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Computer Optimization of Schematic Model for Sawing a Log into Rectangular and Trapezoidal Cross-section Boards for Panel Products

Serhii Shevchenko[1], Anastasiia Suska[2], Yriy Gradiskiy[3], Natalia Zaslavska[4], Anatoly Babich[5]
[1] Department of Woodworking Technologies and Systems Engineering of Forest Complex, Kharkiv Petro Vasylenko National Technical University of Agriculture, Ukraine, Serg.Shevchen@gmail.com
[2] Department of Woodworking Technologies and Systems Engineering of Forest Complex, Kharkiv Petro Vasylenko National Technical University of Agriculture, Ukraine, n.suscka@gmail.com
[3] Department of Woodworking Technologies and Systems Engineering of Forest Complex, Kharkiv Petro Vasylenko National Technical University of Agriculture, Ukraine, Gradiskiy@khntusg.info
[4] Department of Woodworking Technologies and Systems Engineering of Forest Complex, Kharkiv Petro Vasylenko National Technical University of Agriculture, Ukraine, Zaslavska.N@khntusg.info
[5] Department of theory and design of automobile and special technique, Kharkiv National University named after Ivan Kozhedub Air Force, Ukraine, anatoliypetrovich88@gmail.com

ABSTRACT

To reduce the losses of timber in the process of manufacturing panel construction products made of edged timber, it is proposed to saw the logs into boards of trapezoidal and rectangular cross-sections. The computer technique of optimization of the schematic model parameters for sawing the log into a given even number of boards of rectangular and trapezoidal cross-sections is developed. This determines the number of trapezoidal section boards and the angle between the face and the edge, which is the same for all such boards.

The research was carried out by the method of mathematical modeling. Tasks of finding rational values for the parameters of log sawing schemes are solved using numerical hill-climbing methods.

Key words: edged board, glued panel, log, optimization, sawing pattern, trapezoidal cross-section.

1. INTRODUCTION

Modern wooden house construction technologies are based on the use of glued panel products [1], [2]. However, using rectangular cross-section boards as a workpiece for bonding such units, there is a significant loss of timber. It is worth noting that in the process of manufacturing glued panel products, not only rectangular cross-section workpieces [1], [2], which can significantly reduce the amount of wastes, can be used. Therefore, there is a need to justify the resource-saving schematic models for sawing logs into workpieces to manufacture panel products for joinery and construction purposes.

2. ANALYSIS OF THE LITERATURE

Reference [3] shows that there is no single approach to ensure optimal sawing of logs in all possible manufacturing situations, and optimization of the sawmill requires flexible interaction of the units engaged in sawing stems into logs and logs into boards. This causes a considerable amount of work aimed at studying certain aspects of the issue of the optimal log sawing in the process of sawn timber manufacturing.

When solving the problem of optimizing the schematic model for sawing logs into boards, optimization at the cost of the final product, its volume or optimization by the combined method [4] is applied. The result of solving the optimization task depends essentially on the choice of the objective function. If profit maximization is chosen as the optimization criterion, then achieving maximum economic performance is accompanied by an increase in timber losses. Accordingly, the choice of minimizing timber losses as an optimization criterion does not provide the maximum economic effect.

In [5], the minimization of wastes is a criterion for the optimization of the sawing schematic model. In this case, the amount of timber that does not become a commodity is minimal, which should increase the profit per unit of the timber volume. At the same time, in this approach, the total profit is lower than in the optimization for net profit.

Study of sawing the cylindrical part of the log (for example, in [6] when optimizing the schematic models of sawing logs into radial sawn timber), the coefficient of use of the area of the small-end face of the log is used as an efficiency criterion.

Much of the research is related to the three-dimensional modeling of log-sawing [5], [7]. In this case, the log is mostly considered according to the deviations of the form from the body of rotation. In [7], a dynamic programming algorithm for the optimization of sawing logs with cylindrical defective core was proposed. Studies [5], [7] are based on the computer simulation of the process of sawing logs into boards and aimed at controlling automated lines. These articles detail the algorithms that allow optimizing sawing of logs by the criterion of maximizing the volume of sawn timber, as well as the criterion of maximizing the value of boards. References [5], [7] show the way it necessitates sawing of each deck into boards that vary in thickness, width, and quality. Based on the reviews given in [5], [7], it can be concluded that the majority of studies are aimed at obtaining edged (rectangular cross-section) or general-purpose one-side edged boards.

It is worth noting that manufacturing blanks for glued products, their shape and the size of blanks can vary. For example, in [8] it is proposed to make a glued cant with a longitudinal channel inside, using four workpieces of pentagonal cross-section.

Trapezoidal cross-section cants can be used for manufacturing panel products for construction purposes (two central cants are sawn from one log) [2], [9]. Reference [9] presents the results of comparing the relative indices of bulk outputs of batches of workpieces with different geometric parameters, obtained by the method of simulation modeling. It should be noted that in [9] only two cants can be manufactured from one log. This leads to a significant increase in timber losses if the actual thickness of the log does not correspond to its optimal value, depending on the required thickness of the cant. Also we pay attention to the known method of making panels from the workpieces of the trapezoidal cross-section (with one of the sides of the trapezoid is perpendicular to the bases). It is worth noting that the difference of the angles between the edges and the faces of the workpieces complicates the practical implementation of such technology in the industrial production.

To reduce such losses, the study [10] proposes to saw the log into several edged boards of the trapezoidal cross-section (with the same values of the angle between the face and the edge) to manufacture glued panel products. This allows using logs at most and expanding the range of thicknesses of logs that can be used. During using such kind of panels as elements of external walls of buildings is advisable to treat it by protective material [11]. Thanks to more rational use of logs, the technogenic load on forest ecosystems is reduced [12]. In [10], a technique was developed to optimize the angle between the face and the edge of these boards when live sawing a log (also known as through and through log sawing) into a given even number of boards.

Another example of the use of trapezoidal workpieces is the paper [13] on the manufacture of glued cants. First, a four-edged cant is cut out from the log, which is then cut into two trapezoidal cross-sections. These workpieces are glued together on narrower faces.

The review of the publications makes it possible to conclude that the perspective way of reducing timber losses in the process of manufacturing workpieces for glued panel products is sawing logs to manufacture edged boards of rectangular and trapezoidal cross-sections. In this case, to simplify their application, it is advisable for the angle between the face and the edge of the trapezoidal cross-section boards to be the same for all boards. However, to do this, it is necessary to develop a technique for optimizing the parameters of the corresponding schematic model (log sawing pattern).

3. THE PURPOSE AND TASKS OF THE RESEARCH

The purpose of this article is to develop a technique of optimizing the schematic model for live sawing the cylindrical part of the log into edged boards of the rectangular and trapezoidal cross-section. The log diameter at the small end, the number of boards and their thickness before drying are given, and variable parameters of the sawing pattern are the number of boards of the rectangular cross-section and the angle between the face and the edge of the trapezoidal cross-section boards, which is the same for all such boards. The number of boards is even.

The tasks of the research are:

(1) To obtain the dependence of the end face area of trapezoidal cross-section boards on its thickness, the distance to the log axis, and the angle between the face and the edge.

(2) To formulate the objective function and the task of optimizing the parameters of the log sawing pattern into boards of rectangular and trapezoidal cross-section.

(3) To solve numerically the optimization task at typical parameter values and estimation of the effect of sawing a log into rectangular and trapezoidal cross-section boards compared to sawing only into rectangular cross-section boards.

4. METHODS OF OPTIMIZATION OF THE SCHEMATIC MODEL FOR SAWING A LOG INTO BOARDS OF THE RECTANGULAR AND TRAPEZOIDAL CROSS-SECTION

We will consider manufacturing boards from the cylindrical part of the log. First, let us choose a performance indicator to compare different variants of the log sawing pattern. Assuming that the cost of production depends only on its volume, we will analyze only geometric indicators of sawing performance. We will take into account the restrictions on the minimum width of such workpieces. Therefore, the parts of the log closest to the area of shortening of the edged boards cannot be used to manufacture the boards, subject to this restriction. As for these parts of the log, it is advisable to use them to make short lumber or wood chips. Thus, the use of the coefficient of use of the area of the small-end face of the log as a performance indicator of its sawing is not fully consistent with the purpose of the study. Therefore, the log sawing pattern, as in [10], will be characterized by the coefficient of use of the area of the small-end face of the two-edged cant, which covers the ends of the manufactured edged boards.

Assume that the log small-end diameter, the kerf thickness, the number and thickness of boards before shrinkage are given. The scheme of the ends of the boards within the end of the two-edged cant that covers them is shown in fig. 1.

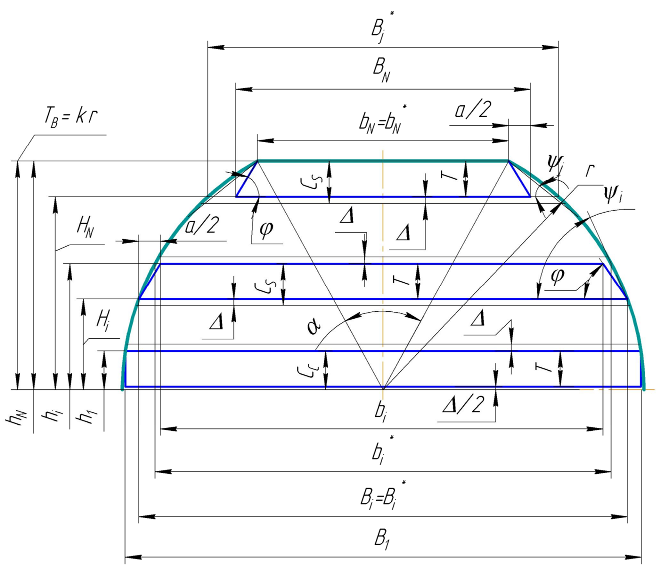

Figure 1: Scheme of sawing a two-edged cant to manufacture boards of the rectangular and trapezoidal cross-section (the upper half is shown)

Depending on the layout of the board, there are three varieties of them, shown in Fig. 1. First, boards of the rectangular cross-section are made from the area of the log closest to its axis. Second, if the trapezoidal cross-section board is relatively close to the log axis, then the angle ψ between the chord, which is cut off by the section plane and the board face exceeds a certain angle φ is the same for all trapezoidal boards.

Therefore, when cutting an edge at an angle φ, the width of the outer face of the board will decrease. Third, if the trapezoidal cross-section board is located relatively close to the face of the two-edged cant (hence, $\psi<\varphi$), the width of its inner face will decrease when trimming the edge of the board.

Let us determine the dimensions that characterize the location of the boards relative to the log axis, and the area of cross-sections of boards. To do this, we determine the consumption of wood (measured perpendicular to the face of boards) for sawing boards by using generally accepted formulas:

$$C_S = T + \Delta \ , \tag{1}$$

$$C_C = T + \Delta/2 \ , \tag{2}$$

where C_S is wood consumption for sawing the sideboard (m); T is board thickness before shrinkage (m); Δ is kerf thickness (m); C_C is wood consumption for sawing the centre board (m).

Let us determine the thickness of the two-edged cant, which covers the manufactured boards, and its relative value (i.e., the coefficient of coverage of the log small-end with sawing pattern):

$$T_{TEC} = 2C_C + (N_B - 2)C_S = \\ = N_B T + (N_B - 1)\Delta = N_B C_S - \Delta \ , \tag{3}$$

$$k = \frac{T_{TEC}}{d} = \frac{N_B C_S - \Delta}{d} \ , \tag{4}$$

where T_{TEC} is thickness of the two-edged cant (m); N_B is total number of boards; k is relative thickness of the two-edged cant; d is log small-end diameter (m).

Let us determine the width of the outer face of the *i*-th unedged board at the narrow end:

$$b_i^* = 2\sqrt{r^2 - h_i^2} \ , \tag{5}$$

where b_i^* is width of the outer face of the *i*-th unedged board at the narrow end (m); i is board number (in the upper half of the sawing pattern, counting from the log axis); r is log small-end radius (m); h_i is distance from the log axis of the two-edged cant to the outer face of the *i*-th board, (m).

It is worth noting that the width of the rectangular cross-section board coincides with the width of the outer face of the *i*-th unedged board at the narrow end. Let us determine the distance from the log axis to the outer face of the *i*-th unedged board:

$$h_i = (T + \Delta)i - \Delta/2 == C_S i - \Delta/2 \ . \tag{6}$$

Let us move from the absolute values of the sizes included in (4-6) to their relative values (relative to the log small-end diameter):

$$k = N_B c_S - \delta \quad , \tag{7}$$

$$c_S = \frac{k+\delta}{N_B} \quad , \tag{8}$$

$$\delta = \frac{\Delta}{d} \quad , \tag{9}$$

$$h_i = (2c_S i - \delta)r \quad , \tag{10}$$

$$b_i^* = 2\sqrt{r^2 - (2c_S i - \delta)^2 r^2} = = 2r\sqrt{1-(2c_S i - \delta)^2} \quad . \tag{11}$$

where c_S is relative wood consumption for sawing the side board; δ is relative value of the kerf thickness.

Let us express the thickness of the board by the log small-end radius and the relative parameters of the sawing pattern:

$$T = C_S - \Delta = C_S d - \delta d = r(2c_S - 2\delta) \quad , \tag{12}$$

This allows determining the end face area of the rectangular cross-section board:

$$S_i = b_i^* T = 4r^2\sqrt{1-(2c_S i - \delta)^2}\,(c_S - \delta) \quad , \tag{13}$$

where S_i - is end face area of the *i*-th board of rectangular cross-section (m^2).

Using (13), we shall clarify the expression obtained in [10] to calculate the coefficient of use of the area of the small-end face of the two-edge cant in the process of manufacturing rectangular cross-section boards. In this case, we proceed from the central angle α (see Fig. 1) to the relative height of the cant:

$$\alpha = 2\arcsin\left(\sqrt{1-k^2}\right) \quad , \tag{14}$$

$$S_{TEC}(k) = \pi r^2 - r^2(\alpha - \sin\alpha) = r^2 s_{TEC}(k) \quad , \tag{15}$$

$$s_{TEC}(k) = \pi - 2\arcsin\left(\sqrt{1-k^2}\right) + +\sin\left(2\arcsin\left(\sqrt{1-k^2}\right)\right) \quad , \tag{16}$$

$$N = N_B / 2 \quad , \tag{17}$$

$$K_R = \frac{2\sum_{i=1}^{N} S_i}{S_{TEC}(k)} = \frac{4\sum_{i=1}^{N}\sqrt{1-(ci-\delta)^2}\,(c-2\delta)}{s_{TEC}(k)} \quad , \tag{18}$$

where α is central angle (rad); S_B is area of the small-end face of the two-edged cant (m^2); s_{TEC} is area of the small-end face of the two-edged cant of single radius (m^2); K is coefficient of use of the area of the small-end face of the two-edged cant in the process of manufacturing rectangular cross-section boards; N is the number of pairs of boards.

For the following calculation of the dimensions of the trapezoidal boards, we shall determine the distance from the log axis to the inner face of the *i*-th board:

$$H_i = (T + \Delta)(i-1) + \Delta/2 = 2c_S\, r(i-1) + r\delta \; . \tag{19}$$

This allows calculating the width of the inner face of the unedged board at the narrow end:

$$B_i^* = 2\sqrt{r^2 - H_i^2} = 2r\sqrt{1-(2c_S\,(i-1)+\delta)^2} \quad . \tag{20}$$

Using (20) and (5), we determine the difference in width of the unedged board on the inner and outer faces at the narrow end:

$$a = B_i^* - b_i^* \quad , \tag{21}$$

where a is difference of the unedged board width on the inner and outer faces at the narrow end (m).

To determine the angle between the inner face of the board and the chord of the arc, cut off by the sawing plane, we use the dependence that was applied in [10] and proceed to the relative values of the parameters of the sawing pattern:

$$\psi_i = \text{arcctg}\frac{a}{2T} = = \text{arcctg}\frac{\sqrt{1-(2c_S\,(i-1)+\delta)^2} - \sqrt{1-(2c_S i - \delta)^2}}{2c_S - 2\delta} \quad , \tag{22}$$

where ψ_i is angle between the inner face of the *i*-th board and the chord of the arc, cut off by the sawing plane (deg).

Let us determine the width of the boards on the inner and outer face, depending on its location (distance from the log axis), the ratio of the angle φ between the face and the edge of the trapezoidal cross-section board and the angle ψ between the inner face of the board and the chord of the arc, cut off by the sawing plane:

$$\begin{cases} b_i = b_i^*, & \text{if } i \le n_R \\ b_i = B_i^* - 2a, & \text{if } \varphi < \psi_i,\ i > n_R \\ b_i = b_i^*, & \text{if } \varphi \ge \psi_i,\ i > n_R \end{cases} \quad , \tag{23}$$

$$\begin{cases} B_i = b_i^*, & \text{if } i \le n_R \\ B_i = B_i^*, & \text{if } \varphi < \psi_i,\ i > n_R \\ B_i = b_i^* + 2a, & \text{if } \varphi \ge \psi_i,\ i > n_R \end{cases} \quad , \tag{24}$$

where B_i is width of the inner face of the i-th board (m); φ is angle between the face and the edge of the trapezoidal cross-section board (deg); n_R is number of pairs of rectangular cross-section boards in the sawing pattern.

Let us convert (23, 24) using (11):

$$\begin{cases} b_i = 2r\sqrt{1-(2c_S i-\delta)^2}, \text{ if } i \le n_R \\ b_i = 2r\left(\sqrt{1-(2c_S(i-1)+\delta)^2} - 2(c_S-\delta)\operatorname{ctg}\varphi\right), \\ \qquad \text{if } \varphi < \psi_i,\ i > n_R \\ b_i = 2r\sqrt{1-(2c_S i-\delta)^2}, \text{if } \varphi \ge \psi_i,\ i > n_R \end{cases}, \quad (25)$$

$$\begin{cases} B_i = 2r\sqrt{1-(2c_S i-\delta)^2}, \text{ if } i \le n_R \\ B_i = 2r\sqrt{1-(2c_S(i-1)+\delta)^2}, \text{ if } \varphi < \psi_i,\ i > n_R \\ B_i = 2r\left(\sqrt{1-(2c_S i-\delta)^2} + 2(c_S-\delta)\operatorname{ctg}\varphi\right), \\ \qquad \text{if } \varphi \ge \psi_i,\ i > n_R \end{cases}, \quad (26)$$

In this case, the number of trapezoidal cross-section boards is determined by the formula:

$$N_T = N_B - 2n_R, \quad (27)$$

where N_T is number of trapezoidal cross-section boards.

Let us determine the areas of the ends of the boards by using (25, 26):

$$S_i = T(B_i + b_i)/2, \quad (28)$$

$$\begin{cases} S_i = 4r^2(c_S-\delta)\sqrt{1-(2c_S i-\delta)^2}, \text{ if } i \le i_R \\ S_i = 4r^2(c_S-\delta)\left(\sqrt{1-(2c_S(i-1)+\delta)^2} + \right. \\ \left. +(-c_S+\delta)\operatorname{ctg}\varphi\right), \text{ if } \varphi < \psi_i,\ i > i_R \\ S_i = 4r^2(c_S-\delta)\left(\sqrt{1-(2c_S i-\delta)^2} + \right. \\ \left. +(c_S-\delta)\operatorname{ctg}\varphi\right), \text{ if } \varphi \ge \psi_i,\ i > i_R \end{cases}. \quad (29)$$

Let us transform (29) taking into account (15, 16), moving from the absolute values of the areas of the ends of the boards to their relative values (relative to the area of the small-end face of the two-edged cant):

$$s_i = \frac{S_i}{S_{TEC}}, \quad (30)$$

$$\begin{cases} s_i = \dfrac{4(c_S-\delta)\sqrt{1-(2c_S i-\delta)^2}}{s_{TEC}(k)}, \text{ if } i \le i_R \\ s_i = \dfrac{4(c_S-\delta)\left(\sqrt{1-(2c_S(i-1)+\delta)^2} - (c_S-\delta)\operatorname{ctg}\varphi\right)}{s_{TEC}(k)}, \\ \qquad \text{if } \varphi < \psi_i,\ i > i_R \\ s_i = \dfrac{4(c_S-\delta)\left(\sqrt{1-(2c_S i-\delta)^2} + (c_S-\delta)\operatorname{ctg}\varphi\right)}{s_{TEC}(k)}, \\ \qquad \text{if } \varphi \ge \psi_i,\ i > i_R \end{cases}, \quad (31)$$

where s_i is relative area of the end face of the i-th board.

Let us determine the dependence of the coefficient of use of the area of the small-end face of the two-edged cant on the number of rectangular cross-section boards, as well as the angle between the face and the edge of trapezoidal cross-section boards:

$$K(i_R,\varphi) = \frac{2\sum_{i=1}^{N} S_i(i_R,\varphi)}{S_{TEC}} = 2\sum_{i=1}^{N} s_i(i_R,\varphi), \quad (32)$$

where K is coefficient of use of the area of the small-end face of the two-edged cant in the process of manufacturing rectangular and trapezoidal cross-section boards.

Using dependence (32) as the objective function, we formulate the task of optimizing the parameters of the log sawing pattern (33), taking into account the constraints (34, 35):

$$K(i_R,\varphi) \xrightarrow[i_R,\varphi]{} \max \Rightarrow i_{R\ opt}\ \varphi_{opt}, \quad (33)$$

$$i_R \le N, \quad (34)$$

$$0 < \varphi \le 90, \quad (35)$$

where $i_{R\ opt}$ is optimum number of pairs of rectangular cross-section boards in the log sawing pattern; φ_{opt} is optimal angle between the face and the edge of trapezoidal cross-section boards (deg).

5. THE RESULTS OF OPTIMIZATION OF THE SCHEMATIC MODEL FOR SAWING A LOG INTO BOARDS OF THE RECTANGULAR AND TRAPEZOIDAL CROSS-SECTION

We will illustrate the application of the developed technique of optimization of the log sawing pattern into boards of the rectangular and trapezoidal cross-section. We will optimize the log sawing pattern under rather typical conditions, when the coverage of log small-end with the sawing pattern is 90% (the width of the outer edging board is 87% of the diameter of the specified end) and the kerf thickness is equal to 1% of the diameter of the specified end. Illustrations of the dependences of the coefficient of use of the area of the small-end face of the two-edged cant (32), which covers the boards, the number of trapezoidal cross-section boards and the angle between the face and the edge of such boards are presented in Figs. 2.

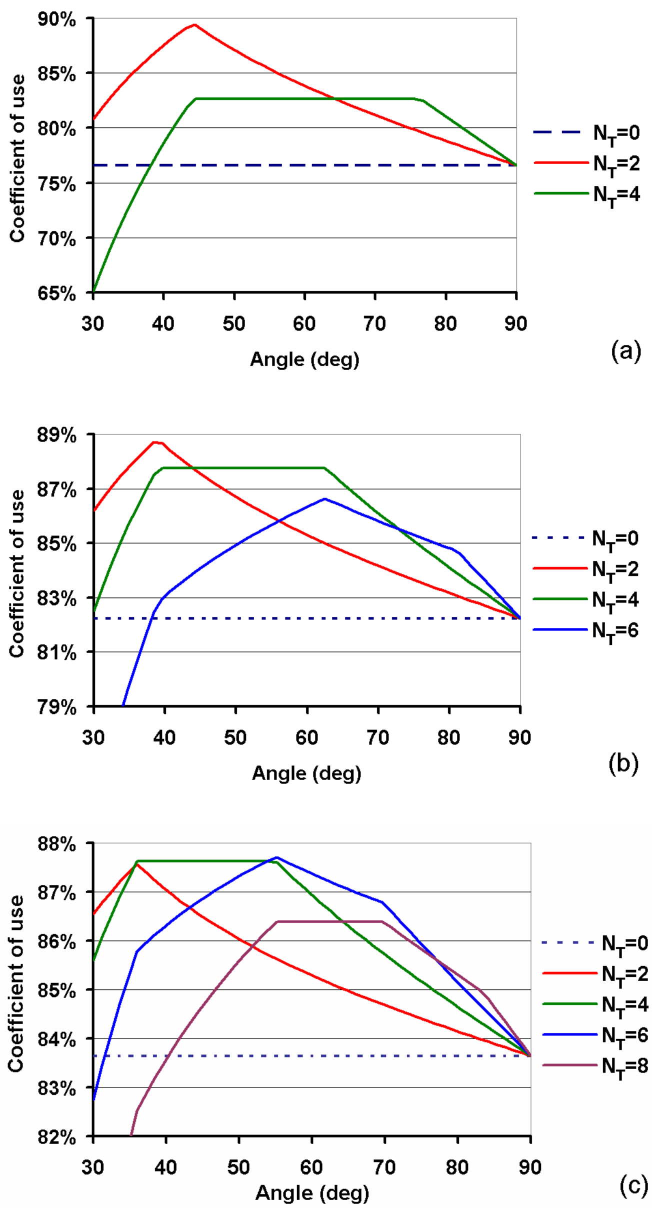

Figure 2: Dependences of the coefficient of use of the area of the small-end face of the two-edged cant on the number of boards of the trapezoidal cross-section and the angle between the face and the edge of such boards (at a relative thickness of the two-edged cant 0.9): a – to manufacture 4 boards; b - to manufacture 6 boards; c - to manufacture 8 boards.

Since the task (33) is nonlinear discrete optimization task, it is possible to find only rational values of sawing pattern parameters by using numerical hill-climbing methods. The corresponding results are presented in Table 1.

Table 1: Results of the log sawing optimization

Number of boards	**Rational values of sawing pattern parameters**		**Coefficient of use of the small-end face area of the two-edged cant**	
	the number of trapezoidal cross-section boards	**the angle between the face and the edge of the trapezoidal cross-section boards, deg**	**manufacturing only rectangular cross-section boards**	**manufacturing boards of the rectangular and trapezoidal cross-section**
4	2	44,1	76,6%	89,5%
6	2	38,9	82,2%	88,8%
8	6	55,2	83,6%	87,7%

6. DISCUSSION OF THE RESEARCH RESULTS

Comparing the results with the previous studies, we can note the following. Sawing a log to manufacture two sawn timber (trapezoidal cross-section cants), the optimal value of the angle between the face and the edge is 60°, which corresponds to the recommendations [9]. In the process of manufacturing only trapezoidal boards from the log, the proposed technique of optimization of the parameters of the sawing pattern corresponds to the technique developed in [10].

As the table. 1 shows, under rather typical above-mentioned conditions, the increase in the output of edged boards is 4.7-16.9%. In this case, the output of the edged boards is the greatest if the pair of outer boards have a trapezoidal cross-section, and the angle between the face and the edge of these boards is equal to the angle between the sawing planes and the chord, which are cut off by these planes. Accordingly, as the number of boards increases and their thickness decreases, this angle decreases. The greatest effect occurs when making four boards from a log; as the number of boards increases, this effect decreases (which is explained by the reduction of timber losses in the wany).

6. CONCLUSION

The techniques of optimization of the schematic model for sawing a log into boards of rectangular and trapezoidal cross-section is developed and their quantity and the angle between a face and an edge of a trapezoidal cross-section board are determined. The techniques are developed for live sawing logs into boards of a given thickness, with the number of boards being even. Sawing a log to manufacture boards of the rectangular and trapezoidal cross-section makes it possible to significantly increase the utilization of timber.

Since the diameters of logs can vary significantly, it is advisable to use the technique [14] to accumulate measurement information and make optimal decisions. The total width of the boards in each layer of the shield will exceed its width. Therefore, when picking boards on the layers of the panel, it is advisable to use the methodology [15] to reduce wood loss.

REFERENCES

1. D. Sandberg. **Radially sawn timber – the Primwood Method for improved properties**, *Holz Roh Werkst*, vol. 63, pp 94–101, 2005. https://doi.org/ 10.1007/s00107-004-0531-9
2. Ю. Б. Левинский, Г. Н. Левинская, Р. И. Агафонова, В. В. Савина, Н. В. Волегова. **Рациональная переработка пиловочного сырья на заготовки для производства клееных материалов строительного назначения = Rational processing of raw material for sawn timber on preparation for manufacture glued condtructive materials**, в *Трудах международного евразийского симпозиума «Деревообработка: технологии, оборудование, менеджмент XXI века»*, Екатеринбург, 2006, pp. 53-56.
3. T. C. Mannes and D. M. Adams. **The combined optimization of log bucking and sawing strategies**, *Wood and Fiber Science*, vol. 23, no. 2, pp. 296-314, 1991.
4. C. L. Todoroki and M. E. Ronnqvist. **Combined primary and secondary log breakdown optimization**, *Journal of the Operational Research Society*, vol. 50, no. 3, pp. 219-229, 1999.
5. F. P. Vergara, C. D. Palma and H. Sepulveda. **A comparison of optimization models for lumber production planning**, *Bosque*, vol. 36, no. 2, pp. 239-246, 2015. https://doi.org/10.4067/S0717-92002015000200009
6. С. І. Яцишин, Ю. І. Грицюк. **Методика визначення та аналіз оптимальних схем розкрою колод на радіальні пиломатеріали**, *Науковий вісник НЛТУ України*, vol. 17.1, pp. 136-146, 2007.
7. W. Lin, J. Wang and E. Tomas. **Development of a 3D log sawing optimization system for small sawmills in Central Appalachia, US**, *Wood and Fiber Science*, vol. 43, no. 4, pp. 378 -393, 2011.
8. D. W. Patterson, R. A. Kluender and J. E. Granskog**. Producing inside-out beams from small-diameter logs**, *Forest Products Journal*, vol. 52, no. 1, pp. 23-26, 2002.
9. Е. А. Питухин, П. С. Чикулаев. **Моделирование объема пиломатериалов с учетом сбеговой зоны ствола**, *Ученые записки Петрозаводского государственного университета*, no. 4, pp. 71–75, 2011.
10. С. А. Шевченко, А. П. Абдин. **Раскрой бревен на обрезные пиломатериалы трапецеидального сечения = Sawing logs on trapezoidal cross section lumber**, *Вісник Харківського національного технічного університету сільського господарства імені Петра Василенка*, no. 155, pp. 110-115, 2014. http://nbuv.gov.ua/UJRN/Vkhdtusg_2014_155_20
11. S. I. Ovsyannikov and V. Y. Dyachenko. **Wooden nano-composite materials and prospects of their application in wooden housing construction**, in *Materials Science Forum*, vol. 931, pp. 583-588, 2018. http://doi.org/10.4028/www.scientific.net/MSF.931.583
12. I. V. Koshkalda, V. V. Tyshkovets and A. A. Suska. **Ecological and economic basis of anti-erosion stability of forest-agrarian landscapes**, *Journal of geology, geography and geoecology*, vol. 27, no. 3, pp. 444-452. https://doi.org/10.15421/111868
13. M. Kakeh, J. Dahlen, R. Shmursky, P. D. Jones and R. D. Seale. **Bowtie Beams: novel Engineered Structural Beams from Southern Pine Lumber**, *Wood Fiber Science*, vol. 44, no. 3, pp. 1–9, 2012.
14. Sang Boem Lim. **Classification and Big Data Usages for Industrial Applications**, *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 8, no. 4, pp. 1117–1122, 2019. https://doi.org/10.30534/ijatcse/2019/18842019
15. Vincent Rafael Sayoc, Tomm Kenzo Dolores, Markquis Casslin Lim and Lia Sophia San Miguel. **Computer Systems in Analytical Applications**, *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 8, no. 3, pp. 772–777, 2019. https://doi.org/10.30534/ijatcse/2019/68832019