Investigation of technological variants of performing processing operations of logging works using chainsaws

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Abstract. The paper proposes a new method to evaluate technical, technological and organizational parameters of the developed automated system for designing logging operations based on multi-level structural improvement in the processing procedure. To justify the optimal technology of this procedure, the complex indicator of specific energy consumption was introduced, and a mathematical apparatus sensitive to changes in a wide range of the worker’s characteristics was developed. Besides, the natural environment of the parameters of gasoline-powered tools, technology and process organization, and the worker’s individual characteristics such as qualification and fatigue were considered. The algorithms and programming software written in Delphi were elaborated to reliably predict the operation of various sets of gasoline-powered tools in 12 possible technological sequences based on the mathematical apparatus obtained. The discrepancy between the experimental and modeling data was found not to exceed 3-6%. As a result of using the considered tools and software, it became possible to improve the performance of processing operations by identifying optimal technical and technological solutions under the given conditions of production and the natural environment at the stage of technological design.

1. Introduction

Currently, chainsaws are widely used while performing felling of trees, cleaning their trunks from branches and bucking whips on assortments. This can be especially observed in mountainous areas, in large forests or during felling care of planting, where other tools are limited in operation due to their technical characteristics, forestry or environmental requirements, and economic feasibility.

The effectiveness of mechanized processing operations in the cutting area depends on the cutting method and its characteristics, technological process variant (option), method and parameters of the apiary development, a set of gasoline-powered tools, and worker’s individual characteristics. The analysis of works published in this field [1-7] shows the complexity of justifying optimal solutions at the stage of technological design. The main reasons for this are represented by a large number of options compared in a wide range of changes in the natural and production conditions of the developed cutting areas and parameters of logging, different qualification and fatigue of workers, as well as the need for a multilateral assessment of the studied operations.

To overcome the above-mentioned problem, the authors of the papers [8-10] proposed the following criteria: time spent on performing processing operations, productivity, coefficient of using gasoline-powered tools over time, and complex output per worker. In the studies described in the papers [11,12], energy costs were considered to assess the efficiency of technological operations simultaneously with...
the indicator of the duration of their implementation. In the work [13], much attention is paid to time and energy costs, as well as to losses of wood raw materials due to the low qualification of team workers. At the same time, the necessity of a mandatory consideration of the physiological state of the worker in assessing its labor efficiency is noted. The paper [14] also indicates the absence of taking the human factor into account and the lack of sensitivity of the existing mathematical models to the performer’s individual characteristics.

Modern methods of mathematical and simulation modeling, which are based on statistical and logical analysis of technological processes and take into account the changing conditions of production and the natural environment of each developed site as well as worker’s qualification and fatigue, are widely used for solving this issue [15-17].

Considering the aforementioned, the aim of the present work was to substantiate the technology of processing operations by introducing the complex indicator of specific energy consumption and developing a mathematical apparatus sensitive to changes in the worker’s characteristics.

2. Methods

In the present work, to justify the technology of processing operations, it was proposed to use the indicator of specific energy consumption \( E_{sd,n} \) in the following form:

\[
E_{sd,n} = \frac{\sum_{k=1}^{K} N_k t_k}{P_{ork}},
\]

(1)

where \( N_k \), \( t_k \) are the power and time, respectively, spent on the execution of the \( k \)-th element of single or several consecutive processing operations (W and s, respectively); \( P_{ork} \) is the replaceable performance of the chainsaw for single or several consecutive processing operations consisting of \( K \) elements (m³); \( N_{pk} \) is the number of workers employed to perform single or several consecutive processing operations (people).

The advantage of this indicator can be confirmed by the possibility of simultaneous accounting of total energy costs, the number of people involved in the work, and labor productivity when performing processing operations using various sets of gasoline-powered tools (chainsaws) in any technological sequence of logging works (figure 1).

**Figure 1.** Variants of processing operations for logging works using gasoline-powered tools. \( F_i \) is the tree felling; \( C_b \) is the tree cleaning from branches; \( S_t \), \( S_w \) and \( S_a \) are the tree, whip and assortment skidding, respectively; \( B_w \) is the whip bucking on assortments; \( L_t \), \( L_w \) and \( L_a \) are the tree, whip and assortment loading, respectively.
Reliable forecasting of labor productivity regarding the felling of trees, cleaning their trunks from branches and bucking whips under the changing production conditions and the natural environment is required in determining the specific energy consumption [18]. For this purpose, it was proposed to employ the method of sequential time modeling of logging processes in the calculations, the implementation of which is presented below at the block diagram of the mathematical model of processing operations according to one of the compared technological options (figure 2). The following symbolization of parameters was used when it was created: $t_{wd}$ is the time of the worker’s movement between the trees (s); $t_{wp}$ is the time of the workplace preparation (s); $t_{uc}$ is the saw cut lead time (s); $t_{pct}$ is the transition time from saw cut to sawing (s); $t_{dp}$ is the time of the worker’s movement between the trees (s); $t_{ufe}$ is the time of the worker’s movement from the butt to the top of the tree and back in the process of cutting twigs and bucking (s); $t_{un}$ is the time of transverse cutting in the whip bucking (s); $t_{sk}$ is the time of hilling timber (s); $V_{ld}$ is the whip volume (m$^3$); $q$ is the forest reserve per hectare (m$^3$/ha); $k$ is the reserve share to be cut (dimensionless); $V_{md}$ is the worker’s speed at his movement between the trees (m/s); $d_c$ is the diameter of the tree at the cutting point (m); $p_1$ is the coefficient of cutting area increase by saw cut (dimensionless); $P_{\alpha}$ is the performance of chainsaw clean sawing (m$^2$/s); $f$ is the total area of branch cutting on the same tree (m$^2$); $l_{ld}$ is the length of the tree (m); $l_p$ is the length of the top of the tree (m); $V_c$ is the worker’s speed from the butt to the top of the tree and back in the process of cutting branches and bucking (m/s); $l_\ell$ is the length of assortment (m$^3$); $n_c$ is the average number of assortments cut from a single whip (dimensionless); $t_{wh}$ is the hilling time of a single assortment (s); $M$ is the number of hours per shift (dimensionless); $\varphi_1$ is the coefficient of shift time consumption (dimensionless); $\varphi_i$ is the coefficient of the worker’s individual characteristics for processing operations.

The time spent during the shift on processing operations is summarized and compared in block 21 with the shift time ($13600 \cdot M \cdot \varphi_i \cdot \varphi_j$). Using the coefficient of the worker’s individual characteristics, at the same time, opens up wide opportunities to study the impact of the human factor on the effectiveness of the logging processes. The following formula is proposed to determine the values of this indicator:

$$\varphi_i = \left(\sum_{k=1}^{K} T_k\right)M \sum_{m=1}^{M} T_m,$$

where $T_k$ is the average model value of the duration of the $k$-th element of single or several consecutive processing operations (s); $T_m$ is the average value of the actual duration of the processing cycle time of one tree at the $m$-th hour of the worker’s activities (s).
Figure 2. A block diagram of the mathematical model for performing processing operations of logging works using gasoline-powered tools according to technology No. 8.
3. Results and discussion
The Delphi-written computer software “Program for justification of technological options for processing operations using gasoline-powered tools” was created on the basis of the obtained mathematical models and algorithms of processing operations. The interface forms of this program for entering initial data are presented in figure 3. They are divided into four groups: “Natural and production conditions”, “Individual characteristics of motorists (workers)”, “Organization of technological processes”, and “Technical characteristics of gasoline-powered tools”.

![Figure 3](image)

**Figure 3.** Front-end forms to enter initial data to the computer software “Program for justification of technological variants of processing operations using gasoline-powered tools”.

The developed program compares 12 options different from each other in the composition of processing operations, place of their execution, tool, as well as number of workers, their individual characteristics, and chainsaws involved in the work on felling trees, delimbing and bucking whips.

The results of the simulation of the studied technologies for processing operations were obtained for one of the cutting areas developed by the “LK Kedr” logging company in the Alexander forestry of the Vladimir region are shown in figure 4. The calculations were carried out under the following conditions: selective cutting; cutting area $S_c = 30 \text{ ha}$; cutting intensity $k_i = 0.4$; forest reserve $q = 168 \text{ m}^3 / \text{ha}$; average whip volume $V_{wl} = 0.39 \text{ m}^3$; average length of the tree $l_{wl} = 21 \text{ m}$; for delimbing using technology 2, 4, 5, 10, 11 – Stihl chainsaw S 260, $N_k = 2.4 \text{ kW}$, $P_m = 0.008 \text{ m}^2 / \text{s}$; for cutting, delimbing and bucking using technology 1, 3, 6, 7, 8, 9, 12 – Husqvarna chainsaw 357, $N_k = 3.2 \text{ kW}$, $P_m = 0.01 \text{ m}^2 / \text{s}$.
Figure 4. Results of modeling of the studied technologies for processing operations in relation to the conditions of the Alexander forestry (Vladimir Region).

The results of the calculations made it possible to determine that for the second type of the technological logging process VP-2 (whip removal), technology No. 3 ($E_{yd,n} = 11130$ W·s·people/m³) is as the most preferred option for processing operations, and concerning technology No. 2 ($E_{yd,n} = 13092$ W·s·people/m³) and technology No. 4 ($E_{yd,n} = 11706$ W·s·people/m³), the number of chainsaw workers involved in the work is one person less, whereas the specific energy consumption is reduced by 15% and 5%, respectively. For the third type of technological logging process TP-3 (assortment removal), when performing all processing operations on the cutting area, technology No. 8 was found to be the most preferred option, and the number of chainsaw workers involved in the work is reduced by two people concerning technology No. 5 and by one person concerning technologies No. 6 and No. 7. Regarding the specific energy consumption for technology No. 8 ($E_{yd,n} = 52465$ W·s·people/m³) in comparison with technology No. 5 ($E_{yd,n} = 65753$ W·s·people/m³), technology No. 6 ($E_{yd,n} = 86681$ W·s·people/m³) and technology No. 7 ($E_{yd,n} = 53004$ W·s·people/m³), it was found to be 21.2, 39.5 and 1.1% less, respectively. When performing delimbing and bucking at top storage, technology No. 10 ($E_{yd,n} = 61162$ W·s·people/m³) was found to be the most preferred option, where the specific energy consumption was reduced by 35.5% in comparison with technology No. 9 ($E_{yd,n} = 94700$ W·s·people/m³). When performing only the bucking operation at the top storage, technology No. 12 ($E_{yd,n} = 51330$ W·s·people/m³) was found to the best one, where the specific energy consumption was reduced by 18.9% in comparison with technology No. 11 ($E_{yd,n} = 63242$ W·s·people/m³).

The developed mathematical apparatus and software allow to study the nature and degree of influence of the most important factors on the efficiency of processing logging operations. Figure 5 shows the dependences of the specific energy consumption ($E_{yd,n}$) and the labor productivity ($P_{mk}$) on the coefficient of the worker’s individual characteristics ($\bar{P}$), as well as on the other major factors such as performance of chainsaw clean sawing ($P_{ca}$), whip volume ($V_{hl}$), forest reserve per hectare ($q$) and share of reserve to be cut ($k_i$) obtained in the simulation modelling of technology No. 8 for processing logging operations.
Figure 5. Dependency graphics constructed for technology No. 8: (a) $E_{yd,n} = f (\overline{\varphi}; P_{cn})$; (b) $E_{yd,n} = f (P_{cn}; V_{hL})$; (c) $E_{yd,n} = f (k; q)$; (d) $E_{yd,n} = f (P_{cn}; q)$.

The reliability of the results of forecasting considering the indicator of the processing operations duration for logging works using gasoline-powered tools and labor productivity was confirmed during the production inspection conducted in May 2018 (figure 6). The discrepancy between the simulation and production experiment results did not exceed 3-6 %.

Figure 6. Production verification of the results of the simulation experiment performed on the computer for felling, deliming and bucking under the conditions of the Alexander forestry (Vladimir Region).
4. Conclusion

Thus, the following results were obtained after performing the present study:

1. The indicator of specific energy consumption was proposed for use, and models for a comprehensive analysis of 12 compared options by the method of sequential information-logical and mathematical modeling of processes were developed to substantiate the technology of processing operations.

2. The advantage of the obtained mathematical apparatus are as follows: ability of predicting the specific energy consumption and productivity in a wide range of changes in the worker’s characteristics; parameters of gasoline-powered tools; technology and process organization; sensitivity to worker’s individual characteristics such as qualification and fatigue.

3. The algorithms were developed, and the Delphi-written software for computers was created on the basis of the presented mathematical models of processing operations, thereby allowing to reliably predict the operation of different sets of gasoline-powered tools in different technological sequences with an error of not more than 3-6 %.

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