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AVERAGE SKIDDING DISTANCE OF TIMBERIN NON-RECTANGULAR CUTTING AREAS

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Abstract: *The results obtained in this article relate to the scientific and technological development of the timber industry. The main idea of the article is based on the possibility of concentrating several forest plots designated for felling with different percentages of cut components within a single cutting area. On the logging site created in this way, single main skidding and skidding trails were laid, allowing the entire range of logging operations to be carried out. The shape of such combined cutting areas can be a complex geometric figure. The purpose of this article is to improve existing methods and mathematical dependencies to justify the average skidding distance of timber when combining adjacent forest areas into a single cutting area. The article uses the methods of mathematical analysis, in particular, the methods of differential and integral calculus. The developed algorithm made it possible to create a unified methodological approach to find the average skidding distance, regardless of the shape of the cutting area. An important distinguishing characteristic of the created mathematical dependencies is that they can be used in cutting areas consisting of several forest plots characterized by different wood stocks. The forest areas included in the cutting area may differ in the presence of a branched structure of the main skidding and skidding trails. The results obtained can be used effectively by logging enterprises in substantiating the production rates and planning the work for future periods. As a result of using the obtained mathematical dependencies, it becomes possible to effectively place loading points and skidding trails on the territory of the cutting area.*

Key words: *forest compartment, logging, skidding, loading point, method of calculation, cutting area work, timber volume, branched structure of skid trails.*

1. Introduction

Many scientists have been looking for ways to reduce the cost of placing loading areas and developing a system of skidding trails on the territory of cutting areas [3, 5, 13]. Substantiation of the technological characteristics of the skidding operation in the conditions of cutting areas of various non-rectangular shapes is an equally

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important task that requires reliable calculations when performing skidding operations to loading points on cutting areas.

It is known that the parameters and shape of cutting areas, selective cuttings are determined by the size and configuration of forest taxation areas with their natural boundaries, if this does not exceed the maximum area of the cutting area and does not create the danger of a windblow or other negative consequences [17]. With a small size of such plots, a cutting area can include several of the above-described divisions with different stocks of timber on them.

In this regard, when substantiating the technological elements of cutting areas, it is necessary to take into account their non-rectangular shape. One of the characteristics that depend on the shape and uniformity of the distribution of timber stocks in the territory of the plots is the average skidding distance. It plays a significant role in the justification of productivity and the choice of work technology.

Questions of searching for a rational distance between loading points and related methods for finding the average distance of timber skidding in rectangular areas were proposed in various studies [6, 16].

Abuzov and Ryabuhin [1] considered a method for calculating the average skidding distance and productivity for a three-line balloon-cable transport system in hard-to-reach triangular forest areas. The method for calculating the average skidding distance of timber, taking into account non-operating areas, was proposed by Derbin et al. [4]. The method for describing the curvilinear boundaries of the sections, which allows determining the technological parameters of cutting areas using GIS, was proposed by Rozhencova [11].

Analyzing the studies described above, it can be concluded that at present there are known methods for determining the average skidding distance and placing loading points for rectangular and non-rectangular plots. However, the studies described above do not take into account the differences in cut stocks, silvicultural systems in the stands that are part of the combined cutting areas [12-14], the possibility of a non-rectilinear location of landing areas [10, 15] with a combination of various harvesting systems which are typical for the real practice of working in the forest. Thus, for cutting areas characterized by a variation in wood stocks which are further a branched and non-rectilinear structure of skidding trails, these methods require clarification.

2. Materials and Methods

The purpose of this article is to improve existing methods and mathematical dependencies to justify the average skidding distance of timber when combining adjacent forest areas into a single cutting area.

The main objectives of the study, which must be solved within the framework of the goal, include:

1) The creation of a unified methodological approach to find the average distance of skidding, regardless of the shape of the cutting areas being developed;
2) The creation of methodological dependencies for calculating the average skidding distance in cutting areas, consisting of several forest plots with different stocks of wood on them.

The technique presented in the article provides for the division of the analyzed adjacent cutting areas into a number of simple geometric shapes, which allows us to simplify the calculations as much as possible and reduce them to the use of methods of differential and integral calculus.

To determine the average skidding distance, we consider a cutting area (Figure 1) located on the territory of a forest compartment bounded by quarterly clearings 1 and adjacent to a non-straight logging road 2, consisting of two non-rectangular sections. Each of the sections that make up the cutting area is characterized by different stocks of timber. According to the outline of the cutting area with the indicated position of the loading point 3, it is possible to determine all the geometric parameters of the forest area being developed. In different parts of the cutting area under consideration, various options for skidding trails 4 are provided. When performing work on the cutting areas, the trees 5 were felled with the top on the skidding trail.

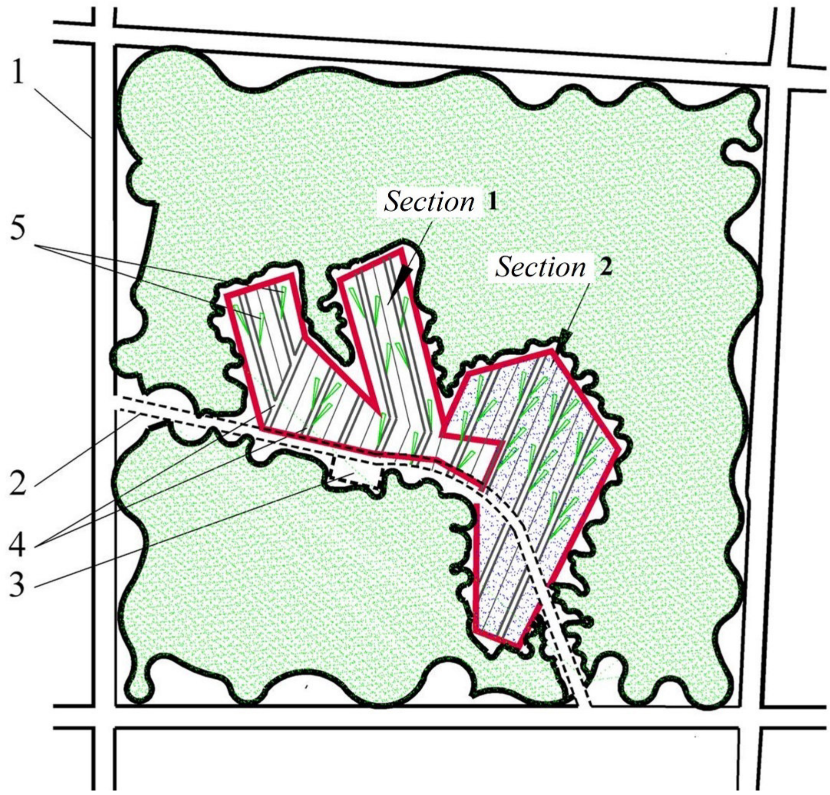

Fig. 1. *Technological scheme for determining the average skidding distance of timber on the combined sections of non-rectangular shape (Source: Compiled by the authors)*

When transforming the shape of forest areas, practical recommendations have been developed that allow dividing the cutting area into a number of simple geometric shapes:

1) The cutting lines are drawn from points corresponding to sharp changes in the perimeter of the original geometric

shape, for each of the plots included in the cutting area; points characterizing the location of loading points and points corresponding to sharp bends on sections of the logging road;

2) The division of the territory of the cutting area into simple geometric shapes is carried out by secant straight lines parallel to the direction of the skidding trails closest to them;
3) The end point of each secant straight line is the nearest point of its intersection with a section of a straight line that characterizes the direction of the main skidding trails or the boundaries of the corresponding skiddings roads;
4) The lines that limit the original geometric figure, the lines drawn by secant lines and the lines connecting their end points, delimit the shapes of new geometric figures.

The use of the proposed recommendations makes it possible to divide the previously presented cutting area of complex configuration into nine simple geometric shapes as shown in Figure 2, of which those shown in panels 1, 2, 4, 6÷9, are adjacent to the logging road, and those from panels 3 and 5 are remote from it; panels are located on the left (1, 2) and right (3÷9) sides of the loading point and plots have the shape of a trapezoid (1÷7, 9) and a triangle 8.

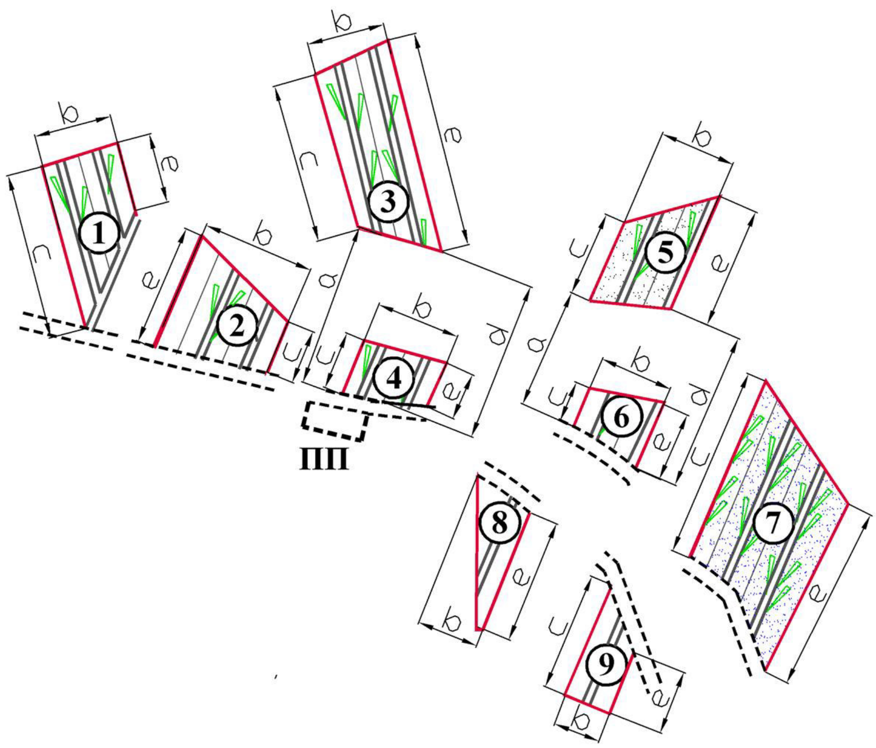

Fig. 2. *A variant of dividing the cutting area into simple geometric shapes (Source: Compiled by the authors)*

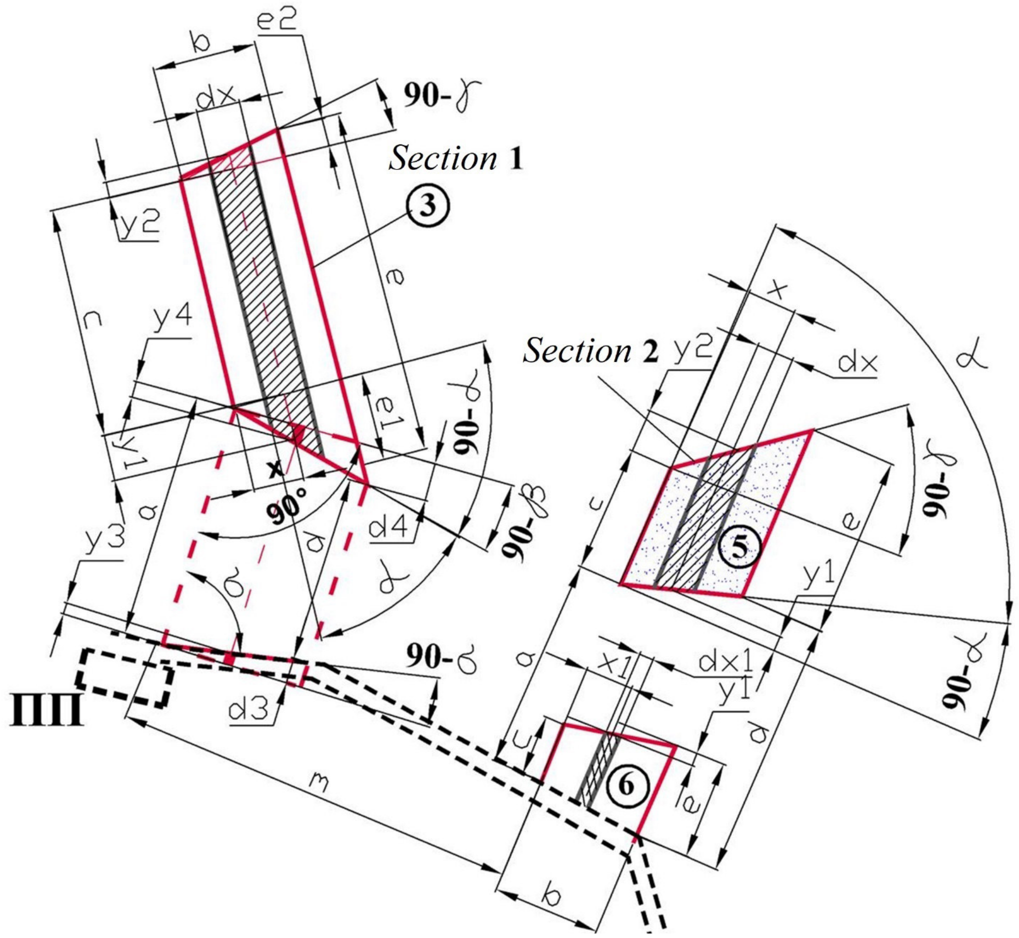

Fig. 3. *Calculation scheme for determining the average skidding distance in areas of various configurations (Source: Compiled by the authors)*

Each figure has its own dimensional characteristics. However, despite the numerical differences, these indicators have the same names.

Consider Figure 3, which has the shape of a trapezoid and is located at a distance from the landing area. Such a form and location represent a general case of the location of plots within a united cutting area. Plots of a different geometric shape or adjacent to the landing area are special cases of solving the problem.

To determine the average skidding distance, we select an elementary area dx in the trapezoid. The magnitude of the vertical elementary area will be (1) and (2):

$$dS = (c + y_1 + y_2)dx \tag{1}$$

$$tg\alpha = \frac{y_1}{x} = \frac{e_1}{b};\ tg\gamma = \frac{y_2}{x} = \frac{e_2}{b}$$

$$y_1 = \frac{e_1}{b} \cdot x;\ y_2 = \frac{e_2}{b} \cdot x \tag{2}$$

Taking into account the presented equations, we obtain (3):

$$dS = \left(c + \frac{e_1}{b} \cdot X + \frac{e_2}{b} \cdot X \right) dx = \left(c + \left(e_1 + e_2 \right) \cdot \frac{X}{b} \right) dx = \left(c + \left(e - c \right) \cdot \frac{X}{b} \right) dx \quad (3)$$

Skidding distance from an elementary area can be determined by the formulas (4) and (5):

$$\ell_3 = \frac{(c + y_1 + y_2)}{2} + m + \frac{x \cdot \cos\beta}{\cos\alpha \cdot \cos\sigma} + a - y_3 - y_4 \quad (4)$$

$$\sin\sigma = \frac{y_3 \cdot \cos\alpha}{x} = \frac{d_3 \cdot \cos\alpha}{b}; \quad \sin\beta = \frac{y_4 \cdot \cos\alpha}{x} = \frac{d4 \cdot \cos\alpha}{b} \quad (5)$$

Consequently:

$$y_3 = \frac{d_3 \cdot x}{b}; \quad y_4 = \frac{d_4 \cdot x}{b} \quad (6)$$

Substituting the obtained patterns into the previously proposed formula for calculating the skidding distance from an elementary area, we get (7), (8) and (9):

$$\ell_3 = \ell_3^{M} + \ell_3^{\Pi} \quad (7)$$

where: ℓ_3^{M} is the skidding distance from the elementary area along the main skidding trails [m], and ℓ_3^{Π} is the skidding distance from an elementary area along main skidding trails [m].

$$\ell_3^{M} = m + \frac{x \cdot \cos(90 - \beta)}{\cos(90 - \alpha) \cdot \cos(90 - \sigma)} \quad (8)$$

where:

- α is an acute angle between the main skidding trails of the plots and the side of the plot crossing them in the direction of skidding [degree];
- β – an acute angle between the skidding trails extending from the plot and the side of the figure crossing them in the direction opposite to the direction of skidding;
- σ – an acute angle between the skidding trails and the main skidding trail (timber road)crossing them.

$$\ell_3^{\Pi} = \frac{\left(c + (e - c) \cdot \frac{x}{b} \right)}{2} + a - \frac{x}{b} \cdot (a - d) \quad (9)$$

Then:

$$\ell_3 = \frac{\left(c + (e - c) \cdot \frac{x}{b}\right)}{2} + m + \frac{x \cdot \cos(90 - \beta)}{\cos(90 - \alpha) \cdot \cos(90 - \sigma)} + a - \frac{x}{b} \cdot (a - d) \qquad (10)$$

The work ($m^3 \cdot m$) spent on skidding timber from the plot to the landing area along the skidding trails will be (11):

$$R_y = \frac{q_i}{10^4} \cdot \int_0^b \ell_3^{\Pi} dS = \frac{q_i}{10^4} \cdot \int_0^b \left[\left(\frac{c + (e - c) \cdot \frac{x}{b}}{2} + a - \frac{x}{b} \cdot (a - b)\right) \cdot \left(c + (e - c) \cdot \frac{x}{b}\right)\right] dx =$$

$$= \frac{q_i \cdot b}{6 \cdot 10^4} \cdot \left[c \cdot (c + 2 \cdot a + d + e) + e \cdot (a + 2 \cdot d + e)\right] \qquad (11)$$

where *qi* is the average wood stock in the area limited by the plot [m^3].

The work [m^3 x m] spent on skidding timber from the figure to the landing area along the main skidding trails will be:

$$R_y = \frac{q_i}{10^4} \cdot \int_0^b \ell_3^{M} dS = \frac{q_i}{10^4} \cdot \int_0^b \left[(m + x \cdot f) \cdot \left(c + (e - c) \cdot \frac{x}{b}\right)\right] dx = \frac{q_i}{10^4} \cdot \left[\frac{b^2 \cdot f \cdot \left(e + \frac{c}{2}\right)}{3} + \frac{b \cdot m \cdot (e + c)}{2}\right] \qquad (12)$$

Where:

$$f = \frac{\cos(90 - \beta)}{\cos(90 - \alpha) \cdot \cos(90 - \sigma)} \qquad (13)$$

3. Results

As a result of the study, it is substantiated that the total work spent on skidding timber from any site, presented in the form of a regular geometric figure, to the loading point will be:

$$R_y = \frac{q_i}{10^4} \cdot \int_0^b \ell_3 dS = \frac{q_i}{10^4} \cdot \int_0^b \left[\left(\frac{c + (e - c) \cdot \frac{x}{b}}{2} + m + x \cdot f + a - \frac{x}{b} \cdot (a - d) \right) \cdot \left(c + (e - c) \cdot \frac{x}{b} \right) \right] dx =$$

$$R_y = \frac{q_i \cdot b}{6 \cdot 10^4} \cdot \left[c \cdot (c + f \cdot b + d + 2 \cdot a + 3 \cdot m + e) + e \cdot (a + 2 \cdot f \cdot b + 2 \cdot d + 3 \cdot m + e) \right] \quad (14)$$

With *a=d, c=e,* the trapezoid takes the form of a rectangle, and with *c=0* or *e=0,* it becomes a triangle. With indicators set at a=0, *d=0, β=0* and *σ=0,* it becomes possible to analyze the plots adjacent to the main skidding trail (timber road). Plots 5 and 6 presented in the calculation diagram (Figure 3) can serve as an example, where the average skidding distance can be calculated without any transformation of the presented dependence.

When the indices *α, β, σ* are different from zero, it becomes possible to analyze plots with a sharp change in the direction of skidding trails.

If the cutting area configuration has a complex shape or consists of several sections of various shapes and sizes, on the territory of which various types of cuttings are carried out, then the average skidding distance can be determined by the formula (15):

$$\ell_{cp} = \frac{\sum_{y=1}^{n} R_y}{Q_n} \quad (15)$$

Where $y = 1 \dots n$ is the number of figures of various configurations gravitating towards one loading point; and Q_n is the total harvested stock on the cutting areas [m^3].

4. Discussion

Comparison of the results presented in the article with the results of previous studies described above allows us to note that none of the scientific studies carried out by other authors aimed at analyzing cutting areas consisting of several forest plots with different stocks of wood on them [1, 4, 10, 7-9]. The present new study is also distinguished by the fact that it allows an assessment of cutting areas of any shape, and the plots included in the cutting areas may differ in the presence of a branching structure of the main skidding and skidding trails.

This research allows improving the accuracy of calculations in any natural and production conditions. Questions about the expediency and inexpediency of using such highly accurate results in practice and their practical complexity for forest users with mathematical justification can be removed by increasing the level of informatization of forestry workers. Thus, one of the promising directions for using the results obtained in the article is writing software for computers that can be executed in any of the existing programming languages.

5. Conclusion

The results presented in this article have been experimentally tested under production conditions. They are recommended for use in enterprises engaged in the development of cutting areas formed by combining several forest compartments. Implementation of the obtained results into production creates conditions for efficient placement of loading points, laying skidding trails, reducing costs for the development of logging sites, and increasing the productivity of skidding equipment

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