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Plowshares Wear Investigation of the Plows Working in Mountainous Conditions Using Statistical Probabilistic Modeling

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Abstract: A general technique for modeling of the wear of machine parts using the theory of probability and mathematical statistics is developed, which is implemented through the example of plows of agricultural plows. Regularities of their wear during working under mountainous conditions are established, an adequate probabilistic-statistic mathematical model is obtained, general characteristics of the distribution of wear are determined using statistical moments and their most common (modal) values are determined which allow to substantiate the method of restoring worn parts for the purpose of increasing their life. This technique can also be utilized to study the regularity of wear of parts of other machines.

Key words: Plow, ploughshare, wear, modeling, statistical probabilistic model.

1. Introduction

Among the operations for cultivating agricultural crops, deep tillage is the most important, which is carried out by plows. ploughshares are the most important working parts of plows, which operate under difficult soil and climatic conditions. When working in the mountainous terrain, these conditions are more severe—the alternating dynamic loads, humidity, abrasive soil particles, mountain relief exposure, inclinations, waviness, etc. constantly act on the plowshares [1]. These factors cause intensive wear of the plowshares and their failures. As a result, downtime of plows occurs and the agrotechnical terms of plowing are violated, which adversely affects the yield of agricultural products. Therefore, the study of the regularity of wear of plowshares is relevant because, knowing the modal values of wear, you can choose a rational way to restore them and increase the resource.

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2. Materials and Methods

The collection of statistical materials on the wear of plowshares was carried out in the mountainous regions of Georgia—Racha-Lechkhumi and Samtskhe-Javakheti to identify the patterns of wear. It was found that the plowshare wears out the front side, the toe and the cutting part intensively. Measurement of wear of worn out plowshares was carried out using modern measuring materials-electronic calipers, micrometers and hour-type indicators. The results obtained were recorded in a special journal of statistical observations.

A general methodology for the probabilistic and statistical modeling of wear of parts has been developed, using statistical moments. The essence of this methodology is as follows:

- The optimal number of measurements is determined according to the number of intervals by Sturgess formula and the width of the intervals.
- The initial and central statistical moments are calculated statistical moments [2-4].

- The general characteristics of plow wear-average arithmetic mean, variance, standard deviation, coefficient of variation, median and modal (most common) wear are determined.
- A probabilistic statistical model of wear is shown and its adequacy is checked by Kolmogorov's criterion.

3. Results and Discussion

Implementation of the methodology developed is presented below.

Probabilistic statistical modeling of statistical data was carried out with the help of statistical moments. Statistical and variation series of wear of the plowshare were compiled, as a result of which the number of intervals-*K* is determined by the Sturgess formula, the number of intervals-*K* and their width-*h* is determined by the formula of Sturgess [5].

$$K = 1 + 3.2 \lg * N \quad (1)$$

where $N = 100$ – number of measurements.

$$h = \frac{X_{\max} - X_{\min}}{K} \quad (2)$$

where $X_{\max}$ = 26 mm is the maximum wear value of the share, $X_{\min}$ = 10 mm is the minimum. $h = \frac{26-10}{8} = 2$ mm.

Table 1 presents the results of determining the frequencies and empirical probability of wear.

To establish the theoretical law of the distribution of the plowshare, it is necessary to determine the general charasteristics using statistical moments. For this purpose, Table 2 is compiled.

x' is determined by the following formula:

$$x' = \frac{x_i - x_0}{h} \quad (3)$$

x_0 = 15 mm, the wear value to which the maximum empirical frequency corresponds. Table 2 defines the statistical moments:

$$\nu_1 = \frac{\sum_{i=1}^{k} x'mi}{N} = \frac{128}{100} = 1.28 \quad (4)$$

$$\nu_2 = \frac{\sum_{i=1}^{k} (x')^2 mi}{N} = \frac{494}{100} = 4.94 \quad (5)$$

$$\nu_3 = \frac{\sum_{i=1}^{k} (x')^3 mi}{N} = \frac{1616}{100} = 16.16 \quad (6)$$

Table 1 Statistical indicators of the wear of plow.

Wear interval *a-b*	Empirical frequency m_i	Empirical probabilit w_i
10-12	6	0.06
12-14	9	0.09
14-16	23	0.23
16-18	20	0.2
18-20	16	0.16
20-22	12	0.12
22-24	9	0.09
24-26	5	0.05

Table 2 Data for the determination of statistical moment.

Wear interval *a-b*	The middle of the interval x_i	*x*'	m_i	$x'm_i$	$(x')^2m_i$	$(x')^3m_i$	$(x')^4m_i$
10-12	11	-2	6	-12	24	-48	96
12-14	13	-1	9	-9	9	-9	9
14-16	15	0	23	0	0	0	0
16-18	17	1	20	20	20	20	20
18-20	19	2	16	32	64	128	256
20-22	21	3	12	36	108	324	972
22-24	23	4	9	36	144	576	2,304
24-26	25	5	5	25	125	625	3,125
			Amount	128	494	1,616	6,782

$$\nu_4 = \frac{\sum_{i=1}^{k}(x')^4 mi}{N} = \frac{6782}{100} = 67.82 \quad (7)$$

$$\mu_2 = \nu_2 - \nu_1^2 \quad (8)$$

$$\mu_3 = \nu_3 - 3\nu_2\nu_1 + 2\nu_1^3 \quad (9)$$

$$\mu_4 = \nu_4 - 4\nu_3\nu_1 + 6\nu_2\nu_1^2 - 3\nu_1^4 \quad (10)$$

$$\mu_2 = 4.94 - 1.28^2 = 4.94 - 1.638 = 3.3;$$

$$\mu_3 = 16.16 - 3 \times 4.94 \times 1.28 + 2(1.28)^3 = 0.38;$$

$$\mu_4 = 67.82 - 4 \times 16.16 \times 1.28 + 6 \times 4.94 \times 1.28^2 - 3 \times 1.28^4 = 25.58.$$

$\nu_1, \nu_2, \nu_3, \nu_4$: initial statistical moments of the first, second, third and fourth orders, respectively.

μ_2, μ_3 , μ_4: central statistical moments of the second, third and fourth orders.

After that, the general characteristics of the wear of the share:

The arithmetic mean value:

$$\bar{x} = x_0 + \nu_1 \cdot h = 15 + 1.28 \times 2 = 17.56 \text{ mm} \quad (11)$$

Standard deviation:

$$\sigma = h\sqrt{\mu_2} = 2 \times 1.82 = 3.64 \text{ mm} \quad (12)$$

The coefficient of variation:

$$V = \frac{\sigma}{\bar{x}} = \frac{3.64}{17.56} = 0.21 \quad (13)$$

Modal wear:

$$M_0 = \bar{x} + 3(M_e - \bar{x}) = 17.56 + 3(19.33 - 17.56) = 22.87 \text{ mm} \quad (14)$$

where M_e = 19.33 mm is the median distribution of the inbred ploughshare [6].

$$M_e = L + \frac{h \cdot (\frac{\sum_{i=1}^{k} mi}{2} - S)}{m_{Me}} = 18 + \frac{2(50-38)}{18} = 19.33 \text{ mm} \quad (15)$$

S-accumulated empirical probability:

$$S \le \frac{\sum_{i=1}^{k} mi}{2} \le 50; \; S = 38$$

$$m_{Me} = 18\text{мм} - \text{ empirical frequency in the median} \quad (16)$$

By the value of the coefficient of variation (V = 0.21), the theoretical law of the distribution of wear of the share is chosen to be the normal and theoretical frequency determined by the following formula [7, 8]:

$$m_x = \frac{N \cdot h}{\sigma} \cdot Z_t = \frac{100 \times 2}{3.64} \cdot Z_t = 36.2 \cdot Z_t \quad (17)$$

Z_t is the wear distribution density. The results of the calculations are presented in Table 3.

After this, empirical and theoretical curves for the distribution of wear of plowshares were constructed (Fig. 1).

As it can be seen visually, the theoretical and empirical results are close, but for a more accurate checking of the adequacy of the obtained mathematical model, the Kolmogorov agreement criterion is used [9]. For this purpose, Table 4 is compiled.

The integral distribution function determines, using the formula:

$$F(x) = 0.5 + 0.5\Phi(t) \quad (18)$$

$\Phi(t)$ is the integrated Laplace function.

To determine the coincidence of theoretical and empirical results by the Kolmogorov's criterion, it is necessary to determine the parameter λ:

$$\lambda = D_{\max} \cdot \sqrt{N} = |F_{(x)} - W_{н}|_{\max} \cdot \sqrt{N} = |0.0465| \times 10 = 0.47 \quad (19)$$

According to the results based on Ref. [10], if λ = 0.47, the probability of coincidence of theoretical and empirical results: P (λ) = 0.9. Therefore, the mathematical model is adequate.

Table 3 Data for determining the theoretical frequency of wear of plowshares.

Wear interval *a-b*	The middle of the interval x_i	$t = \frac{x_i - \bar{x}}{\sigma}$	Z_t	Empirical frequency m_i	Theoretical frequency m_x
10-12	11	-1.8	0.0790	6	4.3410
12-14	13	-1.25	0.1826	9	10.0338
14-16	15	-0.7	0.3123	23	17.1608
16-18	17	-0.15	0.3945	20	21.6777
18-20	19	0.4	0.3683	16	20.2344
20-22	21	0.95	0.2541	12	13.9627
22-24	23	1.49	0.1515	9	8.3249
24-26	25	2.04	0.054	5	2.9673

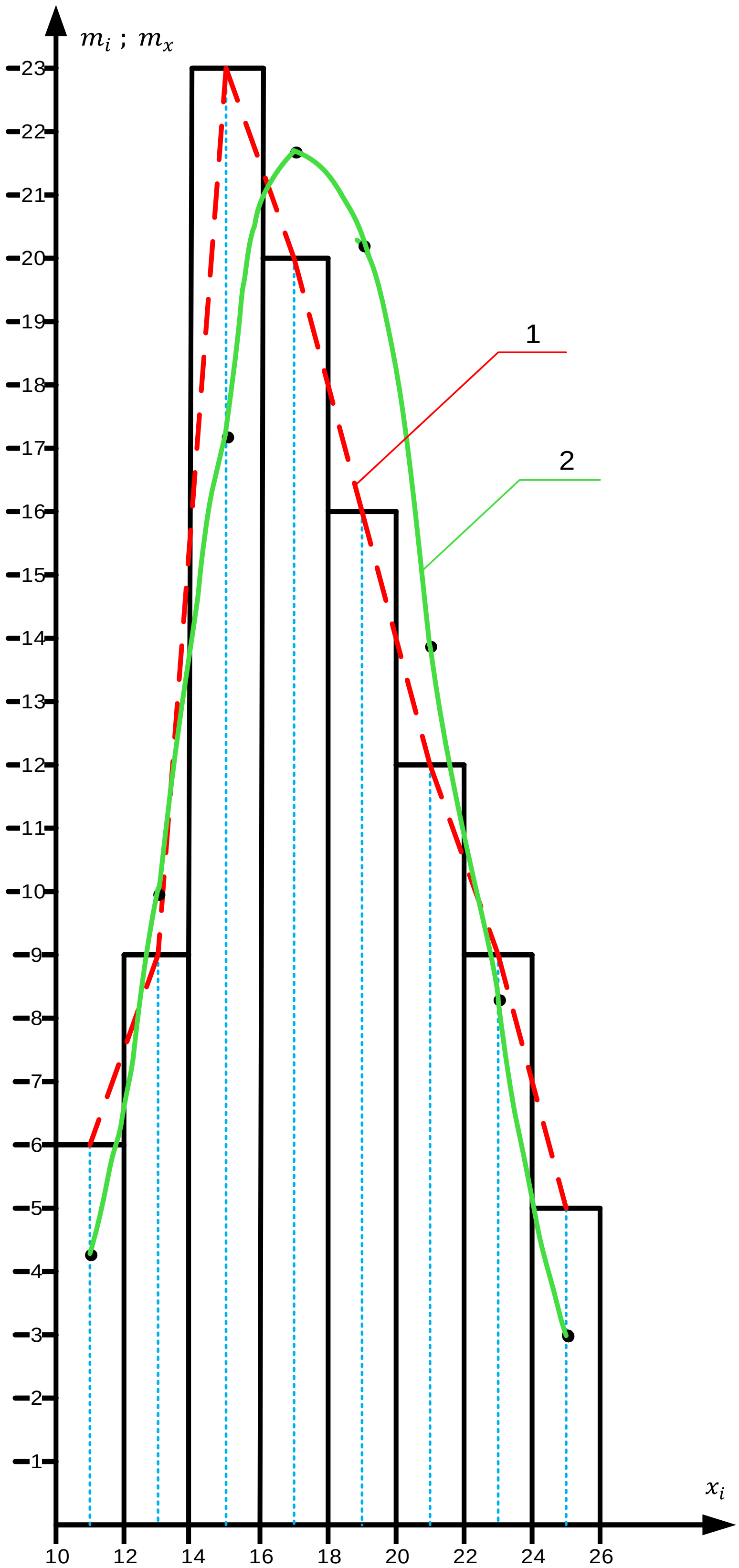

Fig. 1 Empirical (1) and theoretical (2) plows wear distribution curves.

Table 4 Data for the Kolmogorov test.

Wear interval a-b	The middle of the interval x_i	$t = \frac{x_i - \bar{x}}{\sigma}$	$\Phi(t)$	$\frac{1}{2}\Phi(t)$	W_i	$W_н$	$F_{(x)}$	$F_{(x)} - W_н$
10-12	11	-1.53	-0.874	-0.437	0.06	0.06	0.063	0.003
12-14	13	-0.98	-0.6729	-0.3365	0.09	0.15	0.1635	0.0135
14-16	15	-0.43	-0.3328	-0.1665	0.23	0.38	0.3335	0.0465
16-18	17	0.12	0.0955	0.048	0.2	0.58	0.548	0.032
18-20	19	0.67	0.4971	0.2485	0.16	0.74	0.7485	0.0085
20-22	21	1.22	0.7775	0.389	0.12	0.86	0.889	0.029
22-24	23	1.77	0.9233	0.4615	0.09	0.95	0.9615	0.0115
24-26	25	2.32	0.9797	0.49	0.05	1	0.99	0.01

4. Conclusions

As a result of the theoretical and experimental studies carried out, the following conclusions can be drawn:

(1) The regularities of wear of plowshares are investigated, working in the mountain regions of Georgia and it was found that the plowshare wears out the front side, the toe and the cutting part intensively.

(2) The methodology for calculating the statistical parameters of the plows of the plows has been developed and implemented, which can be used for parts of other machines. General characteristics and modal depreciation have been defined to justify the method of restoration of share in order to increase their resources.

(3) An adequate probabilistic statistical mathematical model of share wear has been obtained, which can be used to predict the resources of plows

(4) In conclusion, it may be stated that the technique developed by us can be successfully used to study the patterns of wear of parts of other machines.

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