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Study of the work of modern logging machines in mountain conditions

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Abstract. The article presents the results of a study on the operation of the Mounty 4000 machine with the Woody H60 processor head in the mountainous conditions of Bulgaria. The structuring of the machine operation cycle was carried out and for each component the values of their durations were obtained in the course of a production experiment. This allows predicting the productivity of work, as well as the economic efficiency of using the "mountain harvester" in logging. In the course of the simulation experiment, the dependence of the damage of tree trunks left in the cutting area on the density of planting, the distance of skidding and the intensity of felling during the primary transportation of wood was established. This allows for a comprehensive assessment of the functioning of the Mounty 4000 machine simultaneously from economic and environmental points of view at the stage of technological design of logging operations.

1 Introduction

At present, up to 70% of the entire forested area in Bulgaria falls on mountainous or hilly terrain. Logging in such conditions leads to a decrease in productivity, an increase in energy intensity and labor intensity of production. At the same time, the high ecological sensitivity of mountain forests implies the use of environmentally friendly technologies. All this increases the cost of logging [1-4].

The cost of primary transportation of wood increases especially sharply when skidders are used. Their use is limited in use by the steepness of the slope of 15 ... 20 degrees and causes significant damage to the forest environment [5]. Installations are not significantly inferior to most tractors in terms of performance [6-7].

Particular attention deserves mobile rope installations based on trucks equipped with a manipulator with a processor head for trimming trees from limbs and bucking whips, as well as sorting assortments and loading them onto timber transport. They are called "mountain

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harvesters". This technique can significantly reduce the danger and labor intensity of work on processing operations [8].

Today, in Bulgaria, private logging companies use three such machines of the Mounty 4000 brand with a Woody H60 processor head in logging in mountainous areas (Fig. 1). The results of their work largely determine: the type of forest exploitation massif, the shape of the slope, the slope of the terrain, the configuration and technological parameters of the cutting area being developed, the taxation characteristics of the plantation, the type of felling and its intensity [9-11]. At the same time, there are no norms for the cycle time of work and norms for the production per shift of such equipment, taking into account the indicated factors.

a) *b*) *c*)

Fig. 1. General view of Mounty 4000 machine with Woody H60 processor head and cutting area technology.

A wider application of such machines requires the study of the process of their operation in various natural and industrial conditions of mountainous regions in order to reliably predict the total costs of primary transportation, as well as damage to the forest environment.

2 Materials and methods

The following expression can be used to determine the total costs for the primary transportation of timber:

$$C_1 = \frac{C_{msm} M_j \sum_{i=1}^{I} T_i}{3600 V_p m \varphi} = \frac{C_{msm} M_j \left(\begin{matrix} T_1+T_2+T_3+T_4+T_5+ \\ T_6+T_7+T_8+T_9+T_{10}+T_{11} \end{matrix} \right)}{3600 V_p m \varphi} \quad (1)$$

where C_{msm}- the cost of maintaining a machine shift, rub; M_j- is the volume of wood cut down in the cutting area in the j-th cutting stage, m^3; m- is the number of hours in a shift; φ - coefficient of use of shift time; V_p- is the volume of the transported pack, m^3; T_i- is the duration of the -th component of the time of the cycle of primary transportation of wood, s; I- is the number of time components of the primary transportation cycle; T_1- duration of lifting the hook to the carriage, s; T_2- the duration of the movement of the carriage from the working platform to the place of formation of a pack of objects of labor (trees, whips, assortments), s; T_3- the duration of lowering the hook from the carriage to the choker, s;T_4- the duration of pulling the hook with a cable to the place of hitching objects of labor (trees, whips, assortments), s; T_5- the duration of the chokering of objects of labor (trees, whips, assortments), s;T_6- the duration of skidding of objects of labor (trees, whips, assortments) to the ropeway, s; T_7-the duration of the lifting of the podrelevanny objects of labor (trees, whips, assortments) to the carriage, s;T_8- duration of skidding of objects of labor (trees, whips, assortments) along the ropeway, s; T_9- the duration of waiting for the operator's signal about the end of the processing of objects of labor (delimbing, bucking, sorting, stacking) from the previous batch, s; T_{10}- the duration of lowering the objects of labor (trees, whips, assortments) to the working platform, s; T_{11}- duration of uncoupling of objects of labor (trees, whips, assortments) at the working site, s.

To predict the performance of the Mounty 4000 machine, as well as the cost of primary transportation, an experimental research program was developed, which includes passive production experiments to collect the necessary information on the components of hauling time.

Observations were carried out from March 2018 to May 2020 in the south-central part of Bulgaria, where coniferous plantations predominate: spruce, white pine and fir. Measurements of the duration of working operations were carried out by the chronometric method with an accuracy of 1 second. The dimensions of the objects of labor were measured with a tape measure with an accuracy of 1 cm. 1250 cycles of wood transportation were recorded with a time measurement error of less than 3%. The study was carried out during the harvesting and hauling of wood from 33 rope installation routes with daily productivity from 20.9 to 58.0 m3. The average travel load during selective felling was 0.9 m3. The average skidding distance was 181 m (Fig. 2).

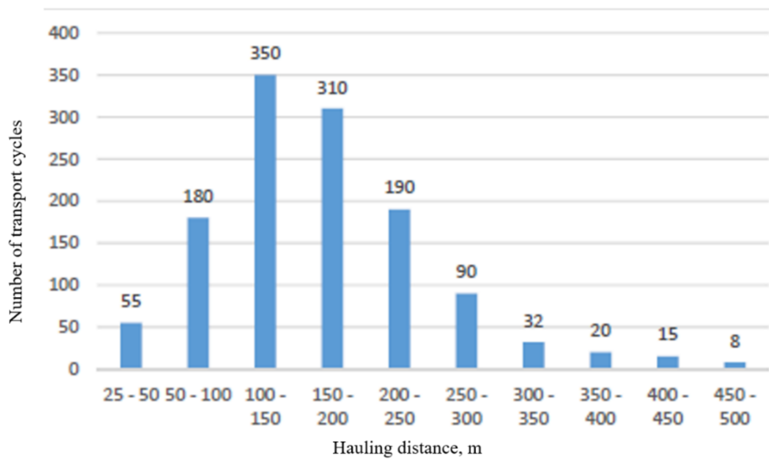

Fig. 2. Number of observation cycles for different distances of primary timber transportation.

To assess the impact of the Mounty 4000 machine on the trees left in the cutting area, it was proposed to use the C_2 indicator of their contact with the objects of labor (whips, assortments) during the first stage of the primary transportation of wood (moving from the apiary from the place of felling and processing to the rope installation route). This required the establishment of its regression dependence $(C_2 = f(N, l_n, k_{изр})$ on such main silvicultural and technological factors of influence as planting density - N , the distance of skidding (pulling whips or assortments from the apiary to the portage) - l_n , as well as the degree of thinning of the forest stand on open felling - $k_{изр}$.

To do this, with the help of CAD Solid works, a simulation experiment was carried out with the implementation of a matrix of a full-factorial plan, where three factors vary at two levels - minimum and maximum, and the number of experiments is 8, with duplication of each of them 15.

During the experiment:

- the configuration of its surface was created according to the outline of the allotted cutting area;

- according to the data of the taxation description, the spatial structure of the arrangement of trees in the cutting area with their individual characteristics was set;
- trees for selective felling were determined taking into account the thinning factor;
- the tree was removed from the stump and laid in its individual direction, taking into account the adjacent trees, as well as the direction of subsequent hauling;
- the trajectory of skidding of the object of labor (whip or assortment) was built;
- the number of contacts of tree trunks left in the cutting area with objects of labor in the process of their pulling from the apiary to the route of the cable installation, i.e. the number of trees related to the skidding trajectory, was determined.

3 Results and discussion

The results of chronometric observations for collecting data on the components of the cycle time of the Mounty 4000 machine are presented in Table 1-3.

Table 1. Results of measurements of the components of the cycle of the Mounty 4000 machine.

Cycle time components	Average duration, sec	Standard deviation, sec	Minimum, sec	Maximum, sec
T_1	5.0	-	4	6
T_3	11.9	6.6	5	41
T_4	65.4	14.8	3	121
T_5	134.1	43.8	18	220
T_6	49.0	9.4	0	79
T_7	12.7	4.7	8	35
T_9	7.1	6.5	2	30
T_{10}	6.5	3.8	2	20
T_{11}	8.6	4.3	5	65
Sum	**303.4**			

Table 2. The results of measurements of the component of the cycle of work T_2 depending on the average skidding distance

Distance/time	100 m	200 m	300 m	400 m	500 m	600 m
Average duration,sec	31	50.1	62.9	94.5	149.6	201.3
Standard deviation,sec	8.0	14.3	17.9	6.5	16.1	10.4
Minimum,sec	25	45	61	95	122	185
Maximum,sec	48	57	92	120	192	232

Table 3. The results of measurements of the component of the cycle of work T8 depending on the average skidding distance

Distance/time	100 m	200 m	300 m	400 m	500 m	600 m
Average duration,sec	40.0	89.9	135.3	180.2	180.2	225.5
Standard deviation,sec	8.2	7.9	16.5	18.1	18.1	11.4
Minimum,sec	42	81	128	161	161	205
Maximum,sec	63	113	166	206	206	264

In the course of processing the data of the simulation experiment, a regression equation was obtained that makes it possible to study the nature of the impact of rope installations on the remaining forest stand, taking into account the density of planting, the distance of skidding, the degree of thinning of the forest stand, as well as the volume of the whip and the stock of wood:

$$C_2 = -0.085153 - 0.000294\,N + 0.1414816\,l_n + 4.6392857\,k_{изр} + \\ -0.000331\,N\,l_n + 0.0167399\,N\,k_{изр} + 0.673806\,l_n\,k_{изр} + 0.009938\,N\,l_n\,k_{изр}. \quad (2)$$

The reliability of the obtained regression model was confirmed in the course of a full-scale production experiment (with an error of 5% for a slope of up to 8 degrees and 7% for a slope of up to 15 degrees) in the highlands of Russia (Dzhubga forestry, Krasnodar Territory).

4 Conclusion

Based on the conducted research, the following conclusions can be drawn:

1. The structuring of the Mounty 4000 machine operation cycle for the primary transportation of wood in mountainous areas was carried out. For each component of the cycle time in the course of a passive production experiment in the mountainous conditions of Bulgaria, weighted average values of their duration were obtained. This allows predicting the performance of the "mountain harvester", as well as the economic efficiency of its operation.
2. A simulation experiment was carried out based on the results of which the dependence of the damage of tree trunks left on the cutting site on the planting density (N=121…1681 pieces/ha), skidding distance (ln=2…38 m) and felling intensity (k_{sp}= 0, 2…0.8) when performing the primary transportation of wood, which makes it possible to reliably predict (93…95%) environmental consequences, taking into account the technology used. The reliability of the obtained regression model was confirmed in the course of a full-scale production experiment (with an error of 5% for a slope of up to 8 degrees and 7% for a slope of up to 15 degrees).
3. The results of the carried out are recommended to be used at the design stage of logging operations for a comprehensive assessment of the functioning of the Mounty 4000 machine simultaneously from an economic and environmental standpoint.

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