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Time study of an all-terrain vehicle (ATV) with a forwarding trailer in the Eagle Mountains in the Czech Republic

*Zbyněk Kincl**

Faculty of Forestry and Wood Sciences, Czech University of Life Sciences, Prague, Czech Republic

**Corresponding author: firma@zkincl.cz*

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Abstract: In this research, the time consumption of a CF Moto Gladiator 800 all-terrain vehicle (ATV) with a Vahva Jussi 1500/320 log trailer was researched by the timber forwarding in the forests of the Eagle Mountains in the Czech Republic. The study was conducted in an area with a minimal slope, the terrain was full of obstacles, the average forwarding distance was 480 m, while the random harvesting of trees affected by bark beetle was carried out in the forest. A total of 81 forwarding cycles were measured. The elemental time study method and stepwise regression analysis were applied to develop the forwarding time prediction model. In the study, it was found that the total forwarding cycle time is mostly influenced by the forwarding distance and the number of logs loaded. The total average time per forwarding cycle was 22.53 min, of which an average of 40% was transport time and 60% was time for loading and unloading of logs. An average of 1.43 m^3 of timber was forwarded per forwarding cycle. Therefore, the estimated productivity of the ATV forwarder was 3.89 $m^3 \cdot h^{-1}$.

Keywords: chronometric analysis; forwarding trailer; labour productivity; small-scale machines in forestry

Interest in so-called small-scale production technologies began to develop in European forestry in the 1980s (Neruda, Simanov 2013), and in the Czech Republic especially after 1989, when some forests were transferred to private ownership. Small-size machines are generally used for lower volumes of work and are characterized by lower acquisition and operating costs, as well as easier handling and better manoeuvrability even in difficult terrain conditions (due to their smaller size) and also by their lower environmental impact (due to their lower weight and lower pressure on the soil). Currently, there is a greater emphasis on smaller forest interventions and working with light machinery, which has created a need to modernize these technologies. As a result, the all-terrain vehicle (ATV) – the so-called four-wheeler – has been incorporated into forest work. The American National Standards Institute (ANSI) defines the all-terrain vehicle as "a motorized off-highway vehicle designed to travel on four low pressure tires, having a seat designed to be straddled by the operator and handlebars for steering control" (ANSI/SVIA 2017). The first ATVs began to be produced in Japan and North America in the 1970s and 1980s. Over time, ATVs have spread around the world and their uses have ex-

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panded. Nowadays, we mainly distinguish between sport and universal (recreational/work/utility) ATVs. Universal ATVs are more robust, taller and heavier than sports ATVs, they usually have four-wheel drive and can be fitted with a range of working accessories – front and rear carriers and storage boxes, winches, various types of trailers, snow ploughs, tillers and cutters, mowers or mulchers, etc. For winter, utility ATVs can be equipped with snow tracks instead of wheels. Universal ATVs soon found their way into agriculture and forestry. They began to be deployed for forwarding and transporting timber in forestry, for transporting materials needed for work in the forest and for hunting.

In spite of the mentioned advantages of small mechanization means, a modified agricultural tractor is still the most commonly used vehicle for timber harvesting in small-scale private forestry, i.e. the machine that is not understood as a small-size machine in Czech conditions (Neruda, Simanov 2013). Small-scale forestry equipment is rarely used typically, and when it is, mainly in Sweden and other Scandinavian countries, as well as in Austria and North America (Russell, Mortimer 2005).

In the Czech Republic, forests cover approximately one third of the total area. One fifth of the forests are privately owned. When harvesting timber in smaller forests, an agricultural tractor or forwarder is most often used, less often a horse or small forwarders. While ATVs are available, they are not used on a larger scale (Russell, Mortimer 2005).

Research on the use of ATVs in forestry and the measurement of the productivity of ATVs (and small-size machines in general) in timber harvesting has been more widely studied in Canada (Dunnigan et al. 1987; Cadorette 1995; Masson, Greek 2006) and in the USA (Updegraff, Blinn 2000; Halbrook 2005; Meadows et al. 2008), and in European countries, especially in Sweden (Nordfjell 1990, 1995; Edenhamn 1991; Loftaeng 1991), England and Ireland (Jones 1997; Drake-Brockman 1998; Russell, Mortimer 2005; Kent et al. 2011), less so, for example, in Italy and other countries (Picchio et al. 2005; Savelli et al. 2010; Varol 2020). Several research inquiries on this topic have also been conducted in the Czech environment (Cink 2001; Valenta, Neruda 2001; Kincl 2013).

Since 2002, an international journal for multidisciplinary research in the field of small-scale forestry, named Small-Scale Forestry (Springer Netherlands), has been published under the auspices of the Small-Scale Forestry Group of the International Union of Forest Research Organizations (IUFRO).

MATERIAL AND METHODS

The present study was carried out in the Eagle Mountains (Orlické hory) in the north-east of Bohemia near the border with the Republic of Poland. The altitude of this area is 670 m a.s.l. and the average annual rainfall is 1 200 mm. The forest land was flat, but the terrain was full of obstacles, with many of them at a height of 30–50 cm. Table 1 presents the main characteristics of the study area.

In the stand there was random harvesting of individual trees affected by bark beetle. The timber harvesting was carried out by one worker, a man aged 60 with 25 years experience and a degree in mechanical engineering. The timber was forwarded using a small forwarder consisting of a CF Moto Gladiator V800 EFI ATV and a Vahva Jussi 1500/320 log trailer with hydraulic crane (Figure 1).

Tables 2 and 3 show the main characteristics of the ATV and the log trailer.

Experimental measurements were made using the chronometric analysis method, by successive snapshots of the work during working hours. The job of the ATV operator was not just forwarding, but also felling and clearing brush. But only the forwarding work was monitored and measured in this study. The forwarding work operation was analysed for the following work elements: 1 – travel

Table 1. Characteristics of the study area

Characteristic	Value
Location	forest land in Černá Voda near Orlické Záhoří, Eagle Mountains (Orlické hory), Czech Republic
Altitude (m a.s.l.)	670
Average slope (%)	< 10
Silvicultural system	random harvesting – single trees
Species	spruce
Mid diameter range of the logs (95% interval)	21–33 cm
Terrain passability	bumps, depressions, obstacles higher than 30 cm at a distance of less than 5 m (stumps)
Maximum forwarding distance	850 m

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Figure 1. ATV Forwarder – CF Moto Gladiator V800 EFI ATV and Vahva Jussi 1500/320

unloaded from the landing site to the tree; 2 – loading/creating a load; 3 – travel loaded to the landing site; 4 – unloading/depositing the load at the landing site (Dvořák et al. 2010). The landing site was located at the edge of the stand.

A total of 81 working cycles were observed. For each work cycle the following variables were observed:

– forwarding distance;

– forwarding route properties: weather- and moisture-dependent forwarding route properties were recorded. The three conditions were: 1 – dry (the surface of the route was dry); 2 – damp (the surface of the route was damp, mud was forming in the depressions); 3 – wet (the surface of the road was wet, there was water in the depressions). The given properties were homogeneous along the entire route. The classification of properties was carried out by sight;

– number and length of logs loaded: in this operation, 4 m long assortment and 2.5 or 2.8 m long assortment were produced; hereafter referred to as long (4 m) and short (2.5 m, 2.8 m) assortments;

– average diameter of logs produced: the average diameter of logs was measured only for 4 m long logs. For shorter logs, the average volume was calculated based on the size of the load and the number of logs (the size of the load was determined by measuring the spatial volume of the whole load);

– the character of the loading: the following two conditions were established: 1 – the individual logs are located in the stand, the forwarder has to drive into the stand and drive to the individual logs; 2 – the individual logs are located close to the gravel forest road, the forwarder drives only on the gravel forest road when loading.

Table 2. ATV CF Moto Gladiator X8 V-twin 800 EFI (CF Moto 2017)

Characteristic	Value
Manufacturer	CF Moto, China
Dimensions	length: 2 320 mm; width: 1 180 mm; height: 1 360 mm; wheelbase: 1 480 mm
Weight	387 kg
Motor	type: 4-stroke, 8-valve twin cylinder; displacement: 800 cc; power: 14.8 kW/5 600 rpm
Transmission	automatic CVT – variator; lockable front differential; P/R/N/H/L gears (park/reverse/neutral/fast forward/terrain reduction)
Tires	front: 26/9 R14; rear: 26/11 R14
Brakes	hydraulic disc brakes

Table 3. Vahva Jussi 1500/320 log trailer (JPJ Forest 2021)

Characteristic	Value
Manufacturer	Kreisi Metall OÜ, Estonia
Dimensions, weight	3 900 × 1 250 mm; weight incl. hydraulic arm: 320 kg
Load capacity, capacity	load capacity: 1 500 kg; capacity: 2.0 m^3; length of loading area: 2.3 m; ground clearance: 35 cm
Tires	22/11 R8
Hydraulic arm	weight: 150 kg; reach: 3.2 m; max. lifting force: 550 kg; swivel angle: 330°
Hydraulic system drive	Honda unit (6.5 hp), 175 bar

The time consumption for each working operation and the total volume of timber exported were recorded. The collected data were statistically analysed in the statistical software SPSS (Version 24, 2021).

It was assumed that the total time per cycle is a function of the above-mentioned variables. The stepwise regression analysis was applied to develop a model of this function. In this method, if any variable has a significant effect on the RMS (residual mean squares) of the model, it would be used in the model.

The evaluated dependent variable was the total time per cycle. Factors whose effect on the dependent variable was analysed were the forwarding distance, the forwarding route properties, the character of the loading, the total load volume, the number of 4 m long and shorter logs and the average diameter of the logs produced.

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RESULTS AND DISCUSSION

Table 4 shows the average working time and the share of elemental times of working cycle. The total operating time for one cycle of forwarding was 22.53 min on average. The most time-consuming work operation was operation 2 – loading (37%). The least time-consuming work operation was work operation 1 – travel unloaded (18%). Comparable amounts of time were required by work operations 3 – travel loaded, and 4 – unloading (22%). No delay times were measured during the individual forwarding cycles. No personal, mechanical or operational delays were recorded.

Table 4 further shows that the time required for loading is 70% more than the time for unloading. This result is logical, as the creation of the load represents a more complex working operation – the time is increased by the need to clear the different logs from different points in the stand by hydraulic crane and possibly by travelling. On the other hand, the time for unloading can be prolonged, e.g. by straightening the logs into different piles. In our measurements, the clearing of timber was more time-consuming than the straightening of timber into piles.

It is also interesting to compare the time required to drive an empty machine from the landing site to the stand and the time required to drive a machine with a load from the stand to the landing site. Here it could be assumed that travel loaded machine would be more time-consuming than travel unloaded machine. However, Table 4 shows that the difference between the travel times of a loaded machine and an unloaded machine is not too great. Travel loaded requires on average only 21% more time than travel unloaded. In explaining this small difference, we must also consider the properties of the forwarding route. When the results are examined in more detail, we see that in the case where the forwarding route was wet, the time required for travel loaded and the time for travel unloaded hardly differed, i.e. the operator of the forwarder was forced to drive slowly even when the forwarder was empty. Conversely, when the forwarding route was dry, the ATV operator could afford to drive faster with the empty machine than with the loaded machine – the difference between the times is higher here (Table 5).

Table 6 presents the statistics of operational variables of forwarding in the study area.

The average volume of one load was 1.43 m^3. The capacity of the log trailer (2 m^3 – stated by the manufacturer) was not therefore fully used. The operator of the ATV justified this by his concern for the life of the machine, he loaded the log trailer always only up to the level of the stake, the maximum measured load volume was 1.85 m^3. There were on average 11 logs per load (4 long logs and 7 short logs). As the operator of the ATV worked in the system of tree felling, bucking – forwarding, it happened that only half of capacity of the log trailer was used (minimum measured volume of the load – 1 m^3), as the operator did not have enough logs ready to fill the capacity of the machine. Since no delay times were recorded, we can assume that if the forwarding process was not interrupted by felling, the average machine productivity would be 3.89 $m^3 \cdot h^{-1}$. Such labour productivity is quite high in the context of previous research. The manufacturer of the Vahva Jussi forwarding trailer states that the average productivity of the Vahva Jussi 1500/320 log trailer is 1.25 to 2.5 $m^3 \cdot h^{-1}$ (JPJ Forest 2013). Kincl (2013) measured the labour productivity of a Polaris Sportsman 800 ATV with a Kranman T 1900 4WD log trailer (i.e. a forwarder comparable to the forwarder in this study) and found the labour productivity of 1.2 $m^3 \cdot h^{-1}$. However, the forwarding conditions here were different from our study

Table 4. Average time and share of time segments

Elemental times of working cycle	Time (min)	Time (%)
Travel unloaded	4.14	18.4
Loading	8.43	37.4
Travel loaded	4.98	22.1
Unloading	4.98	22.1
Total transport time	9.12	40.0
Total loading/unloading time	13.41	60.0

Table 5. Difference between time for travel unloaded and time for travel loaded depending on the properties of the forwarding route

Properties of the forwarding route	Average time for travel unloaded (min)	Average time for travel loaded (min)	Difference (%)
1 – dry	3.12	4.45	43
2 – damp	3.98	4.62	16
3 – wet	5.00	5.55	11

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Table 6. The statistics of operational variables of forwarding in the study area

Variable	Units	Mean	Standard deviation	Minimum	Maximum
Forwarding distance	(m)	478	184	150	850
Number of logs in the load	(pcs)	10.67	2.70	5	17
Number of 4 m long logs		3.58	2.07	0	8
Number of short logs of 2.5 m and 2.8 m		7.09	4.36	0	17
Total load volume	(m^3)	1.43	0.16	1.00	1.85
Average volume of logs		0.14	0.04	0.08	0.29
Total forwarding cycle time	(min)	22.53	3.47	16.75	32.97
Travel unloaded		4.13	1.38	1.37	6.57
Loading		8.43	1.55	5.80	13.78
Travel loaded		4.98	1.22	2.37	7.22
Unloading		4.98	0.80	2.83	6.90
Total transport time		9.12	2.57	3.78	13.78
Total loading/unloading time		13.42	2.05	9.08	20.37
Estimated labour productivity	($m^3 \cdot h^{-1}$)	3.89	0.65	2.45	5.51

– in particular, the forwarding distance (1 400 m) and the slope of the ground (45%) were different. If we assume that the productivity of the forwarder decreases with increasing forwarding distance and with increasing slope of the terrain, then we can say that the results of both researches are analogous. Other researchers have measured the productivity of the ATV in forwarding timber with other technologies than the log trailer. For example, Halbrook (2005), Kent et al. (2011), or Valenta and Neruda (2001) studied the productivity of an ATV with a log hauler. Savelli et al. (2010) measured the productivity of an ATV with a single chain choker. In Table 7 we can see a comparison of the results of the available research.

The data measured in our study were analysed in the statistical program SPSS. The stepwise regression analysis was applied to the time study data base to develop a cycle time equation. The variables selected were the total load volume, the number of 4 m long and shorter logs, the average diameter of the logs produced, the forwarding distance, the properties of the forwarding route and the character of the loading. The parameters total load volume and number of logs are highly correlated, the influence of one variable overrides the influence of the other and it is not therefore appropriate to use them together in a single model. Thus, we created two models, one using the load volume parameter (model T_1) and the other using the parameters number of long and

Table 7. Comparison of ATV productivity in timber harvesting based on available research

Characteristic	This study	Kincl (2013)	Valenta, Neruda (2001)	Halbrook (2005)	Savelli et al. (2010)	Kent et al. (2011)
Technologies	hydraulic arm log trailer	hydraulic arm log trailer	log hauler	log hauler	chain choker	log hauler
Slope (%)	< 10	< 45	< 10	10	20	n/a
Average volume of logs (m^3)	0.14	0.13	0.05	0.2	0.12	0.06
Total cycle time (min)	22.53	73.00	n/a	5.23	4.52	11.65
Forwarding distance (m)	480	1 400	180	110	80	170
Load volume (m^3)	1.4	0.5	0.1	0.5	0.3	0.1
Labour productivity ($m^3 \cdot h^{-1}$)	3.89	1.2	1.22	5.4	3.8	0.57

n/a – not present in the study

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short logs and their average volume (model T_2). Both of these models meet the assumptions of a linear model. The normality of the data distribution was checked by a graphical dependence between the observed and predicted values. There were no outliers in the data. The Durbin Watson statistic was also checked, which showed acceptable values (1.24 for the first model, 1.36 for the second model).

In the first model (T_1), the stepwise regression analysis showed that only the forwarding distance, the properties of the forwarding route and the total load volume are significant variables (Table 8). According to the standardized coefficient β = 0.617, we see that the forwarding distance has the greatest influence on the total time of the forwarding cycle. The time required for one forwarding cycle increases as the forwarding distance increases. The total time of the forwarding cycle is also significantly influenced by the weather -related properties of the forwarding route. The forwarding route was a gravel forest road with depressions that filled with water after rain, in which case it was necessary to drive more slowly. The time required for one forwarding cycle was therefore longer. Load volume is another statistically significant variable, but here only at the α = 0.05 level. Even according to the lower standardized coefficient β = 0.180, we can see that the volume of the load has less influence on the total time of the forwarding cycle compared to the forwarding distance and properties of the forwarding route.

Based on the unstandardized *B* coefficients, we can arrive at a substantive interpretation of the measurement results. If the forwarding distance is extended by 1 000 m, the total time is extended by 12 min, so it takes the forwarder an average of 1.2 min to travel 100 m. The total forwarding cycle time is also increased depending on the properties of the forwarding route, by approximately 1.5 min if the forwarding route is damp compared to a dry forwarding route, and by further 1.5 min if the forwarding route is wet. As the volume of the load increases, the total forwarding cycle time increases by approximately 4 min for each additional cubic meter, i.e. it takes the operator of the forwarder an average of 24 s to load 0.1 m^3.

From the model T_1 we can derive the following Equation (1):

$$T = 8.411 + 0.012D + 1.480P + 3.853V \quad (1)$$
$$R^2 = 0.588$$

where:

T – cycle time (min);

D – forwarding distance (m);

P – forwarding route properties (1 – dry; 2 – damp; 3 – wet);

V – load volume (m^3).

The coefficient of determination R^2 of 0.588 expresses that this regression equation explains 59% of the dependent variable, i.e. the total time of the forwarding cycle, so the prediction is quite strong. The significance level of the ANOVA table (Table 9) shows that the model is significant at α = 0.001.

The graphs in Figures 2 and 3 illustrate the linear dependence of the total time on the forwarding distance and on the properties of the forwarding route. Thus, we can see that (*i*) the longer the forwarding distance, the longer the total forwarding cycle time; and (*ii*) the more unfavourable (in terms of moisture) the surface of the forwarding route, the longer the total forwarding cycle time. Such findings are logical.

In the following model (T_2), the variables number of long logs and number of short logs were used in-

Table 8. Total forwarding cycle time, model T_1

Variable	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	std. error	β		
(Constant)	8.411	2.449	–	3.434	0.001**
Forwarding distance (m)	0.012	0.001	0.617	8.372	< 0.001***
Forwarding route properties	1.480	0.285	0.384	5.194	< 0.001***
Load volume (m^3)	3.835	1.585	0.180	2.420	0.018*

*;**;*** significant at α = 0.05; α = 0.01 and α = 0.001 respectively; t – t-statistic; Sig. – significance

Table 9. ANOVA, model T_1

	Sum of squares	df	Mean square	F	Sig.
Regression	572.956	3	190.985	36.663	< 0.001***
Residual	401.104	77	5.209	–	–
Total	974.060	80	–	–	–

***significant at α = 0.001; F – F-statistic; Sig. – significance

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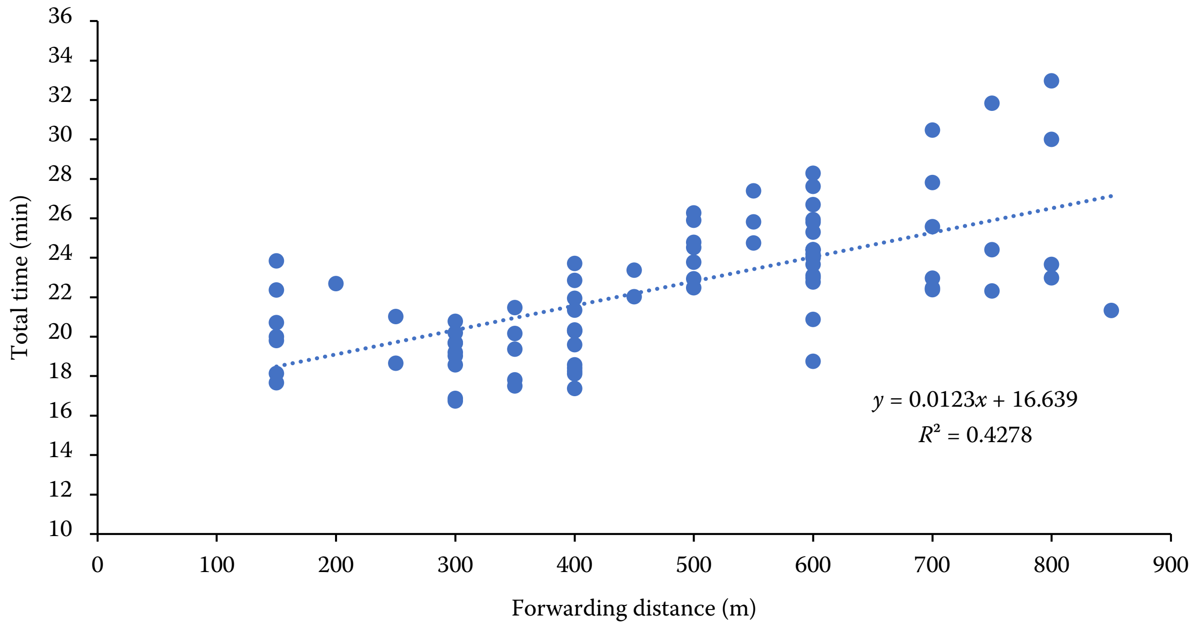

Figure 2. Dependence of the total time on the forwarding distance

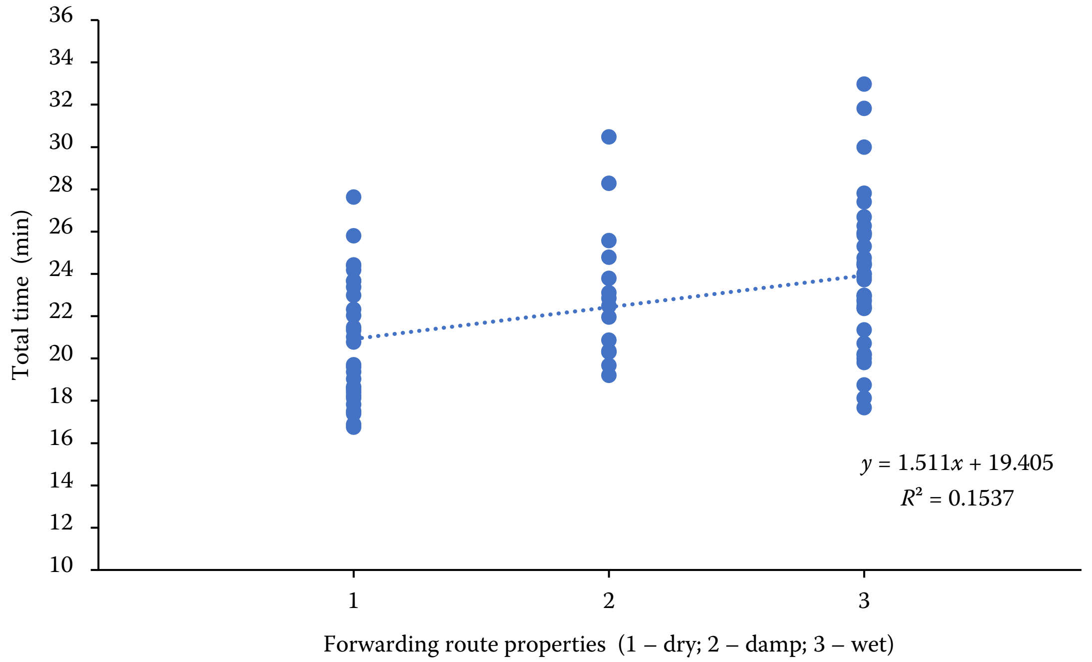

Figure 3. Dependence of the total time on the properties of the forwarding route

stead of the variable load volume. Table 10 shows the regression analysis of the value of total forwarding cycle time based on these variables. The stepwise regression analysis showed that only forwarding distance, forwarding route properties, and the number of long and short logs are significant variables here.

It shows that using the variables number of long logs and number of short logs is more advantageous than using the variable load volume in the regression analysis of the value of total forwarding cycle time. Here we see the dependence is significant at the $\alpha = 0.01$ and $\alpha = 0.001$ levels, while for the load volume

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variable the dependence was significant only at the α = 0.05 level. Based on the standardized β coefficients, we see that the number of long logs has the most pronounced effect on the total forwarding cycle time (β = 0.611). As the number of long logs increases, the total forwarding cycle time increases by approximately 1 min per piece. The forwarding distance has a similarly pronounced effect (β = 0.548) on the total cycle time. The effect of the number of short logs and the properties of the forwarding route is less pronounced but statistically very significant.

Based on the unstandardized coefficients *B*, we arrive at similar substantive results like in model T_1. As the forwarding distance is extended, the total forwarding cycle time increases by an average of 1.1 min per 100 m. The unfavourable properties of the forwarding route increase the total forwarding cycle time by 1.6 min if the forwarding route is damp and by further 1.6 min if the forwarding route is wet. It takes the operator approximately 1 min to load long assortment. It takes the operator only approximately 0.4 min to load short assortment.

From model T_2 we can derive the following Equation (2):

$$T = 6.967 + 0.011D + 1.638P + 1.023N_L + 0.436N_S \quad (2)$$
$$R^2 = 0.631$$

where:

T – cycle time (min);
D – forwarding distance (m);
P – forwarding route properties (1 – dry; 2 – damp; 3 – wet);
N_L – number of long logs (pcs);
N_S – number of short logs (pcs).

The coefficient of determination R^2 of 0.631 expresses that this regression equation explains 63% of the dependent variable, i.e. the total time of the forwarding cycle, so the prediction is quite strong, and it is also stronger than in the case of model T_1. From this we can conclude that using model T_2 is more accurate for calculating the total forwarding cycle time than using model T_1 (R^2 = 0.588). The significance level of the ANOVA table (Table 11) shows that the model is significant at α = 0.001.

For a more accurate result, the total cycle time can be divided into the transport time (travel unloaded plus travel loaded) and the time for loading and unloading. Variables from model T_2 were used because its R^2 was higher. The variables were logically divided into transport time and loading/unloading time. Significant variables affecting transport time include the forwarding distance and the properties of the forwarding route (Table 12).

In Table 12 we see that the forwarding distance has a more pronounced effect on the transport time than the properties of the forwarding route. Both variables have a statistically significant effect at the α = 0.001 level. The substantive results are similar to the previous models: for every 100 m of forwarding route, the transport time increases by 1 min on average; with unfavourable forwarding route properties, the transport time increases by 1.4 min on average.

From model T_T, we can derive the following Equation (3):

Table 10. Total forwarding cycle time, model T_2

Variable	Unstandardized coefficients		Standardized coefficients	*t*	Sig.
	B	std. error	β		
(Constant)	6.967	1.979	–	3.520	0.001**
Forwarding distance (m)	0.011	0.001	0.601	8.553	< 0.001***
Forwarding route properties	1.638	0.281	0.425	5.832	< 0.001***
Number of long logs (pcs)	1.023	0.261	0.611	3.913	< 0.001***
Number of short logs (pcs)	0.436	0.122	0.548	3.585	0.001**

;*significant at α = 0.01 and α = 0.001 respectively; *t* – *t*-statistic; Sig. – significance

Table 11. ANOVA, model T_2

	Sum of squares	df	Mean square	*F*	Sig.
Regression	615.047	4	153.762	32.550	< 0.001***
Residual	359.013	76	4.724	–	–
Total	974.060	80	–	–	–

***significant at α = 0.001; *F* – *F*-statistic; Sig. – significance

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$$T_T = 1.421 + 0.010D + 1.393P \quad (3)$$
$$R^2 = 0.793$$

where:
T_T – transport time (min);
D – forwarding distance (m);
P – forwarding route properties (1 – dry; 2 – damp; 3 – wet).

This regression equation explains 79% of the dependent variable, i.e. transport time, so the prediction is very strong. The significance level of the ANOVA table (Table 13) shows that the model is significant at $\alpha = 0.001$.

The significant variables affecting the length of loading/unloading time are the number of long logs and the number of short logs (Table 14).

Table 14 shows that both variables have a similarly pronounced effect on the loading/unloading time, with statistical significance for both variables at the $\alpha = 0.001$ and $\alpha = 0.01$ level. Table 14 further shows similar substantive results like in the previous models: it takes the operator of a forwarder approximately 0.8 min to load long assortment; it takes the operator approximately 0.4 min to load short assortment.

From model T_L we derive the following Equation (4):

$$T_L = 7.679 + 0.844N_L + 0.383N_S \quad (4)$$
$$R^2 = 0.159$$

where:
T_L – loading/unloading time (min);
N_L – number of long logs (pcs);
N_S – number of short logs (pcs).

The prediction of the loading/unloading time according to this model is distinctly lower than the prediction of the transport time ($R^2 = 0.159$). We hypothesize that there may be a number of other influences at work here that were not observed in this study, e.g. terrain irregularities and soil bearing capacity in the stand, scheduling of load assembly, distribution of logs to different piles, etc. In contrast, we do not expect a pronounced effect of other factors for the prediction of transport time ($R^2 = 0.793$). The significance level of the ANOVA table (Table 15) shows that the model is significant at $\alpha = 0.01$.

Table 12. Transport time, model T_T

Variable	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	std. error	β		
(Constant)	1.421	0.468	–	3.040	0.003*
Forwarding distance (m)	0.010	0.001	0.720	13.949	< 0.001***
Forwarding route properties	1.393	0.147	0.488	9.462	< 0.001***

*;***significant at $\alpha = 0.05$ and $\alpha = 0.001$ respectively; t – t-statistic; Sig. – significance

Table 13. ANOVA, model T_T

	Sum of squares	df	Mean square	F	Sig.
Regression	422.551	2	211.275	149.126	< 0.001***
Residual	110.507	78	1.417	–	–
Total	533.058	80	–	–	–

***significant at $\alpha = 0.001$; F – F-statistic; Sig. – significance

Table 14. Loading/unloading time, model T_L

Variable	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	std. error	β		
(Constant)	7.679	1.514	–	5.071	< 0.001***
Number of long logs (pcs)	0.844	0.222	0.854	3.800	< 0.001***
Number of short logs (pcs)	0.383	0.106	0.816	3.632	0.001**

;*significant at $\alpha = 0.01$ and $\alpha = 0.001$ respectively; t – t-statistic; Sig. – significance

Table 15. ANOVA, model T_L

	Sum of squares	df	Mean square	F	Sig.
Regression	54.102	2	27.051	7.381	0.001**
Residual	285.853	78	3.665	–	–
Total	339.955	80	–	–	–

**significant at $\alpha = 0.01$; F – F-statistic; Sig. – significance

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Here we must mention that the above models are valid only for similar conditions like in the monitored location (one worker, average slope < 10%). We are aware that time consumption can also be affected by other factors, such as the higher average slope or the human factor. These variables are analysed in our further research, on the basis of which it will be possible to perform some generalization and standardization of data.

CONCLUSION

In our study, the total average time per forwarding cycle of an ATV with the forwarding trailer was 22.53 min, of which an average of 40% was transport time and 60% was loading/unloading time. The estimated labour productivity of the forwarder was 3.89 $m^3 \cdot h^{-1}$. This labour productivity is considerably high in the context of available research measuring the productivity of an ATV in timber forwarding. This may be due to, for example, a minimal slope, properly selected logging technology and relatively high capacity of the forwarder.

The stepwise regression analysis shows that the number of long (4 m) logs ($\beta = 0.611$) and the forwarding distance ($\beta = 0.601$) have the greatest influence on the forwarding cycle time, followed by the number of short logs ($\beta = 0.548$) and by the forwarding route properties ($\beta = 0.425$). Loading long logs is more time-consuming than loading shorter logs. According to our measured data, it takes approximately twice as long to load 4 m long assortment as it does to load 2.5 m long assortment. On the other hand, four-meter long logs have approximately twice the volume of short logs. Therefore, it is not possible to say unambiguously which length of the logs is more advantageous for forwarding with the CF Moto Gladiator 800 ATV and the Vahva Jussi 1500/320 log trailer, or the length of the logs does not play a pronounced role when maintaining a comparable load volume. The addition of short logs to four-meter-long logs also seems to be a suitable solution. The solution of this problem may be to move away from the time study and to focus on labour productivity (relating time consumption and produced quantity). This is the subject of our further research. Since one of the most important parameters for the forwarding cycle time is the forwarding distance, we can confidently state the recommendation that, especially for longer forwarding distances, it is advisable to ensure the maximum possible capacity utilization of the forwarder.

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