front and rear, track weight 5.1 m, ground pressure front ~140 g cm^{-2}, ground pressure load ~ 460 g cm^{-2} (450 mm track), ground clearance front 3.8 m, ground clearance back 5.5 m.
4.	Dimensions and weight	Trailer width 2.0 m, front unit width 1.8 m, overall length from 6.7 to 7.2 m, height 2.7 m, unloaded weight 5.1 tonnes.
5.	Load space	Load space 1.9 m^2, load capacity 4 tonnes.
6.	Timber loader Cranab FC 45	Reach 6.1 m, extension length 1.5 m, grab area 0.2 m^2, grab opening 1.0 m.

Time study of forwarding was carried out manually by the continuous time study method using the hand-held data logger Allegro CX. In the time study one work cycle can include up to 15 work elements (Table 2.). Total working time (E_0) of forwarding includes all work elements, but productive working time (E_{15}) includes all work elements except "delays".

Table 2

Work elements of forwarding operations

Number of work elements	Work elements	Description of work element
1	Driving unloaded	Starts when the forwarder leaves the landing area and ends when the forwarder stops at the first loading site.
2	Reach during loading	Starts with the crane movement to reach the log pile and ends when the grapple reaches the pile of roundwood.
3	Gripped during loading	Starts with accessing the log pile and ends with grabbing of logs.
4	Loading	Starts with lifting the grapple with logs and ends when the grapple is rested on the bunk and opened.
5	Sorting load	Sorting the logs in the bunk.
6	Moving during loading	Movement between log piles with no crane movement. Starts when the operator prepares move to the next loading site and ends when the forwarder stops at the next loading site.
7	Road packing	Starts with the crane movement to piles of branches to put or remove them from forwarding roads and ends when the operator starts to move the crane in order to start another work operation.
8	Driving loaded	Starts when the operator moves to the landing area with a load and ends when the wheels cease to rotate and the operator starts to move the crane.

Table 2 (continued)

Number of work elements	Work elements	Description of work element
9	Reach during unloading	Starts with the crane movement to start unloading and ends when the grapple reaches the pile of logs in the forwarder’s bunk.
10	Gripping during unloading	Starts when the crane movement stops, with an empty grapple, towards the forwarder’s bunk and ends with closing the grapple with pile of logs in the forwarder’s bunk.
11	Unloading	Starts with lifting the crane and ends when the grapple is located over the pile and opened.
12	Sorting roundwood yard	Sorting of logs on the landing pile.
13	Moving during unloading	Movement between the piles at the landing area. Starts when the operator prepares move to the next pile and ends when the forwarder stops at the next pile.
14	Other operations	Other activity in forwarding (planning of work, lifting of fallen logs etc.) The reason of the activity is recorded.
15	Delays	Time not related to productive forwarding work, e.g., personal breaks, repairing or maintenance of the forwarder, phone calls. The reason of the activity is recorded. Delays longer than 15 minutes.

Fuel consumption of the forwarder was measured using AIC-904 VERITAS measure equipment, installed above the fuel filter.

During the trials, the weather conditions were appropriate to the season. In the period, when the first part of trials were done (11.04.2016 to 12.04.2016), the first half of the month (10 days before the trials), an average temperature was 6.3 ºC. In the days, when forwarding was performed, daily average temperatures were 6.4 and 7.9 ºC, respectively. During the period considered no significant precipitation was detected (1.1 mm in total per period). In the period, when the second part of trials was done (06.01.2017 to 24.01.2017), 2 weeks before the start of the trials the average temperature was in the range of 1.0 to -16.7 ºC, which contributes to freezing of the surface of soil. Relatively strong frost period lasted for several days. The average daily temperature in the period of the trials was between 1.6 and -3.8 ºC, thus the soil deep layers remained frozen. During the trial the surface layer of soil was covered with snow.

Logs are prepared according to the quality requirements of the LSF. Harvesting residues according to the work order are loaded into strip roads to improve the driving conditions.

Prime cost calculation of forwarding was done according to calculation models used in similar studies carried out previously [12-14]. Such indicators as average dimensions of extracted trees and productivity indicators for each unit of machinery, forwarding distance (270 m), forwarding speed (45 $m \cdot min.^{-1}$) and road transportation distance (50 km) are used in the cost calculation. It was assumed that two forwarder operators work in two shifts (eight-hour shift). Detailed cost monitoring data provided by the logging Service Company were used in prime cost calculation. Assumed profit margin is 5 %.

In order to determine the significance level of the data the Kolmogorov-Smirnov test was used.

Results and discussion

In total, 54 loads or 189 m^3 of roudwood were forwarded in the trials. The most of the roundwood (70 %) was forwarded from forest stands with bad forwarding conditions.

Forwarding of roundwood from areas with moderate forwarding conditions took 43.1 min. of productive or 50.8 min. of total time per load or 12.8 min. of productive or 15.1 min. of total time per solid cubic meter (m^3). On average loading and unloading of one load took 27.3 and 5.6 min., accordingly. The average productivity in moderate forwarding conditions was 1.4 loads or 4.7 m^3 per productive hour (loading 7.4 m^3 and unloading 36.0 m^3 per productive hour).

No significant difference was found between the forwarding productivity in bad forwarding conditions, where harvesting was done using the chainsaw and harvester, therefore, the average productivity values were used in the calculation. On average 32.1 min. of productive time (loading and unloading of one load 15.5 and 4.7 min., accordingly) or 38.4 min. of total time per load, or 9.0 min. of productive and 10.7 min. of total time per solid cubic meter was spent for forwarding of roundwood from areas with bad forwarding conditions. According to the results obtained in the trials, the average productivity in bad forwarding conditions was 1.9 loads or 6.7 m^3 per productive hour (loading 13.9 m^3 and unloading 46.1 m^3 per hour, accordingly).

In moderate forwarding conditions the average length of the forwarding distance was 395 m and the average speed of forwarding was 77.5 m $min.^{-1}$ or 4.6 km per hour (with average load of 3.4 m^3). In bad forwarding conditions the forwarding distance was considerably shorter (270 m) and the average speed of forwarding was significantly smaller (45.0 $m \cdot min.^{-1}$ or 2.7 km per hour with average load of 3.6 m^3). The forwarder speed in moderate forwarding conditions was bigger by about 42 % in comparison to bad forwarding conditions. The study approved the assumption that the forwarder driving speed is significantly influenced by geophysical factors [11].

The share of productive work time in moderate and bad forwarding conditions is similar, respectively 84 % and 85 % of the total work time.

Comparison of productivity of forwarding of 1 m³ of logs in different conditions demonstrated that in bad forwarding condition about 30 % less productive work time is spent in comparison to moderate conditions. Analysis of the productive work time elements depending on the forwarding conditions (Figure 1) proves statistically significant differences in reaching time during loading ($p = 0.00007 < 0.05$, in bad conditions 42 % less time is spent), gripping during loading ($p = 0.0009 < 0.05$, in bad conditions 36 % less time is spent), loading ($p = 0.0002 < 0.05$, in bad conditions 40 % less time spent), sorting of load ($p = 0.0002 < 0.05$, in bad conditions 58 % less time spent) and moving during loading ($p = 0.006 < 0.05$, in bad conditions 36 % less time is spent).

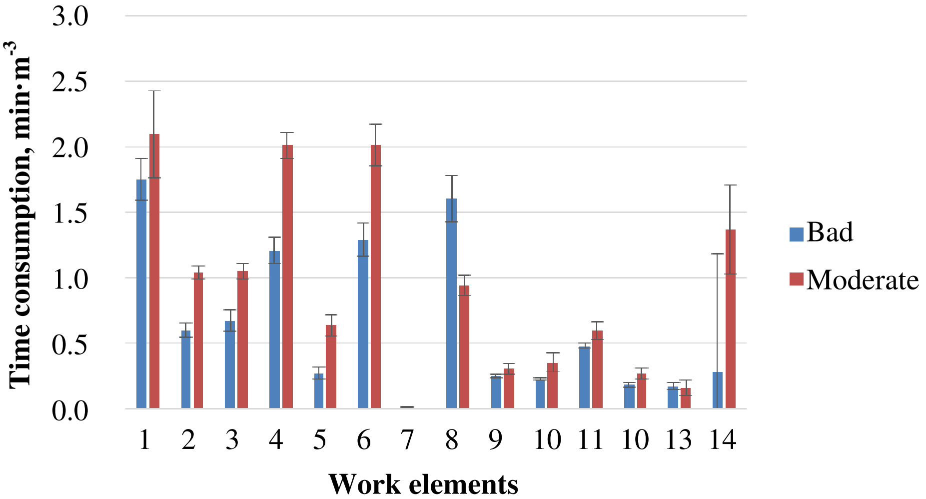

Fig. 1. **Distribution of work elements of productive time in forwarding of 1 m^3 roundwood depending on forwarding conditions**

Further analysis approved considerable impact of dimensions of logs – in bad conditions considerably bigger trees were harvested, respectively dimensions of the logs can have considerably bigger impact on productivity than forwarding conditions, if operators are able to use the loading capacity of the machines to full extend [14-16]. Another factor potentially affecting the productivity was the harvesting method – in moderate conditions the Vimek harvester was used; it creates dense network (after every 10 m) of narrow (less than 2.5 m) strip-roads, which can hamper the productivity of forwarding in comparison to the trials in bad conditions [16; 17], where strip-roads were 4 m wide and distributed in twice smaller density, respectively the forwarder can take at least twice more logs at every loading point. Forwarding distance and utilization of load capacity also can have significant impact on the productivity of forwarding [5; 18].

According to the measurements of fuel consumption the average fuel use of the Logbear F4000 forwarder was 4.93 ± 0.26 (standard deviation) l per hour (1.14 ± 0.14 (standard deviation) l m^{-3}) during the trials.

According to the assumptions in prime cost calculation a forwarder works 2 905 productive hours annually. Prime cost calculation proves (Table 3) that in case, if harvesting is carried out with a chainsaw and forwarding – with the Logbear F4000 forwarder in bad forwarding conditions, the prime cost of roundwood is 22.5 EUR m^{-3}, including 17.4 EUR m^{-3} of harvesting and forwarding cost. If harvesting is carried out with the Vimek 404 T5 harvester and forwarding – with the Logbear F4000 forwarder in moderate forwarding conditions, the prime cost of roundwood is 22.1 EUR m^{-3}, including 17.0 EUR m^{-3} of harvesting and forwarding cost. Prime cost of forwarding ranges from 6.8 to 7.9 EUR m^{-3} and is significantly influenced by reduction of the average load (from 3.8 m^3 to3.0 m^3, respectively) at the same forwarding distance (270 m). The average annual cost (115 thousands EUR) of the forwarder consists of investments (38 %), operational costs (29 %), staff costs (28 %), and profit margin (5 %). Forwarding cost significantly increases with increase of the forwarding distance, mainly due to the relatively small load size [3; 5; 11].

Table 3

Prime cost calculation depending on forwarding conditions

Parameters	Harvesting with chainsaw		Harvesting with Vimek 404 T5 harvester		Road transport
	harvesting	forwarding	harvesting	forwarding	
Equipment unit costs, EUR yr.					
Investments	1 916	43 728	35 263	43 728	15 206
Staff costs	99 368	32 485	41 911	32 485	14 536
Machine costs	18 381	33 634	76 059	33 634	31 207
Estimated profit	5 983	5 492	7 662	5 492	3 047
In total, EUR yr.	**125 647**	**115 339**	**160 895**	**115 339**	**63 997**
Productivity					
Roundwood (with bark), m³ per E_{15}	**1.5**	**6.0**	**6.5**	**6.9**	**10.1**
Total annual production					
Roundwood (with bark), $m^3 \cdot yr^{-1}$	15774	16157	18699	18753	14070
Roundwood (without bark), $m^3 \cdot yr^{-1}$	13260	14556	15719	16895	12676
Bark and other forest residues, $m^3 \cdot yr^{-1}$	1459	1601	1729	1858	1394
Prime cost					
Roundwood, $EUR \cdot m^{-3}$	**9.48**	**7.92**	**10.24**	**6.83**	**5.05**

Conclusions

1. The productivity values observed in bad forwarding conditions were by 30 % better in comparison to moderate forwarding conditions, which could be explained by different harvesting technologies applied in the studies; however, this hypothesis should be verified in further studies to improve the overall performance of small sized forest machines.
2. No difference was observed in forwarding productivity depending on the harvesting technology – with chainsaws or harvesters; therefore, other factors like the distance between strip-roads and dimensions of logs might have bigger impact than the harvesting equipment.
3. Fuel consumption per roundwood unit was significantly affected by the forwarding distance; the average fuel consumption per 1 m³ does not exceed the values observed in earlier trials with

medium-sized forwarders in the same range of forwarding distances. The average fuel consumption of Logbear F4000 is 4.9 l per hour (1.14 l m^{-3}).

4. Prime cost of roundwood forwarding in bad forwarding conditions is 6.8 EUR m^{-3} but in moderate conditions – 7.9 EUR m^{-3}. Prime cost is significantly affected by the forwarding distance and the load size.

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