Improvement of technological solutions of wood processing based on cybernetics and automation methods

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Abstract. The urgency of the task of rational wood processing is, on the one hand, a shortage of timber resources and, on the other hand, an increase in consumer demand for the nomenclature of forest products in conditions of the preservation of a normal ecological situation. Resource conservation is possible under the condition of proper operations, ranging from felling of trees and ending with bucking of logs and the production of other wood products. Among the measures aimed at the effective use of wood of round wood in the conditions of the modern market, one of the main ones is the optimal cutting of logs. The purpose of this study was to develop a method and algorithm for maximizing a cylindrical volume during dumping by identifying the optimal pattern of cutting a whip by the method of successive approximations to the optimal solution. The whip model is justified and the input parameters are listed. Taking into account the limitation of the cutting zone and the possible number of logs, the procedure for forming trial cutting patterns and the principle of choosing the optimal scheme are described. The presented algorithm reduces the number of calculations by orders of magnitude compared with the sequential enumeration of all possible options for cutting, so it can be considered as one of the links of promising systems for automated management of the process of bucking and accounting of timber volumes.

1. Introduction

To increase the use of forest raw materials, a transition to waste-free and resource-saving technologies is necessary. One of the ways is the optimization of technological processes.

Process simulation modelling provides tools and methodologies for developing robust control software and manufacturing automation. Over the past thirty years, modelling and simulation of software processes have become one of the main areas of research for effective understanding, research, management and improvement of production processes [12].

The studies [4, 8, 9, 10, 11, 13, 14] present examples of automation systems and optimization of processes for the primary processing of wood. Anyway, each of these systems seeks to give the maximum final benefit to the manufacturer, for example, the volume of forest products produced.

Today, accounting for the volume of round timber in the Russian Federation is most often determined by the tabular method according to GOST 2708-75 "Round timber". Butt and middle logs of the same diameter in the upper section may have different actual volume, so this method can lead to excessive overestimation or understating of wood volumes [5].

Modern technological operations of wood processing to achieve high accuracy in determining the volume of timber should be based on the readings of automatic measuring tools that allow modeling
the shape of the whips and determining the wood species [5, 7, 9, 14]. Such an approach will allow to calculate the volume output of timber before the yarn and optimize the cutting scheme. However, the search for the optimal cutting scheme, by sequential search, requires the analysis of hundreds of thousands or even millions of options, which without modern software systems will be almost impossible to solve [6].

In this regard, we are faced with the task of finding acceptable methods and developing an algorithm for finding the optimal bucking patterns for tree logs in terms of maximizing the volume of the produced roundwood.

2. Methods

The maximization of a cylindrical volume can be achieved by the method of successive approximations to the extremum of the objective function by specifying the optimal decoupling scheme [6]. The method is to improve the basic cutting scheme by trial changes in the lengths of logs in the cutting scheme. Each following analyzed scheme should give a positive gain of the objective function in comparison with the previous one.

Maximizing \(Z\) objective function is a process with \(k\) transitions with a trial change in the length of the logs. The process does not end until the increase in the objective function stops. The cutting pattern obtained at the end of the process is optimal. In comparison with the baseline, the optimal version of the skipping gives a significant increase in \(V_c\) output of the cylindrical volume of the logs.

The procedure for maximizing a cylindrical volume during the stripping is as follows.

1. Data entry. The input data for the algorithm are the parameters of the whip, the parameters of the assortments and the optimization criterion.

The set of geometric parameters of the whip depends on the model of its shape. Since the tree trunk is not an object formed according to the laws of mechanics, any mathematical models have some deviations of the calculated diameters from the actual ones, which can lead to incorrect results. But for ideal calculations, it would be necessary to scan the whip and create its exact individual model [14].

The most accurate mathematical model of the whip shape is the equation of their generators, defined as a function of relative runoff relative length [1, 6]. The initial data on this model are as follows: the kind, \(H\) whip length, the diameter of the whip in \(d_{0.5}\) middle of the length. The required diameter at \(l\) distance from the butt is determined from the expression:

\[
D(l) = d_{0.5} \cdot f\left(\frac{l}{H}\right);
\]

The parameters of the assortments depend on the specific production conditions, requirements of standards and consumers of the final product. All round timber, depending on their purpose, has certain dimensional characteristics: length and diameter. According to GOST 9463-2016, timber for processing is characterized by a minimum diameter in \(d_{\text{min}}\) upper end, and timber for use in round form with both a minimum and maximum diameter at \(d_{\text{ma}}\) upper end, all timber has a number of \(a\) nominal lengths, while the actual length should take into account the allowance along \(b\) length [2]. The series of lengths taking into account the allowance will be denoted as \(h = a + b\).

The optimality criterion depends on the specific production tasks. One of these tasks is making a profit. Commodity yield directly depends on the quantitative yield of finished products from a unit of raw materials. Thus, to optimize the cutting, we have identified the following criteria for optimality:

- maximization of the cylindrical volume of logs \(V_c \rightarrow \max\);
- maximum use of the length of the optimized zone \(L_{pr} \rightarrow \max\);
- maximization of the cylindrical volume of logs with the maximum use of the length of the optimized zone (achieved by the product of the volume and length) \(V_c \cdot L_{pr} \rightarrow \max\).
2. Determining the length of the cutting zone. To cut a certain assortment, a whip zone must be defined within which it can be obtained, that is, a cutting zone. To determine the length of \( L \) cutting zone, it is necessary to take into account the amount of \( L_b \) otsoime and find the location of the required \( d_{\text{min}} \), \( d_{\text{max}} \) diameters along the length of the whip [3].

3. Determining the number of logs. In order to avoid an increased yield of shortened or elongated logs, the length of sawn logs should tend to medium-planned \( a_{sr} \) [6]. Then \( n \) number of logs is determined with rounding to the nearest integer using the formula:

\[
n = \frac{L}{a_{sr}}.
\]  

(2)

In case the cutting scheme of \( n \) logs goes beyond the cutting zone even with the minimum length of the assortment taking into account the allowance \( h_{\text{min}} \), that is \( n \cdot h_{\text{min}} > L \), then \( n \) is redefined with rounding to a smaller integer using the formula:

\[
n = \frac{L}{h_{\text{min}}},
\]  

(3)

4. Formation of the basic cutting scheme. In order for it to be repulsive, an array is formed of some initial equal length of \( a_{\text{bas}} \) logs, that is \( B_{ij} = a_{\text{bas}} \) \( (i = 1, 2 \ldots n \) is the number of the trial cutting scheme; \( j = 1, 2 \ldots p \) is the number of the log in the scheme cutting the bill of butt; \( p \) is the number of trial schemes).

If the gradation of the nominal length is the same, then the longest length of the assortment is selected as the initial length, provided that \( n \cdot a_{\text{bas}} \leq L_{pr} \). Otherwise, the initial length is taken as the minimum length of the assortment \( a_{\text{min}} \).

5. Formation of trial cutting schemes. When the length of the log in the basic scheme is equal to the length of the assortment number \( m \), that is, if \( B_{ij} = h_m \), the length of the log in the trial scheme is assigned the length of the assortment number \( m+M_{ij} \),

\[
T_{ij} = h_{m+M_{ij}},
\]  

(4)

where \( T_{ij} \) is the length of the \( j \)-th log in the \( i \)-th cutting scheme; \( M \) is the matrix of options for changing the scheme (table 1), \( m \) is the ordinal number of the length of the assortment (in a row in ascending order). So that \( m \) index does not take the wrong value, the condition \( 1 < m + M_{ij} < N \) must be met, otherwise \( T_{ij} = h_m \). \( N \) is the number of lengths in \( h \) raw.

The matrix of the plan for changing the scheme provides for the following options: the length of the logs does not change (the first row of the matrix); the length of one log is reduced; the length of one log increases; the length of one log decreases and the length of the other log increases.

**Table 1.** Scheme change plan matrix.

| Trial scheme N | 1 | 2 | 3 | 4 | 5 | \( j \) | \( n \) |
|---------------|---|---|---|---|---|------|------|
| 1             | 0 | 0 | 0 | 0 | 0 | \( M_{1j} \) | 0   |
| 2             | -1| 0 | 0 | 0 | 0 | \( M_{2j} \) | 0   |
| 3             | 1 | 0 | 0 | 0 | 0 | \( M_{3j} \) | 0   |
| 4             | 0 | -1| 0 | 0 | 0 | \( M_{4j} \) | 0   |
| 5             | 0 | 1 | 0 | 0 | 0 | \( M_{5j} \) | 0   |
| 6             | 1 | -1| 0 | 0 | 0 | \( M_{6j} \) | 0   |
| 7             | -1| 1 | 0 | 0 | 0 | \( M_{7j} \) | 0   |
| 8             | 0 | 0 | -1| 0 | 0 | \( M_{8j} \) | 0   |
| 9             | 0 | 0 | 1 | 0 | 0 | \( M_{9j} \) | 0   |
| 10            | 0 | 1 | -1| 0 | 0 | \( M_{10j} \) | 0   |
| 11            | 0 | -1| 1 | 0 | 0 | \( M_{11j} \) | 0   |
| 12            | 1 | 0 | -1| 0 | 0 | \( M_{12j} \) | 0   |
The number of trial circuits depends on the number of logs and is determined by the formula:

\[ p = n^2 + n + 1. \]  

(5)

6. Verification of trial circuits. The software length (the sum of the log lengths) must not exceed the length of the assortment zone \( L_{pr} \leq L \). If this condition is not met, the test circuit is discarded.

7. The calculation of the objective function. For each trial circuit, a cylindrical log volume and a program length are calculated.

\[
V_c = \frac{\pi}{4} \sum_{j=1}^{n} (D(l)^2 \cdot T_j);
\]

(6)

\[
l = \sum_{j=1}^{n} T_j + L_a;
\]

(7)

\[
L_{pr} = \sum_{j=1}^{n} T_{ij};
\]

(8)

where \( L_a \) is the distance from the butt to the beginning of the cutting zone (the amount of splitting and other delimitations from the butt are taken into account).

Depending on the optimality criterion, the best trial cutting scheme is determined, and the objective function is assigned the value of the criteria

\[ Z_k = \max(V), \quad Z_k = \max(L_{pr}) \text{ или } Z_k = \max(V \cdot L_{pr}). \]

8. After calculating all volumes, a test circuit is determined with the highest value of \( Z_k \) objective function. If \( Z_k > Z_{k-1} \) solution is improved, then the best trial scheme is taken as the basic one and the next cycle of the algorithm is performed starting from point 5. If \( Z_k = Z_{k-1} \) solution stops improving, then the optimization process ends.

Based on the proposed method, an algorithm has been developed, the block diagram of which is presented in figure 1.

For example, we will find a cutting pattern for a pine whip (the coefficients of the generator equation are \( A = 3.1039, B = -8.7363, C = 7.5529, D = -3.0774, E = 1.5505, H = 25 \text{ m}, d_{0.5} = 20 \text{ см}, L_b = 0.15 \text{ м} \) when sawing saw logs \( d_{ \text{min}} = 14 \text{ см}, a = 4; 4.3; 4.6; 5.5; 6.4 \text{ м}, b = 0.05 \text{ м}, a_{ae} = 5 \text{ м}, \) критерий \( V_c \cdot L_{pr} \rightarrow \max \)).

According to calculations \( L = 20.21 \text{ м}, n = 4, p = 21 \), the optimal cutting scheme: 4.05; 6.45; 5.55; 4.05, the program length is 20.05 m, the cylindrical volume is \( V_c = 0.608 \text{ m}^3 \), the total volume of the cutting zone is 0.727 m\(^3\), the total volume of the whip is 0.788 m\(^3\). All calculations were carried out using the MathCad system.
The process of finding the optimal cutting scheme was completed at the transition \( k = 8 \) (table 2), a total of \( k \cdot p = 8 \cdot 21 = 168 \) cutting options were analyzed. Thus, the developed algorithm reduces the number of analyzed solutions by orders of magnitude.

Table 2. The process of finding the optimal cutting scheme.

| Scheme     | \( k \) | Log length, m | \( L_{pt}, \) m | \( V_c, \) m³ |
|------------|--------|---------------|-----------------|--------------|
| Basic      | 0      | 4.05          | 4.05            | 16.2         | 0.564        |
| Intermediate | 1 | 4.05          | 4.05            | 4.05         | 16.5         | 0.569        |
| -/1/-      | 2      | 4.05          | 4.05            | 4.65         | 16.8         | 0.574        |
| -/2/-      | 3      | 4.05          | 4.05            | 5.55         | 17.7         | 0.587        |
| -/3/-      | 4      | 4.05          | 4.05            | 6.45         | 18.6         | 0.595        |
| -/4/-      | 5      | 4.05          | 4.35            | 6.45         | 18.9         | 0.598        |
| -/5/-      | 6      | 4.05          | 4.65            | 6.45         | 19.2         | 0.600        |
| -/6/-      | 7      | 4.05          | 5.55            | 6.45         | 20.05        | 0.606        |
| Optimal    | 8      | 4.05          | 6.45            | 5.55         | 20.05        | 0.608        |

According to the data of the table, one can see how the cylindrical volume of logs grows at each \( k \) transition. This suggests that the solution goes along the trajectory of the optimal search and ends when the extremum of the function of this trajectory is reached. When differentiating the value of individual logs within the cutting scheme, the trajectory of the optimal search can take an interrupted
character and lead to a dead end. Therefore, to take into account price and quality criteria of optimality, an extension of the method of forming trial cutting schemes will be required.

3. Conclusions
The proposed optimization algorithm allows to determine the cutting scheme with the maximum possible output of the cylindrical volume and/or maximum use of the length of the cutting area efficiently, without going through all possible chopping options. At the same time, optimization of chipping on timber for any purpose is possible. With further improvement of the algorithm, the qualitative and price criteria for the optimality of obtaining commercial wood will be taken into account. As a result, this algorithm should become an integral part of promising systems for automated management of the process of bucking and accounting of timber volumes.

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