Istraživanjaiprojektovanjazaprivredu
Journal of Applied Engineering Science

Original Scientific Paper

DOI:10.5937/jaes0-35136
Paper number: 20(2022)3, 997, 908-916
www.engineeringscience.rs * ISSN 1451-4117 * Vol.20, No 3, 2022

MODELING THE FUEL CONSUMPTION OF FORWARDERS BASED ON DIFFERENT LOG SIZES AND FORWARDING DISTANCES

Konstantin Rukomojnikov, EvgeniiTsarev, Tatiana Sergeeva*, Tatiana Gilyazova, YurijShirnin

Volga State University of Technology, Yoshkar-Ola, Russia
**sergeeva2010t@mail.ru*

The aim of the proposed study was to show the fuel consumption of various log skidders and to create models for estimating the fuel consumption for different forwarders operating in cutting areas with different tree size characteristics.Production tests of the forwarders' operation at various cutting areas have been carried out. In experimental studies, forwarders from different countries were used. In particular, forwarders: Amkodor-2682 (Belarus), Komatsu 840 (Japan), TB-1M-16A (Russia).To implement the experiment and estimate the fuel consumption by forwarders, a volumetric method of replenishing the fuel tank at the end of the machine's working cycle was chosen.As a result of the performed experimental studies, the mathematical models for calculating the fuel consumption of forwarders on the dimensional characteristics of trees and the distances of log forwarding have been substantiated. They are necessary for estimating fuel consumption under different operating conditions of forwarders. The results were obtained with a confidence level of 0.95. The coefficients of determination for forwarders: Amkodor-2682, Komatsu 840, TB-1M-16, were 0.81, 0.80 and 0.84, respectively. This shows a high proportion of the influence of the dimensional characteristics of the object of labor on the fuel consumption of machines.The use of the developed mathematical relationships will facilitate the planning and calculation of the operating costs of the forwarding equipment.

Keywords: skidding, log, fuel consumption rate, logging, forwarder

1 INTRODUCTION

In the context of active competition for the consumer market, and presence of many small logging enterprises in most countries harvesting of different timber assortments near a stump is a well established technology of logging operations. Currently, there are various models of forwarders produced in different countries. All of them have different technical characteristics [1, 2]. The performance indicators of forwarders depend not only on their technical characteristics, but also on the operating conditions of the machines [3].

2 LITERATURE REVIEW

One of challenges in the planning and practical use of forwarders is fuel cost justification [4]. It is known that the solution to this challenge is becoming more and more important in connection with rising prices of fuel and energy resources. In 1998, in Canadian forestry, fuel costs 10% of the total cost of assortment harvesting [5]. According to Swedish researchers [6], in 2001 in Sweden, the share of fuel in total costs reached 20%. Fuel prices risen significantly at the beginning of this millennium, so the share of fuel in total costs became even higher [7]. Calculation of the cost of logs in Russia when harvesting logs using a set of machines "harvester + forwarder" shows that the share of costs for fuel resources varies in different natural production conditions in the range from 46 to 70 percent [8]. This is due to the presence of cutting areas with different characteristics of the species composition, the need to cut down significant forest areas of windfall, swampy and low-yield forest areas. According to the results of experimental studies of forwarder operation on slopes in the range from -25 to 25%, reported in Suvinen (2006) [7], it is known that steep terrain significantly increases the fuel consumption of forwarders. This is especially important when moving forwarders with a load uphill.

The ministry of Russian forestry in 1999 [9] had introduced consumption rates fuels and lubricants when performing mechanized work in forestry. However, this normative document does not contain instructions for calculating the fuel of modern machines used for forwarding logs. In the current order of the Ministry of Transport of Russia №AM-23-r dated March 14, 2008 [10], the basic rates of fuel, oil, lubricants consumption for various brands of cars, trucks, buses have been introduced. However, this regulatory document as well as the previous document lacks information on forestry equipment.

Timber industry enterprises solve the problem of fuel consumption accounting by installing special fuel consumption sensors on forwarder [11, 12]. However, the use of this option allows to solve the problem of reporting for the fuel used when accounting for it at the enterprise, but cannot solve the issue of the planned fuel consumption when calculating the projected costs.

According to the experience of Finnish loggers, approximate fuel costs are justified when analyzing the specific actual fuel consumption for the year preceding the calculated one or according to the standards specified in the documentation for the equipment, if any [13, 14]. However, this technique is not applicable according to the legislation of the Russian Federation and cannot be used in the design of new enterprises.

Furthermore, research studies indicate that there are significant differences in the fuel consumption rates for log forwarding operations in different countries. This makes it expedient to substantiate such standards for forest areas in Russia. In particular, according to the estimates of the researchers noted in the article [15], the fuel consumption of a forwarder when it moves without a load ranges from 0.23 to 0.38 liters per 100 meters, and fuel consumption when a forwarder moves with a load is 10% more than this value. According to the results of these studies, it is stated that the average fuel consumption of a forwarder is 13.3 l/h (0.62 l/m^3) for clear cuts and 10.5 l/h (0.92 l/m^3) for selective felling, and it has been proven that 61-62% of fuel is consumed during loading and driving a loaded forwarder.The increase in fuel consumption per cubic meter of harvested wood during selective felling is associated with an increase in the distance of movement of the forwarder when collecting a bundle of logs compared to the distance of movement of the forwarder when collecting a bundle on clear felling. At the same time, the hourly fuel consumption during clear felling is greater than during selective felling, since in an hour during clear felling, the forwarder submerges more logs than during selective felling.

Fuel consumption studies of the «harvester + forwarder» have been carried out in different countries [5, 16]. In Austria, studies were carried out on the operation of 18 forwarders (6 models) for the period from 2004 to 2008 [17]. Research has shown that the average fuel consumption of forwarders was 11.1 l/h. Between 1985 and 2005, Sweden saw a gradual development of technology and there has been a steady decrease in average fuel consumption from 2.5 l/m^3 to 1.7 l/m^3 [6, 18]. At the same time, studies [19] the average estimated fuel consumption by forwarders is 0.94 l/m^3 of harvested wood. According to the results reported in Ackerman et al. (2017) [20] obtained from the analysis of the use of forwarders in the forests of South Africa, average fuel consumption 0.38 l/m^3 or 13.45 l/h.

To summarize the above, there is considerable variation in the data from previous studies of forwarder fuel consumption in various forest areas. Fuel consumption largely depends on the conditions of use of forwarding machines and their technical characteristics. The lack of fuel consumption standards for most modern forwarding machines and the need to plan costs for future periods allows us to conclude that the problem under consideration is relevant.

The aim of the proposed study was to show the fuel consumption of various log skidders and to create mathematical models based on different log sizes and forwarding distances for estimating the fuel consumption of different forwarders.

3 MATERIALS AND METHODS

Forwarders used in the training-experimental forestry enterprise of Volga state university of technology (Russia) were used as the object of the study. In particular, Amkodor-2682 (Belarus) (Fig. 1, a), Komatsu 840 (Japan) (Fig. 1, b), TB-1M-16A (Russia) (Fig. 1, c) (Table 1). The work was carried out in the conditions of logging in the natural and climatic conditions of the Republic of Mari El on the territory of the Russian Federation. The development of mathematical models showing changes in fuel consumption when forwarding assortments at various felling areas will allow a reasonable analysis of fuel consumption when drawing up an estimate of costs for the development of forest areas and effectively planning future expenses.

Table 18. Main technical characteristics of forwarders

The forwarder model	Amkodor-2682	Komatsu 840	TB-1M-16A
Length (m)	10,8	9,1	9,7
Width (m)	2,9	2,8	2,8
Height (m)	3,8	3,8	3,7
Loadcarryingcapacity (kg)	15000	12000	8000
Mass (kg)	20600	14800	18400
Power (kW)	132	128	88
Chassistype	Wheels	Wheels	Tracks

To implement the experiment and estimate the fuel consumption by forwarders, a volumetric method of replenishing the fuel tank at the end of the machine's working cycle was chosen [21]. In experimental studies, selective felling was carried out with the harvesting of logs 6 meters long. Forwarder operators had over 3 years of experience.

a) b) c)

Fig. 26. Production tests for fuel consumption rates of the forwarders: a) Amkodor-2682; b) Komatsu 840; c) TB-1M-16A

The diameters of the trees at the cutting site and the diameters of the harvested logs were recorded. The forwarder's fuel tank was filled to the top of the neck before each experiment. The forwarder was stopped and the fuel tank was filled after each technological operation (moving the forwarder without logs, collecting the bundle of logs, moving the forwarder with logs, unloading the bundle of logs). Each time, the volume of fuel poured into the fuel tank was measured. Forwarding of 90 bundles of logs by each of the analyzed forwarders was carried out during production experiments. The experiments were carried out in several forest areas dominated by pine and birch trees.

In the absence of a fuel consumption sensor installed in the fuel tank of the machine, visual fixation of the fuel level in the fuel tank was carried out using a measuring cup with a graduation rate of 0.1 liter (Fig. 2). The option of using a measuring cup to determine fuel level is more time-consuming option for conducting experiments in comparison with the option of installing a specialized fuel flow sensor. However, this variant of the experiment allows achieving the required measurement accuracy at minimal cost [22].

Fig. 27. A graduated measuring cup for refueling the fuel tank of forwarders

The analysis of scientific research devoted to the work forwarders led to the conclusion that it is advisable to pay special attention to the dimensional characteristics of trees and the distance of forwarding of bundles of logs [15, 23]. The most accessible dimensional characteristic of trees for fixation is their diameter. This indicator was chosen for further use in modeling. This indicator is in direct correlation with the volume indicators of the subject of labor. If it is necessary to use other dimensional characteristics of trees correlated with the diameter in the model, the model can be easily transformed to a new type.

In all the previously mentioned scientific works, only the total fuel consumption of forwarders when performing a cycle of work with each bundle of logs was taken into account. The researchers did not divide this work cycle into separate technological parts. In contrast to these scientific studies, the methodology of the experiment described in the article was divided into two parts:

- Analysis of fuel consumption when collecting logs and unloading logs into a stack without taking into account the part of the technological process associated with the movement of the forwarder along the forwarding trails with and without logs. This stage makes it possible to separate the influence of the dimensional characteristics of trees and ignore the influence of the forwarding distances;
- Analysis of fuel consumption when driving a forwarder with and without logs during a log forwarding operation. This stage is necessary to assess the influence of the distances of forwarding of bundles of logs on fuel consumption during forwarding without taking into account the dimensional characteristics of the logs.

Using this option for collecting experimental data leads to a significant increase in the workload of observers. However, this method allows you to get the most accurate results, which well show the influence of individual factors on fuel consumption. With this method, there is the possibility of a detailed analysis of each of the factors and the preparation of two one-factor models. Combining two one-factor models allows the researcher to get the result he wants.

4 RESULTS

The fuel consumption values obtained during the operations of loading and unloading logs by forwarders, without taking into account the fuel consumption for moving forwarders, are shown in the graphs (Fig. 2). In these graphs, the dots show the fuel consumption values depending on the average diameter of the trees cut down in the cutting area.

When performing the first part of the data analysis according to the methodology described in publications [24-26], regression models (1-3) were obtained that characterize the average fuel consumption in the process of collecting and unloading logs with a forwarder for different diameters of trees cut down in the cutting area. These mathematical relationships do not take into account the fuel consumption for the operation of moving forwarders along the strip roads when forwarding logs.

for the forwarder Amkodor-2682 [27]

$$P_1 = \frac{171{,}18}{d^2} + 0{,}74, \qquad (2)$$

for the forwarder Komatsu 840

$$P_1 = \frac{1852{,}18}{d^3} + 0{,}95, \qquad (3)$$

for the forwarder TB-1M-16

$$P_1 = \frac{18{,}2}{d} + 0{,}11, \qquad (4)$$

where P_1 - fuel consumption when collecting and unloading a bundle of logs, l; P_1 - average diameter of trees, cm.

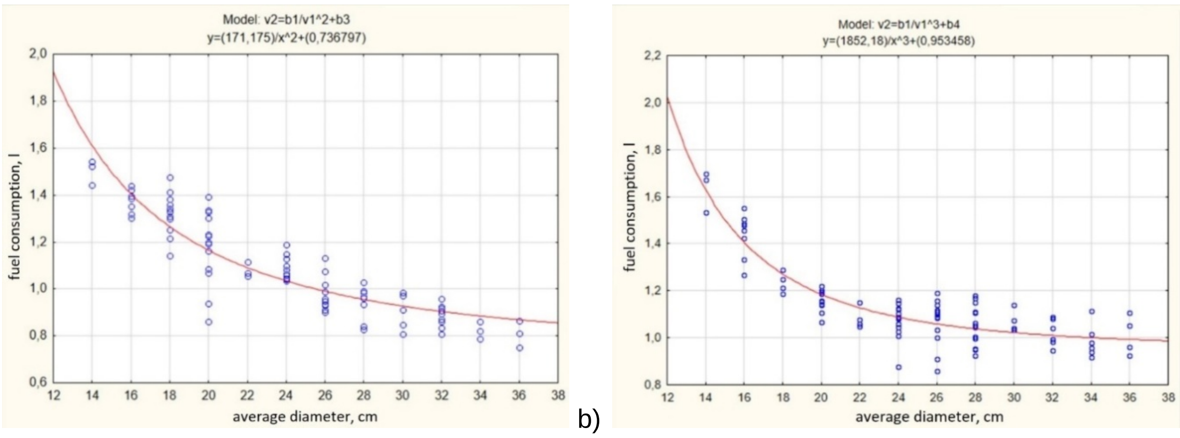
The models ware obtained and can be used with average tree diameters, in felling areas ranging from 14 to 36 cm.

The efficiency of using the obtained model in relation to real data when collecting and unloading a bundle of logs without taking into account the costs of moving the forwarder along the forwarding trails when forwarding logs can be analyzed by studying the graph (Fig. 3).

The results were obtained with a confidence level of 0.95. The coefficients of determination for forwarders: Amkodor-2682, Komatsu 840, TB-1M-16, were 0.81, 0.80 and 0.84, respectively. This shows a high proportion of the influence of the dimensional characteristics of the object of labor on the fuel consumption of machines.

When checking the adequacy of the mathematical model, a conclusion was made about the significance of the coefficient of determination, since the obtained value of the significance level in all the obtained mathematical dependences turned out to be less than 0.05.

Analysis of the obtained mathematical models (Table 2) demonstrates the values of the statistical significance of the coefficients and the sizes of their confidence intervals. The processing of the experimental results in the "Statistica" program shows that the values of the coefficients of the regression equations for all analyzed forwarders are greater in magnitude than their standard errors. The P-value of each model coefficient does not exceed the significance level equal to 0.05. Consequently, each of the coefficients has a significant impact on the result.



a) b)

Fig. 28. Fuel consumption rate estimation models for forwarders based on log diameters: a) Amkodor-2682; b) Komatsu

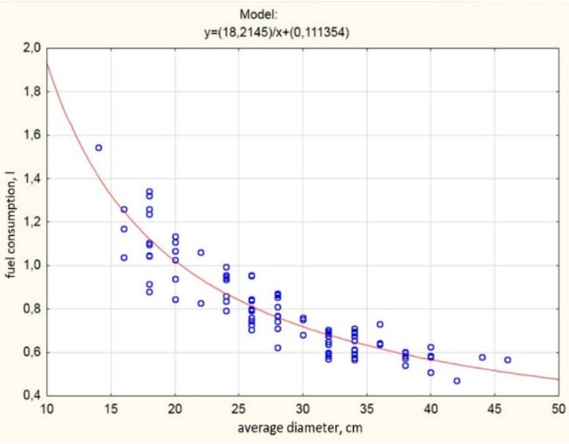
c) 

Fig. 29. Fuel consumption rate estimation models for forwarders based on log diameters: c) TB-1M-16

Table 19. Checking the statistical significance of the coefficients of the regression equation

Statistical indicator	Estimate	Standard error	t-value df=88	p-value	Lo. Conf Limit	Up. Conf Limit
	Forwarder Amkodor-2682. Model is: $P_1 = b1/d^2 + b2$ Level of confidence: 95,0% (alpha=0,050)					
b1	171,1751	8,898407	19,2366	0,00	153,4914	188,8588
b2	0,7368	0,020817	35,39327	0,00	0,6954	0,7782
	Forwarder Komatsu 840. Model is: $P_1 = b1/d^3 + b2$ Level of confidence: 95,0% (alpha=0,050)					
b1	1852,176	98,5049	18,80287	0,00	1656,418	2047,934
b2	0,953	0,01207	78,99662	0,00	0,929	0,977
	Forwarder TB-1M-16. Model is: $P_1 = b1/d + b2$ Level of confidence: 95,0% (alpha=0,050)					
b1	18,21452	0,838399	21,72536	0,00	16,54838	19,88066
b2	0,11135	0,033304	3,34354	0,00	0,04517	0,17754

This analysis makes it possible to assume, with a reliability level of 95%, that the average fuel consumption of the forwarder when collecting and unloading logs is within (4-6):

for the forwarder Amkodor-2682

$$\left[\frac{153{,}49}{d^2} + 0{,}7;\ \frac{188{,}86}{d^2} + 0{,}78\right]; \quad (5)$$

for the forwarder Komatsu 840

$$\left[\frac{1656{,}4}{d^3} + 0{,}93;\ \frac{2047{,}9}{d^3} + 0{,}98\right]; \quad (6)$$

for the forwarder TB-1M-16

$$\left[\frac{16{,}5}{d} + 0{,}05;\ \frac{19{,}9}{d} + 0{,}18\right]. \quad (7)$$

Values falling within this range can be taken as a standard when determining fuel consumption for the conditions of the Republic of Mari El on the territory of the Russian Federation.

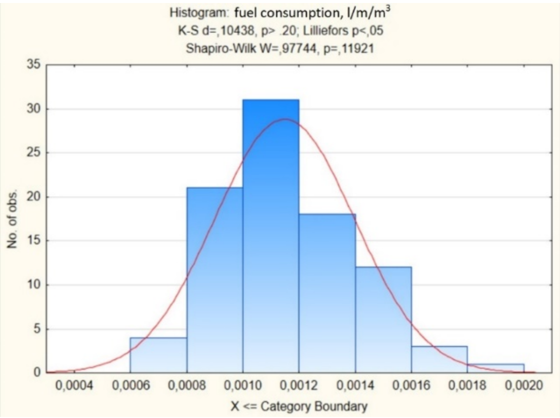
The results of experimental data processing, when moving forwarders with and without logs in the process of forwarding logs along forwarding trails, were based on the determination of average fuel consumption indicators per forwarding of logs with a volume of 1 cubic meter at a distance of one meter. According to experimental data, this indicator was for forwarders: Amkodor-2682, Komatsu 840, TB-1M-16, respectively, 0.0011, 0.0011 and

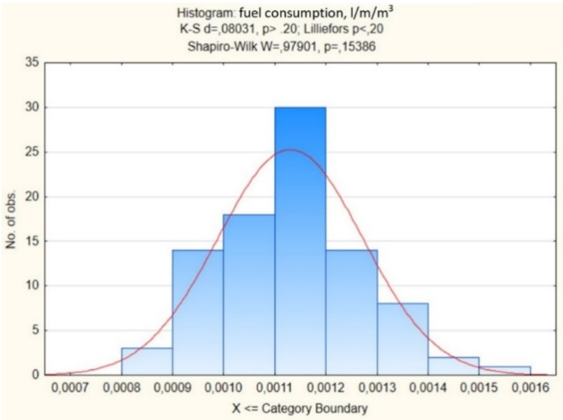
0.0013 $\frac{l}{m \cdot m^3}$. The results of calculating descriptive statistics indicators based on the results of the experiment are presented in Table 3.

With a reliability level of 95%, we can conclude that the average fuel consumption of forwarders when driving with and without logs along the forwarding trails, calculated for forwarding one cubic meter of logs at a distance of one meter, is within the range: [0.0011; 0.0012] for Amkodor-2682 and Komatsu 840 forwarders and within [0.0012; 0.0013] for TB-1M-16 forwarder.

The arithmetic mean values of the experimental results are close to the median of the samples, which indicates compliance with the normal distribution of random variables.

The shape of each histogram (Fig. 4) of the experimental results is well described by the theoretical curve of the normal distribution of random variables. According to the Kolmogorov-Smirnov criterion, the significance level is greater than 0.2. Consequently, the hypothesis about the normal distribution of experimental data is not rejected. According to the Shapiro-Wilk test, the significance level is greater than 0.05. This also does not contradict the hypothesis of the normal distribution of random variables.

a) 

b) 

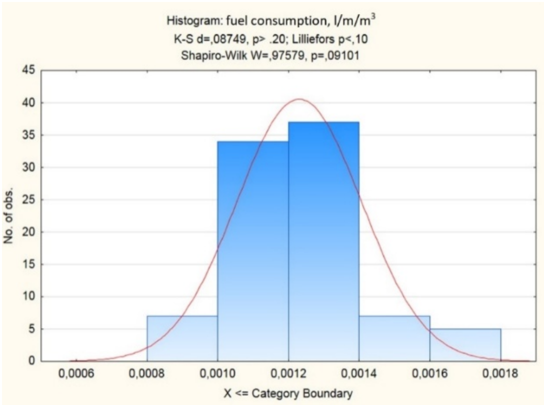
c) 

Fig. 30. Histogram based on the results of observations of fuel consumption during cargo and idling of the forwarder: a) Amkodor-2682; b) Komatsu 840; c) TB-1M-16

Thus, the total fuel consumption when forwarding logs should contain two components. This should be a parameter showing the fuel consumption when the forwarder is moving along forwarding trails with and without logs (P_2) (7-9), and a parameter showing the fuel consumption when collecting and unloading logs (P_1) (1-3).

For the forwarder Amkodor-2682

$$P_2 = 0.00115 \cdot L_{\text{т}}. \quad (8)$$

For the forwarder Komatsu 840

$$P_2 = 0.0011 \cdot L_{\text{т}}. \quad (9)$$

For the forwarder TB-1M-16

$$P_2 = 0.0013 \cdot L_{\text{т}}, \quad (10)$$

where $L_{\text{т}}$ – average distance of log forwarding, m.

Table 20. Calculating descriptive statistics indicators

Statistical indicator	Total fuel consumption when the forwarder is moving with and without logs (excluding the time of loading and unloading logs), $\frac{l}{m \cdot m^3}$.		
	Amkodor-2682	Komatsu 840	TB-1M-16
Mean	0,00114	0,00113	0,0012
Standard error	0,000026	1,49E-05	0,00002
Median	0,001102	0,0011	0,0012
Standard deviation	0,00025	0,00014	0,0002
Reliability level (95,0%)	0,00005	0,000029	0,000037
Estimated minimum number of observations to obtain reliable results	75	90	90
The number of realized observations	90	90	90

The final mathematical models for calculating the fuel consumption of forwarders are as follows (10-13):

$$P = P_1 + P_2, \quad (11)$$

for the forwarder Amkodor-2682

$$\mathrm{P} = \frac{171.18}{\mathrm{d}^2} + 0.74 + 0.00115 \cdot \mathrm{L_т} \quad (12)$$

for the forwarder Komatsu 840

$$P = \frac{1852.18}{d^3} + 0.95 + 0.0011 \cdot L_т \quad (13)$$

for the forwarder TB-1M-16

$$P = \frac{18.2}{d} + 0.11 + 0.0013 \cdot L_т \quad (14)$$

where P- total fuel consumption of the forwarder, taking into account all operations for collecting, forwarding and unloading logs at the loading point, l.

5 DISCUSSION WITH CONCLUSIONS

As a result of the performed experimental studies, mathematical models were obtained, which make it possible to substantiate the fuel consumption of various forwarders with different dimensional characteristics of forest stands in the Republic of Mari El of the Russian Federation. The results were obtained from a comparative analysis of the operation of several forwarders in the same terrain conditions typical for one of the regions of the Russian Federation. However, these results may be relevant for other areas with similar conditions. All forwarders used in the experiment were manufactured in different countries. This makes it possible to assume that the results obtained may be of interest to loggers in different countries.

It is known that the analyzed machines are not comparable in terms of engine torque, engine speed, engine size, total vehicle weight and load capacity. All these indicators have an impact not only on the fuel consumption of cars, but also on their performance and efficiency [28]. Fuel consumption is not the main criterion when choosing a freight forwarder, but it is an important indicator when predicting fuel costs when operating these machines. For all forwarders, fuel consumption depends on their operating conditions [29]. Fuel consumption expressed in $\frac{l}{m * m^3}$ or $\frac{l}{km * t}$ the most accurate fuel consumption indicator because it allows a realistic comparison of different types of machines with different loads (t, m^3) at different extracting distances [26].

Comparison of the obtained experimental results with the results described earlier in this article obtained by other researchers [5, 6, 15 – 20, 28] makes it possible to conclude that the obtained values do not contradict the previously made conclusions. The results are in the same range of performance indicators of fuel consumption as the results of research by other scientists. The differences in the data obtained can be partially explained by the differences in terrain and weather conditions in different countries [30]. However, the results clearly demonstrate that the size characteristics of the logs and their forwarding distances have an important influence on the fuel consumption of all forwarders.

The experimental studies performed proved that the fuel consumption of all the analyzed forwarders is significantly higher when cutting in young trees than when working with large logs. This can be explained by a decrease in the number of movements of the forwarder's manipulator when collecting and unloading a bundle of logs in conditions of working with large logs. It is proved that for any forwarder, the mathematical dependence that characterizes the increase in fuel consumption per 1 m^3 of timber when working with thin logs is not a linear dependence. The reason for this may be the simultaneous influence on fuel consumption of not one, but two factors that have an opposite effect on fuel consumption. These factors are a decrease in the load on the forwarder's manipulator and an increase in the number of manipulator movements when loading and unloading 1 m^3 of logs.

The results obtained cannot be used to analyze the operational efficiency of other skidder models. To improve the adequacy of mathematical models, there is a need to use various increasing or decreasing coefficients, depending on the complexity of the work in the cutting areas. These can be options for working in low ambient temperatures, working with an intern, working in hilly forest areas, etc. This requires additional research.

The results obtained can be used in the design of the work of forwarders in other logging areas. The use of the developed mathematical relationships in the forestry of the Russian Federation and other countries will facilitate the planning and calculation of the operating costs of the forwarding equipment.

6 ACKNOWLEDGMENT

The research was supported by the Ministry of Science and Higher Education of the Russian Federation (Grant № 075-15-2021-674) and Core Facility Centre «Ecology, biotechnologies and processes for obtaining environmentally friendly energy carriers» of Volga State University of Technology, Yoshkar-Ola.

7 REFERENCES

[1] Nordfjell, T., Öhman, E., Lindroos, O., Ager, B. (2019). The technical development of forwarders in Sweden between 1962 and 2012 and of sales between 1975 and 2017, 1-13 / Received 06 Sep 2018, Accepted 28 Feb 2019, Published online: 03 Apr 2019 https://doi.org/10.1080/14942119.2019.1591074.

[2] Abbas, D., Handler, R., Hartsough, B., Dykstra, D., Lautala, P., Hembroff, L. (2014). A survey analysis of forest harvesting and transportation operations in Michigan. Croatian Journal of Forest Engineering, vol. 35, no. 2, 179-192.

[3] Brunberg, T. (2012). Bränsleförbrukningen hos skogsmaskiner. Fuel consumption in forest machines 2012. Skogforsk, Arbetsrapportnr. 789. 10 p.

[4] Lijewski, P., Merkisz, J., Fuć, P., Ziólkowski, A., Rymaniak, L., Kusiak, W. (2017). Fuel consumption and exhaust emissions in the process of mechanized timber extraction and transport. European Journal of Forest Research 136, 153-160, DOI:10.1007/s10342-016-1015-2.

[5] Favreau, J., Gingras, J.F. (1998). An analysis of harvesting costs in eastern Canada. Forest Engineering Research Institute of Canada, Special Report SR, p.129.

[6] Johansson, A. (2001). Forestry Costs and Revenues 2000, A year of storms and floods. Forestry Research Institute of Sweden, Results nr. 4, Uppsala, Sweden. p. 25-36.

[7] Suvinen, A. (2006). Economic Comparison of the Use of Tyres, Wheel Chains and Bogie Tracks for Timber Extraction. Croatian Journal of Forest Engineering, vol. 27, no 2, 81-102.

[8] Golyakevich, S.A. (2017). Energy aspects of functioning of multi-operational logging machines Logging production: problems and solutions: materials of the International Scientific and Technical Conference. Belarussian State Technological University, 64-68.

[9] Consumption rates of fuels and lubricants for mechanized work performed in forestry. 13.09.1999 Approved by order of the Ministry of Forestry of Russia № 180, p. 124.

[10] The order of the Ministry of transport of Russia from 14.03.2008 № AM-23-p (edition of 20.09.2018) On the implementation of the methodological recommendations "Norms of fuel consumption and lubricants for road transport" edition of the orders of the Ministry of Transport of Russia 14.05.2014 № HA-50-p, from 14.07.2015 № HA-80-p, from 06.04.2018 № HA-51-p, from 20.09.2018 № ИА-159-p.

[11] Ivanov, A.S, Morozov, O. A. (2017). Rationing of fuel-lubricants consumption and productivity of tractors by John Deere in the Tyumen region. Polythematic online scientific journal of Kuban State Agrarian University, no. 133, 402-410.

[12] Pandur, Z., Horvat, D., Šušnjar, M., Šarac, Z. (2009). Može li se komercijalni Fleet Management Sustavkoristiti u praćenjuradaiistraživanjimaforvardera? Nova mehanizacijašumarstva, vol. 30, no. 1, 11-17.

[13] Sjunjov, V. S., Sokolov, A. P., Konovalov, A. P. (2008). Comparison of cutting technologies in logging companies of the Republic of Karelia. Joensuu: Finnish forest research Institute, p. 126.

[14] Vaatainen, K., Liiri, H., Asikainen, A., Sikanen, L., Jylha, P., Rieppo, K., Nuutinen, Y., Ala-Fossi, A. (2007). Korjurei den ja Korjuuketjun simulointi ainespuun korjuusa. Metlanty oraportteja, no. 48, p.78.

[15] Nordfjell, T., Athanassiadis, D., Talbot, B. (2003). Fuel consumption in forwarders. International Journal of Forest Engineering, vol. 14, no. 2, 11-20, DOI:10.1080/14942119.2003.10702474.

[16] Zdravko, P., Marijan, Š., Marin, B., Kruno, L., Hrvoje, N., Andreja, Đ. (2018). Fuel Consumption of Forwarders in Lowland Forests of Pedunculate Oak. South-east European forestry, vol. 9, no. 1, 73-80, DOI: https://doi.org/10.15177/seefor.18-07. https://www. seefor.eu/vol-9-no-1-pandur-et-al-fuel-consumption.html.

[17] Holzleitner, F., Stampfer, K., Ghaffariyan, M.R., Visser, R. (2010). Economic benefits of long term forestry machine data capture: Austrian Federal Forest case study. Forest Engineering: Meeting the Needs of the Society and the Environment, July 2010, 11-14, Padova, Italy, p. 8.

[18] Löfroth, C., Rådström, L. (2006). Fuel consumption in forestry continues to fall. Results from Skogforsk 3.

[19] Athanassiadis, D. (2000). Energy consumption and exhaust emissions in mechanised timber harvesting operations in Sweden. Science of The Total Environment, 255 (1-3), 137-145. DOI: https://doi.org/10.1016/S0048-9697(00)00463-0.

[20] Ackerman, P., Williams, C., Ackerman, S., NATI C. (2017) Diesel consumption and carbon balance in South African pine clear-felling CTL Operations: a preliminary case study. Croatian Journal of Forest Enginering, vol. 38, no. 1, p. 65-72.

[21] Rukomojnikov, K.P., Kuptcova, V.O. (2020). Substantiation of Fuel Consumption Rates of a Harvester. Russian Forestry Journal, no. 3, 117–127. DOI: 10.37482/0536-1036-2020-3-117-127; URL: http://lesnoizhurnal.ru/upload/iblock/694/117_127.pdf.

[22] Sever, S., Horvat, D. (1989). Prilogproučavanjapotrošnjegorivapriprijevozudrvakamionskimkompozicijama. Mehanizacijašumarstva, vol. 14 (7-8), 157-162.

[23] Pandur, Z., Šušnjar, M., Bačić, M., Lepoglavec, K., Nevečerel, H., Đuka, A. (2018). Fuel Consumption of Forwarders in Lowland Forests of Pedunculate Oak. Forest - Biogeosciences and Forestry, vol. 12, no.1, SEEFOR 9 73-80, DOI: 10.3832/ifor2872-011.

[24] State industry standard №24026-80. Research tests. Experiment planning. Terms and definitions. (in Russian) Introduction date 01.01.1981. Reissue. January 1991.

[25] State industry standard № 8.563-2009 State system for ensuring uniformity of measurements. Methods (methods) of measurement. (in Russian) Date of change:12.09.2018.

[26] State industry standard №ISO 16269-4-2017 Statistical methods. Statistical data presentation. Part 4. Detection and treatment of emissions. (in Russian) Introduction date 10.08.2017. № 865-ST.

[27] Rukomojnikov, K.P., Kuptcova, V.O., Sergeeva, T.V. (2020). A Mathematical Model of Fuel Consumption for the Forwarder Amkodor-2682 When Performing Forestry Operations. Russian Forestry Journal, no. 6, 148–158, DOI:10.37482/0536-1036-2020-6-148-158.

[28] Pandur, Z., Šušnjar, M., Bačić, M., Đuka, A., Lepoglavec, K., Nevečerel, H. (2019). Fuel consumption comparison of two forwarders in lowland forests of pedunculate oak. iForest 12, 125-131, DOI: 10.3832/ifor2872-011.

[29] Kenney, J., Gallagher, T., Smidt, M., Mitchell, D., McDonald, T. (2014). Factors that affect fuel consumption in logging systems. In: Proceedings of the Global Harvesting Technology. Council on Forest Engineering Annual Meeting, June 22 – 25, 2014. Moline, IL. p. 6.

[30] Manner, J., Nordfjell, T., Lindroos, O. (2016). Automatic load level follow-up of forwarders' fuel and time consumption Pages 151-160 / Received 07 Jan 2016, Accepted 30 Aug 2016, Published online: 23 Sep 2016 https://doi.org/10.1080/14942119.2016.1231484.

Paper submitted: 29.11.2021.

Paper accepted: 14.04.2022.