Theoretical and experimental study of the operational reliability of small-sized agricultural machinery operating in the mountainous conditions of Adjara

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Abstract: *Adjara, with its diverse natural conditions, relief and soil and climatic features, is one of the distinctive regions of Georgia, dominated by mountainous terrain, steep slopes and small areas. Accordingly, the complex mechanization of agricultural processes by mobile agricultural machinery is inappropriate and therefore small-sized agricultural machinery is used. This technique works in difficult soil-climatic and dynamic conditions, it is constantly affected by significant dynamic forces, high humidity, abrasive particles in the environment, mountainous terrain and others. All these factors cause intensive wear and decrease in the reliability of the working bodies of machines. It should be noted that single and complex indicators of the operational reliability of small-scale mechanization equipment operating in the mountainous conditions of Adjara have not been studied and their establishment will contribute to the rational organization of technical service of small-scale mechanization machines.*
The reliability indicators of motoblocks and motor cultivators, such as the probability of failure-free operation, time between failures, the failure rate parameter, the average resource, the coefficients of technical use and readiness, are considered, adequate probabilistic-statistical mathematical models are obtained, the least reliable nodes, types of failures are identified, and a set of measures is outlined to improve reliability.
KEYWORDS: *AGRICULTURAL MACHINERY, MOTOBLOCK, RELIABILITY, PROBABILISTIC-STATISTICAL MODEL, FAILURE.*

1. Introduction: Adjara, due to its natural conditions, relief and soil-climatic features, is one of the original regions of Georgia, in which mountainous relief, steep slopes and low-contour lands predominate. Therefore, the mechanization of labor-intensive agricultural processes with mobile agricultural machines and units is inappropriate and small-sized agricultural machinery is used. The number of such machines of small mechanization, according to official data, is more than 4,000 pieces. Most of them have an engine with a power of 0.1 ... 10 kW. Manufacturers of such machines are Niugoland, Goldon, Kubota, Mitsubishi, and other companies. Mountain conditions and low-contour land adversely affect the operational reliability of small-scale mechanization machines and cause failures. It should be noted that very little design and research work has been carried out in this direction, and the problem of calculating and improving the reliability of small-sized equipment, taking into account local operating conditions, is relevant.

2. Main part: According to pre-prepared logs, statistical data was collected to assess the operational reliability of walk-behind tractors in Kobuleti, Shuakhev, Khulois and Keda municipalities - all failures and their types, time were recorded. spent on their elimination, time to failure and other all the necessary data. Processing of the obtained statistical data was carried out according to the previously compiled by us method according to the NRT plan [1,2]. Received the following series of MTBF of motoblocks:

200; 201; 204; 210; 230; 200; 300; 210; 310; 400; 300; 290; 220; 224; 210; 330; 400; 350; 360; 380; 400; 384; 390; 350; 360; 420; 500; 480; 470; 200; 300; 290; 240; 290; 240; 380; 400; 430; 460; 880; 480; 470; 480; 500; 550; 500; 580; 520; 600; 800; 890; 300; 280; 282; 288; 200; 440; 460; 580; 600; 504; 720; 600; 570; 700; 800; 710; 200; 370; 450; 500; 300; 480; 660; 700; 680; 690; 700; 900; 300; 400; 330; 360; 400; 340; 500; 480; 488; 500; 600; 570; 600; 650; 700; 650; 700; 720; 800; 790; 800; 900; 600.

For mathematical processing of these data and probabilistic-statistical modeling, we compose a variational series of time between failures:

22; 22; 22; 22; 22; 22.1; 22.4; 23; 23; 23; 23; 2 24; 24.4; 25; 26; 26; 30; 30.2; 30.8; 31; 31; 31; 32; 32; 32; 32; 32; 33; 35; 35; 37; 37; 38; 38; 38; 39; 40; 40; 40.4; 41; 42; 42; 42; 42; 42; 42; 42; 45; 46; 47; 48; 48; 49; 49; 50; 50; 50; 50; 50; 50.8; 52; 52; 52; 52; 52; 52.4; 54; 57; 58; 59; 59; 59; 60; 62; 62; 62; 62; 62; 62; 67; 67; 68; 70; 71; 72; 72; 72; 72; 72; 73; 74; 74; 81; 82; 82; 82; 82; 90; 90; 92.

We determine the number of intervals using the Sturgess formula [2] and its width:

$$K = 1 + 3{,}2\ lg\ N = 7$$

$$\text{h} = \frac{X_{max} - X_{min}}{K} = \frac{92 - 22}{7} = 10$$

$\mathbf{K}$ is the number of intervals. $\mathbf{N} = 100$ is the number of motoblocks, h is the number of intervals, $\mathbf{X_{max}}$ and $\mathbf{X_{min}}$ are the maximum and minimum **MTBF** values, respectively. Next, the empirical failure rate and frequency (empirical probability) were determined – **table -1**.

After that, the general characteristics of the time between failures of walk-behind tractors were determined:

Average:

$$\overline{H} = \sum_{i=1}^{k} W_i h_i = 27 \cdot 0.27 + 37 \cdot 0.2 + 47 \cdot 0.18 + 57 \cdot 0.14 + 67 \cdot 0.1 + 77 \cdot 0.08 + 87 \cdot 0.03 = 7{,}29 + 7{,}4 + 8{,}46 + 7{,}98 + 6{,}7 + 6{,}16 = 47\ hours.$$

Dispersion:

$$D = \sum_{i=1}^{k} (H_i - \overline{H})^2 \cdot W_i = (27-47)^2 \cdot 0.27 + (37-47)^2 \cdot 0.2 + (47-47)^2 \cdot 0.18 + (57-47)^2 \cdot 0.14 + (67-47)^2 \cdot 0.1 + (77-47)^2 \cdot 0.08 + (87-47)^2 \cdot 0.03 = 108 + 20 + 14 + 40 + 72 + 48 = 302$$

Table -1. Empirical frequencies and probabilities of failures of walk-behind tractors

MTBF Interval $a \ldots b$	Interval midpoint x_i	Empirical frequency m_i	Frequency (empirical probability) W_i
22...32	27	27	0.27
32...42	37	20	0.20
42...52	47	18	0.18
52...62	57	14	0.14
62...72	67	10	0.10
72..82	77	8	0.08
82...92	87	3	0.03
	Sum	100	1.00

Standard deviation:

$$\sigma = \sqrt{D} = \sqrt{302} = 17{,}4 \quad hours.$$

The coefficient of variation:

$$V = \frac{\sigma}{\overline{H}} = \frac{17{,}4}{47} = 0{,}4$$

The failure rate of walk-behind tractors is:

$$\lambda = \frac{\sigma}{\overline{H}} = \frac{1}{47} = 2 \cdot 10^{-2} \quad hours - 1.$$

Differential failure distribution function or probability density:

$$\varphi(\overline{H}) = \lambda e^{-\lambda H_i} = 2 \cdot 10^{-2}\, e^{-2 \cdot 10^{-2} \cdot H_i}$$

Cumulative distribution function:

$$F(H) = 1 - e^{-2 \cdot 10^{-2} \cdot H_i}$$

Probability of trouble-free operation of walk-behind tractors:

$$P(H) = 1 - F(H) = e^{-2 \cdot 10^{-2} \cdot H_i}$$

According to these formulas, the reliability indicators of walk-behind tractors were calculated and the results are presented in **table -2**.

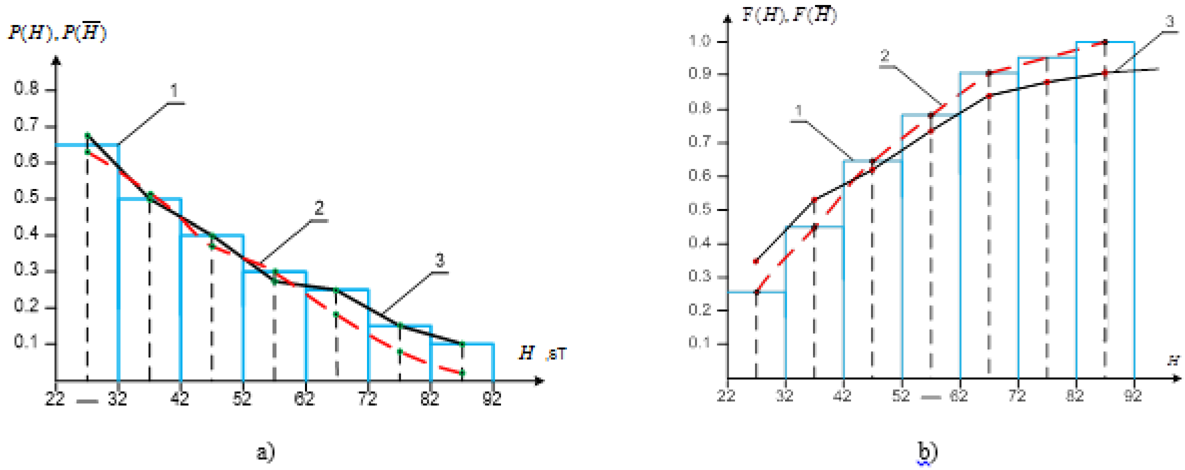
Table -2. The values of the differential distribution function of the time between failures of walk-behind tractors.

MTBF Interval $a \ldots b$	Interval midpoint H_i	Empirical frequency m_i	Frequency (empirical probability) W_i	Distribution density (Empirical) $\varphi(\overline{X}) \cdot 10^{-2}$	**П**Distribution density (Theoretical) $\varphi(X) \cdot 10^{-2}$
22...32	27	27	0.27	1.72	1.82
32...42	37	20	0.20	1.30	1.4
42...52	47	18	0.18	1.02	1.06
52...62	57	14	0.14	0.66	0.78
62...72	67	10	0.10	0.52	0.59
72..82	77	8	0.08	0.44	0.48
82...92	87	3	0.03	0.32	0.34

Table -3. *Shows the indicators of operational reliability of walk-behind tractors.*

Table -3. Indicators of operational reliability of walk-behind tractor.

MTBF Interval $a \dots b$	Interval midpoint H_i	Cumulative distribution function		Probability of uptime		Frequency	
		$F(\bar{H})$	$F(H)$	$P(\bar{H})$	$F(H)$	m_i	m_x
22...32	27	0.27	0.34	0.63	0.66	27	25
32...42	37	0.47	0.50	0.53	0.50	20	18
42...52	47	0.65	0.63	0.35	0.37	18	16
52...62	57	0.79	0.74	0.21	0.26	14	13
62...72	67	0.89	0.82	0.11	0.18	10	9
72..82	77	0.97	0.84	0.03	0.16	8	7
82...92	87	1.00	0.88	0	0.12	3	3



Graphical interpretation of research results is shown in **fig -1. a)** and **b).**

Fig -1. Graphs of indicators of reliability of walk-behind tractors **a)** Probability of no-failure operation. **b)** Probability density. **1**. Histogram, **2.** Empirical curve, **3.** Theoretical curve.

Comprehensive indicators of the operational reliability of walk-behind tractors were determined [4]:

Availability factor

$$K_1 = 47/(47+12) = 0,8$$

Technical utilization coefficient

$$K_2 = 47/(47+5+12) = 0,76$$

Operational indicators of reliability of individual municipalities of Adjara obtained by us are given in **Table -4**.

Table -4. Operational indicators of reliability of individual municipalities of Adjara

Municipality	Mean time between failures $\bar{H}$, hours	Failure rate $\lambda - 1e^{-1} \cdot 10^{-2}$	Probability of uptime $P(\lambda)$	Availability factor K_1	Technical utilization factor K_2
Kobuleti	47	2	0.54	0,8	0.76
Shuakhevi	38	2.6	0.45	0..7	0..66
Keda	36	2,78	0.48	0.65	0.64
Khulo	25	4	0.42	0.6	0.59

Next, the agreement between the theoretical and empirical results was checked using the Pearson criterion [3,4] . For this, it was determined by the $\mathbf{x^2}$ formula:

$$\mathbf{x^2} = \sum_{i=1}^{k} \frac{(m_i - m_x)^2}{m_x}$$

The calculation results are presented in **table -5.**

Table -5. Calculation results. χ^2

MTBF Interval $a \dots b$	m_i	m_x	$\mathbf{x^2}$
200...300	26	24	0.17
300...400	20	18	0.22
400...500	18	16	0.25
500...600	14	13	0.08
600...700	10	9	0.11
700...800	8	7	0.24
800...900	4	3	0.33

The degree of freedom is:

$$r = K - e$$

K - number of intervals. $K = 7$

e - number of binding links and for the exponential distribution: e =2. $r = 7 - 2 = 5$. According to literary sources [2,4] , at and Probability of coincidence of theoretical $\mathbf{x^2} = 1{,}3$ and empirical results $r = 5$.

$$\mathrm{P} = 0{,}5$$

It turns out that the probabilistic-statistical model is adequate.

Failure modes were also investigated and the following results were obtained:

- Construction -30%;
- Manufacturing -26%;
- Operating-44%.

As the analysis of the obtained research results shows, the motoblocks operating in the Kobuleti municipality have the highest operational reliability:

$\overline{H} = 352\ h$, $\mathrm{P(H)} = 0{,}52$

And the lowest in Khuloi municipality:

$\overline{H} = 180\ h$, $\mathrm{P(H)} = 0{,}42$

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The largest share falls on operational failures, which shows that machine operators grossly violate the rules for the technical use of walk-behind tractors and their qualifications need to be improved.

3. Conclusions: Based on theoretical and experimental studies, the following conclusions can be drawn:

1. A methodology has been compiled and theoretical and experimental studies of the operational reliability of small-sized agricultural machinery operating in the mountainous conditions of Adjara have been carried out;
2. Individual and complex indicators of reliability of motoblocks operating in individual municipalities of Adjara have been determined;
3. The main failures of walk-behind tractors have been established and the expediency of using qualified machine operators when using walk-behind tractors has been proved.

4. References:

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