Change of Technical Condition and Productivity of Grain Harvesters Depending on Term of Operation

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Abstract. The regularities of change of technical condition of combine harvester Slavutich KZC-9F depending on service life are determined. It is determined that after the second year of operation, the readiness factors decrease in one season by 0.044 or 5.2%, and the recovery factors increase, respectively, their productivity decreases. Within the normative costs for overhaul repairs of combines and maintenance of their operability during the harvest after the second season of operation, there is an annual decrease in the readiness factor by 0.036. Analysis of rate of change of indicator of selective assessment of the readiness factor allows us to conclude that the service life of the main units, systems, mechanisms of combines is exhausted by the service life of five to six years and a total output of 1200-1400 hours with an average output for the season of 200-280 hours. If the duration of downtime to eliminate failures after the third year of operation changes to a maximum of 22%, the recovery rate increases by 35%. The productivity of the combine harvesters Slavutich KZC-9F increases with increasing service life due to a decrease in the readiness factor. A decrease in the readiness factor by 0.01 causes a decrease in the productivity of the combine by 21.2 tons/season.

1. Introduction

Modern methodological approaches to the development of technological maps of harvesting do not take into account the service life of the combine [1] and its technical condition [2]. Failure to consider the previous service life of combines [3] and the probable values of technical condition leads to significant miscalculations in forecasting the timing of the harvest [4]. For machines of short seasonal use [5], the most significant of the indicators of reliability as serviceable systems are statistical or probable values of operating times between the next failures [6] and the duration of downtime [7].

Modern researchers [8, 9] have found that a comprehensive indicator of the efficiency of recovery systems using the coefficients of technical readiness [10]. This rogue is calculated as the ratio of the average operating time between failures to the average operating time between failures plus the average downtime to eliminate failures [11].
2. Purpose of research
The purpose of the research is to establish the empirical dependences of changes in the technical condition and productivity of combine harvesters Slavutich KZC-9F depending on the service life.

3. Materials and methods
Since the number of tested combines was constant (48 combines), the number of recorded failures, or the total number of hours worked to calculate the reliability indicators with a given accuracy [12], was determined for the recoverable objects [13]. Supervision of combines operation was performed according to the plan \( NM(F \Sigma, T \Sigma) \) [14], according to which \( N = 48 \) combines were simultaneously studied. After each failure of the robot [15], the ability of the combine was restored \( F \Sigma = 80 \) failures, or when reaching the total operating time of all combines reached \( T \Sigma = 257 \) hours. Conditions for conducting ruttan research of the season \( F \Sigma = 80 < 109; T \Sigma = 257 \) hours \( \ll 1500 \) hours. For plans \( NMF[16] \) and \( NMT[17] \) we calculate a sample estimate of operating time for failure of combine for harvest period of the first year of operation: \( \overline{t}_0 = S \cdot m^{-1} = 241 \cdot 13^{-1} = 18.53 \) hours. Selective estimate of the average duration of recovery \( \overline{t}_0 = m^{-1} \sum_{i=1}^{m} t_i = 58 \cdot 13^{-1} = 4.46 \) hours.

The point estimate of the readiness factor [18] for the combine for the harvest period of the first year of operation is calculated by the formula: \( K_t^1 = \overline{t}_0 \cdot (\overline{t}_0 + \overline{t}_1)^{-1} = 18.53 \cdot (18.53 + 4.46)^{-1} = 0.81 \).

Point estimation of readiness coefficients [19] for combines for the harvest period of the first year of operation, respectively for combines №2 \( K_t = 0.58; №3 \ K_t = 0.73; №4 \ K_t = 0.51; №5 \ K_t = 0.76; №6 \ K_t = 0.59; №7 \ K_t = 0.76; №8 \ K_t = 0.57; №9 \ K_t = 0.58; №10 \ K_t = 0.76, \) combine №10 was decommissioned due to engine failure after 60 hours [20].

The average value of the readiness factor for nine combines is determined from the formula: \( K_t^1 = N^{-1} \sum_{i=1}^{N} K_{ti} = 9^{-1}(0.80 + 0.58 + 0.73 + 0.51 + 0.76 + 0.59 + 0.76 + 0.57 + 0.58) = 0.65 \).

4. Results and discussion
The regularity of the decrease in the average value of the readiness factor with increasing service life is shown in figure 1 and the polynomial of the fourth degree: \( K_{ti} = -0.0043X^4 + 0.0784X^3 - 0.5072X^2 + 1.3051X - 0.3009R^2 = 0.9862 \).

![Figure 1](image.png)

**Figure 1.** Regularities of change of stationary coefficient of readiness and non-stationary coefficient of operational readiness.

During the five years of operation after 2013, the value of the readiness factor decreased from the value of \( K_{r2} = 0.86 \) to \( K_{r7} = 0.64, \) ie by 26%. The average seasonal value of the reduction of the readiness factor was \( K_T = 0.044, \) or 5.2% per year. According to the assessment [21], we assume that the statistical indicators of the coefficient of readiness of the pattern of change with increasing service life are close to the Weibull distribution [22]. For the second year of operation of the combine harvester determine. Stationary readiness factor for the second year of operation:
\[ K_F = \mu \cdot (\mu + w)^{-1} = 0.25 \cdot (0.25 + 0.040)^{-1} = 0.86. \]

Non-stationary coefficient of readiness to change jobs:
\[ K_F(f_3) = \mu \cdot (\mu + w)^{-1} + w \cdot (\mu + w)^{-1} \cdot e^{-(w+\mu)t_3} = 0.25 \cdot (0.25 + 0.040)^{-1} + 0.40 \cdot (0.25 + 0.040)^{-1} \cdot e^{-(0.25+0.040)} = 0.866 \approx 0.87. \]

Stationary coefficient of operational readiness for change:
\[ K_F(f_3) = \mu \cdot (\mu + w)^{-1} \cdot e^{-wr} = 0.86 \cdot e^{-0.041\cdot14} = 0.86e^{0.54} = 0.86 \cdot 1.77^{-1} = 0.86 \cdot 0.56 = 0.48. \]

Non-stationary coefficient of operational readiness for a change of work:
\[ K_F(\tau, t) = \left[ \mu \cdot (\mu + w)^{-1} + w \cdot (\mu + w)^{-1} \cdot e^{-(w+\mu)t_3} \right] \cdot e^{-wr} = 0.87 \cdot 0.56 = 0.49. \]

Stationary and non-stationary coefficient differ by 0.01, and stationary readiness factor \((K_F)\) and stationary operational readiness factor \((K_{0,1}(t))\) differ \(\Delta K_F = K_F - K_{0,1}(t) = 0.86 - 0.48 = 0.39\).

We determine the main characteristics of the Weibull distribution for the coefficient of readiness with increasing service life. \(\bar{T}_m = \Gamma(1 + m^{-1})w^{-1}\) – the average value of operating time between failures. 
\(f(t_3) = m\omega(\omega \cdot t)m^{-1}e^{-(\omega t)m} \) distribution density. 
\(F(t_3) = 1 - e^{-w(t)} \) failure probability distribution function. 
\(D\bar{T}_m = w^{-2} \cdot [\Gamma(1 + 2 \cdot m^{-1}) - \Gamma^2(1 + m^{-1})] \) – dispersion.

Calculations of Weibull distribution characteristics for the second year of combine harvester operation (as an example): \(T_{n2} = \Gamma(1 + 27^{-1}) \cdot 0.04^{-1} = 22.23\) hours. \(f_2(t_3) = 2.70 \cdot 0.04(0.04 \cdot 14)2.70^{-1}e^{-(0.04\cdot14)2.70} = 0.033. \)
\(F_2(t_3) = 1 - 2.71^{-2}(0.04\cdot14)^2.70 = 1 - 0.82 = 0.18. \)
\(D\bar{T}_{n2} = 0.04^{-2} \cdot [\Gamma(1 + 2 \cdot 27^{-1}) - \Gamma(1 + 27^{-1})] = 625 \cdot 0.1289 = 78. \)

The patterns of change of the stationary readiness factor and the non-stationary operational readiness factor depending on the service life are shown in figure 1. Regularities of change of density of distribution \(K\), and functions of distribution of probability of failure are shown in figure 2.

![Figure 2](image-url)

**Figure 2.** The function of distribution: a – of operating values between failures with increasing time of operation; b – of probability of failure during the change with increasing time of operation.

The main characteristics of the Weibull distribution of combines with increasing effluents are summarized in table 1. The figure 1 shows that the discrepancy between the experimental and calculated values of Weibull distribution is not significant (up to 3%). With the amount of information \(N = 48\) and the absence of a statistical series, the standard deviation is determined from the formula: \(\sigma_{kg} = (N - 1)^{-1/2} \cdot \left( t_i - t_{cp} \right)^2 = 0.141. \) The value of the coefficient of readiness for the harvest of the first year of operation is: \(K_{1,kg} = 0.65 \pm 0.141. \) Determine the coefficient of variation: \(V = \sigma_{kg} \cdot \left( K_{1,kg} \right)^{-1} = 0.141 \cdot 0.61^{-1} = 0.34. \) According to the known coefficient of variation \(\gamma_p = 0.34\) from table 2 we find the parameters and coefficients of the Weibull distribution: \(b = 3.22; \) \(B_B = 0.896; \) \(C_B = 0.306. \)
Find the offset parameter: \( C = \bar{K}_T - aK_B = 0.61 - 0.418 = 0.198 \). Determine the upper confidence limit for the readiness factor: 
\[
K_w = (\bar{K}_T - C) \cdot Z_1^{1.22} + C = 0.63. \\
K_H = (\bar{K}_T - C) \cdot Z_3^{3.22} + C = (0.61 - 0.198) \cdot 0.96 + 0.198 = 0.59.
\] Analysis of the rate of change of the indicator of selective assessment of the readiness factor allows us to conclude that the service life of the main units, systems, mechanisms of combines is exhausted by the service life of five to six years and a total output of 1200-1400 hours with an average output for the season of 200-280 hours. After the specified service life in years and production in m.-h. the operating time between failures decreases from 25 motor hours to 12-13 motor hours, the duration of downtime on failures is stabilized within 6 hours, and the rate of readiness is reduced to 0.67...0.64 (figure 3).

### Table 1. Characteristics of Weibull distribution of operation of combines with increasing time of operation.

| Years of operation of the combine | \( T \), hours | \( \sigma_{kg} \) | \( f (t) \) | \( N \) |
|-----------------------------------|----------------|----------------|--------|------|
| 1                                 | 10.79          | 0.075          | 0.80   | 49   |
| 2                                 | 22.93          | 0.032          | 0.18   | 78   |
| 3                                 | 19.65          | 0.038          | 0.31   | 94   |
| 4                                 | 14.42          | 0.040          | 0.54   | 141  |
| 5                                 | 11.65          | 0.041          | 0.67   | 89   |
| 6                                 | 11.21          | 0.044          | 0.70   | 82   |
| 7                                 | 10.30          | 0.046          | 0.86   | 73   |

### Table 2. Main characteristics of Weibull distribution of combines.

| Indicators       | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
|------------------|----|----|----|----|----|----|----|
| Experimental value| -  | 0.16 | 0.230 | 0.350 | 0.41 | 0.450 | 0.49 |
| 2 Estimated value | -  | -  | 0.226 | 0.292 | 0.358 | 0.424 | 0.49 |
| Infelicity, %    | -  | -  | 1.700 | 19.800 | 14.52 | 6.100 | 0   |

**Figure 3.** Change of readiness coefficients of the combine depending on time of operation.

The probable value of the coefficient of readiness for the harvest after the second can be calculated empirically 
\( K_{f1} = K_{f2} \cdot e^{-(0.015+0.005x_i)^3} \), where \( x_i \) – year of operation of combine. For example, for the third year of operation: 
\( K_{f3} = 0.86 \cdot e^{-(0.015+0.005-3)^3} = 0.79 \). The average value of the reduction of the readiness factor for the operating season (within seven seasons of operation) can be determined by the formula:

\[
\gamma_K = [K_{max} - K_{min}] \cdot [n - 2 \cdot (0.86 - 0.64) \cdot (7 - 2)^{-1}] \quad \text{season}^{-1}.
\] Within the normative costs for overhaul repairs of combines and maintenance of their operability during the harvest after the second season of operation, there is an annual decrease in the readiness
factor by 0.036. The influence of the readiness factor on the performance of the combine is determined by its influence on the utilization time of the change. The coefficient of readiness determines the relative indicator of technical condition $Z$ introduced by us, which is included directly in the equation according to which the coefficient of use of change time is determined. We accept that the value of $Z$ increases linearly with increasing years of use of the combine. The change in the relative technical condition is shown in figure 4. Productivity (in tons) of combines with increase in service life due to decrease in coefficient of readiness decreases:

$$\gamma Q = (Q_{r_{\text{max}}} - Q_{r_{\text{min}}}) \cdot (n - 2)^{-1} = (1133 - 605) \cdot (7 - 2)^{-1} = 106, \text{ton/season}.$$  

A decrease in the readiness factor by 0.01 causes a decrease in the combine's productivity by 21.2 t/season. Determine the specific decrease in productivity per unit of reduction of the readiness factor: $\Delta \gamma = (Q_{r_{\text{max}}} - Q_{r_{\text{min}}}) \cdot (K_1'_{\text{max}} - K_1'_{\text{min}})^{-1} = 31.3$ tons. According to the results of experimental research, the relative indicator of technical condition for the service life of seven years varies from the values of 0.16 (second year of operation) to the value of 0.49 (seventh year of operation) in figure 4. According to the obtained experimental data, the factors included in the equation have values $Z_2 = 0.16$, $K_2 = 0.066$, ie the equation will be as follows $Z = 0.16 + 0.066 \cdot (n - 2)$, where $n_i$ – serial number of the year of operation. If the coefficient of readiness of the combine harvester decreases with increasing service life, the recovery factor increases in figure 5.

If the duration of downtime to eliminate failures after the third year of operation changes to a maximum of 22%, the recovery rate increases by 135%.
5. Conclusions
1. During the five years of operation of the combine harvesters Slavutich KZC-9F, the value of the readiness factor decreased from 0.86 to 0.64, by 26%. The average seasonal value of the reduction of the readiness factor was 0.044, or 5.2% per year.

2. The productivity of the combine harvesters Slavutich KZC-9F increases with increasing service life due to a decrease in the readiness factor. A decrease in the readiness factor by 0.01 causes a decrease in the productivity of the combine by 21.2 tons/season.

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