Mathematical Modeling and Information Technologies in the Management of Tractor Maintenance Operations

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Abstract. Obtaining the greatest amount of crop with the lowest labor and material costs in agriculture is possible by reducing the operating costs of the equipment used. Reducing the machine and tractor fleet cost is possible only if high performance machines are provided with a sufficient level of reliability of the equipment used. In order to ensure trouble-free machines operation during the stressful agricultural period, it is necessary to determine the level of technical equipment maintenance sufficient to prevent sudden failures and to perform the necessary maintenance and repair operations for the units outside the stressful agricultural period. The article presents an algorithm for calculating the incorrect determination probability of the failure-free tractor operation. Using the probabilistic characteristics of the errors measurement distribution according to the normal law and the tractor reliability indicators according to the Weibull law, it is possible to determine the risks associated with the tractor operation during busy agricultural periods. The obtained mathematical models were used while computer program algorithm writing for planning the maintenance and repair of the agro-industrial complex enterprises fleet.

1. Introduction

In tense periods of the main technological operations implementation at the agro-industrial complex enterprises, the need for stopping the machine-tractor units for maintenance and repair, as part of a planned-preventive system, arises from the timeliness and performance quality, which directly depends on the agricultural enterprise yield and profitability. At the same time, the maintenance and repair work volume increases proportional to the volume of technological operations performed, that is, a contradiction arises: if maintenance is not carried out in time, especially complex and labor-intensive TO-2 and TO-3, the failure rate increases and the tractor fleet is forced to stand idle for repairs and the crop is lost, and if carry out maintenance on time, the number of failures decreases, but maintenance downtime increases, which also leads to delays in the execution of operations and yield losses. The optimal solution here is difficult to find and the mechanic tractor operating decides in favor of carrying out field work to the detriment of maintenance work, which leads to premature wear and equipment failure. To eliminate this contradiction, the machine-tractor fleet maintenance and repair system was developed and introduced at the enterprises of the agro-industrial complex on the basis of scheduling. The main system feature is that complex maintenance services of TO-2 and TO-3, which, according to the principle of a preventive system, fell out during busy agricultural periods, are carried out before the onset of a busy period when tractors are idle [1, 2]. It was assumed that, by conducting the upcoming TO-2 and TO-3 using diagnostic tools, not only maintenance downtime, but also to eliminate failures in the period when it is necessary to achieve maximum productivity during agricultural work, will be eliminated. At the same time, the effect E taken from conducting TO-2 and TO-3 (TO-2 is also performed in the amount of TO-3) before agricultural work, which is determined by the formula:

\[ E = C_1 + C_2 - C_3, \]
where \( C_1 \) and \( C_2 \) are the costs associated with the equipment downtime reduction for maintenance and the failures elimination in the upcoming stressful field work period;

\( C_3 \) - additional costs associated with an increase in the work volume on the tractors maintenance and diagnosis before the stressful period onset.

2. Objects and methods

The main research methods were used methods of mathematical modeling and statistical processing of the results. On the basis of the dependencies obtained, a program for determining the tractor resource based on the Excel Analysis Package Package was written.

Based on the practical application of the criterion of expediency, it does not take into account a number of quite important factors that reduce the effectiveness of this progressive form of maintenance of machines. When applying a form of maintenance using the scheduling system, it is not known whether the machine will work, carrying out the forthcoming amount of field work without causing failures. Will there be “bogus failures” during maintenance? The appearance of different failures types in this system depends on the accuracy of measuring diagnostic parameters and determining the probability of failure-free tractor components operation, which is not taken into account in equation (1).

3. Research results

Let \( x \) be the true parameter value, and \( y \) the measuring result the same parameter with a diagnostic tool to take into account the influence of the probabilistic processes characteristics of technical parameters maintenance and diagnostics on the expediency criterion value.

In this case: \( f(x) \) is the distribution density of the tractor unit status parameter, for example, the gap in the conjugation;

\( \tau = (y-x) \) - parameter measurement error;

\( f(\tau) \) is the density of the measurement error distribution;

\( x \) and \( y \) are random, independent values.

As a result of measuring the value of \( x \) of the parameter \( X \), according to the indications of the diagnostic device, we read the measurement result of \( y \).

The following situations are possible:

- \( S_x \) - value \( x \) is within the tolerance of a parameter change (for example, the nominal and allowable gap in the interface);
- \( S \) - value is outside the tolerance range;
- \( S_y \) - measurement of \( y \) is within the limits of the tolerance field;
- \( S \) - measurement result is outside the tolerance range.

An event with the \( x \) value of the parameter \( X \) and the measurement result \( y \) pairwise compatible.

Then the following complex events are possible:

- \( S_{xy} \) is the \( x \) value and the measurement result \( y \) is within the tolerance range (gap in the conjugation);
- \( S_x \) - value and measurement result \( x \) are outside the tolerance range.

After processing the data we can conclude that in both cases the correct conclusion about the node state is made.

\( P(x) = \int P(S_x \cap S_y) f(\tau) d\tau \),

where \( f(\tau) \) is the measurement error density.
The conditional probability \( P(Sx/\tau) \) must be determined at a fixed value of \( \tau \) (the measurement error has already occurred).

Depending on the instrumental determination outcomes of the technical object state, \( \tau \) may be greater or equal to zero \( \tau \geq 0 \) or \( \tau \leq 0 \).

Consider cases for technical condition parameters, the value of which increases during operation of a component of a car, for example: crankcase consumption when the engine is worn, the gaps in the interface (case I) increase (Fig. 1), or the parameter values decrease, for example, fuel injection pressure at wear of injector nozzles; pressure generated by the fuel pump (case II) (Fig. 1).

Thus, for case \( I \) with \( \tau \geq 0 \) (Fig. 1. I) with fixed \( \tau \):

\[
P\{Sx/y / \tau\}_{\tau \geq 0} = \int_{a-\tau}^{b} f_1(x)dx
\]

For case \( II \) with \( \tau \leq 0 \) (fig. 1. II)

\[
P\{Sx/y / \tau\}_{\tau \leq 0} = \int_{a-\tau}^{a} f_1(x)dx
\]

In the first case, the probability that the value of \( x \) will be within the tolerance field \((a, b)\), and the result of measuring \( y \) is outside it, corresponds to the probability that \( x \) is smaller or larger \((b-\tau)\). In the second case, an identical picture is formed, only the upper limit of integration will be smaller \((a-\tau)\). To go to the full probability \( P(Sx) \) (formula 3) and following [3], integrating with \( a \leq a \) (case I), we get:

\[
P(Sx/y) = \int_{a-\tau}^{a} f_1(x)dx \times \int_{0}^{f_2(\tau)} f_2(\tau) d\tau \bigg|_{\tau > 0}
\]

where \( f_2(\tau)d\tau \) is the measurement error distribution function.

For case \( II, P(Sx) \) will be:

\[
P(Sx/y) = \int_{a}^{a-\tau} f_1(x)dx \times \int_{0}^{f_2(\tau)} f_2(\tau) d\tau \bigg|_{\tau < 0}
\]

The situation when the measurement result is in the tolerance field \((a, b)\) of the parameter change of the technical condition of the tractor component, and its true value is outside it, can be presented for cases (I, II) in the form (Fig. 2):
The conditional probability \( P(y/\tau) \) for a fixed \( \tau \) is equal for case \( I \) (Fig. 2):

\[
P(S_{xy}/\tau)_{\tau<0} = \int_{a-\tau}^{a} f(x)dx
\]

For case \( II \) (Fig. 2):

\[
P(S_{xy}/\tau)_{\tau\geq0} = \int_{a-\tau}^{a} f(x)dx
\]

According to the formula of the total probability for the \( I \) case:

\[
P(S_{xy}) = \int_{a-\tau}^{a} f(x)dx \times \int_{0}^{\tau-a} f_2(\tau)d\tau
\]

For case \( II \):

\[
P(S_{xy}) = \int_{a-\tau}^{a} f(x)dx \times \int_{0}^{\tau-a} f_2(\tau)d\tau
\]

Taking into consideration all mentioned above, the probability of incorrectly determining the state of the diagnosed node for the first case is equal to:

\[
P(S_{xy}) + P(S_{xy}) = \int_{a-\tau}^{a} f_1(x)dx \times \int_{0}^{\tau-a} f_2(\tau)d\tau + \int_{a-\tau}^{a} f_1(x)dx \times \int_{-(a-\tau)}^{\tau-a} f_2(\tau)d\tau
\]

For case \( II \):

\[
P(S_{xy}) + P(S_{xy}) = \int_{a-\tau}^{a} f_1(x)dx \times \int_{-(a-\tau)}^{\tau-a} f_2(\tau)d\tau + \int_{a-\tau}^{a} f_1(x)dx \times \int_{0}^{\tau-a} f_2(\tau)d\tau
\]

In the future, the use of the dependencies we obtained is specified by the distribution laws of the measured parameter \( f(x) \) and measurement errors \( f(\tau) \). The most likely of these are the normal law and the Weibull distribution law. Normal law should be used to characterize measurement errors and parameters of the technical state of components and assemblies with \( \nu = \frac{\sigma}{m} \leq 0.3 \) (\( \nu \) - coefficient of variation) and the Weibull law is the characteristics of the parameters of the components and assemblies technical condition, usually associated with the wear of parts, where usually \( \nu > 0.3 \). The densities of these distributions, respectively, will be:

\[
f(\tau) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(\tau - \tau_x)^2}{2\sigma^2}}
\]

\[
f(x) = \frac{e}{a} \left( \frac{x}{a} \right)^{a-1} e^{-\left( \frac{x}{a} \right)^\nu}
\]
functions, then implement the dependencies (14, 15) and introduce the concepts:

- the nominal value of the parameter $X_n$, corresponding to the state of the diagnostic parameter of the node of the new machine (in the tolerance field, this is “a” figure 1.2);
- $X_p$ is the permissible value of the parameter, at which failure recovery is not yet required (in the tolerance field it is “b”);
- $X_s$ - its limiting value with fully worn parts, as a result of which a failure occurs;
- $\delta_0$ - is the minimum tolerance corresponding to the allowable residual resource from $X_p$ to $X_s$.

\[
P(S_{xy}) + P(S_{yx}) = \frac{1}{\sigma_x \sqrt{2\pi}} \int_0^{\frac{\tau}{\tau}} e^{-\frac{(X_p - X)^2}{2\sigma_x^2}} d\tau \left[ \exp\left( \frac{(X_p - X)}{a} \right) - \exp\left( \frac{(X_p - \tau - X)}{a} \right) \right] +
\]

\[
+ \frac{1}{\sigma_x \sqrt{2\pi}} \int_0^{\frac{(X_s - X)}{\tau}} e^{-\frac{(X_p - X)^2}{2\sigma_x^2}} d\tau \left[ \exp\left( \frac{(X_p - X)}{a} \right) - \exp\left( \frac{(X_p - \tau - X)}{a} \right) \right]
\]

And for the narrowing parameters values of the tractor components and assemblies technical condition when worn:

\[
P(S_{xy}) + P(S_{yx}) = \frac{1}{\sigma_x \sqrt{2\pi}} \int_{(X_s - X)}^{(X_p - X)} e^{-\frac{(X_p - X)^2}{2\sigma_x^2}} d\tau \left[ \exp\left( \frac{(X_p - \tau - X)}{a} \right) - \exp\left( \frac{(X_p - X)}{a} \right) \right] +
\]

\[
+ \frac{1}{\sigma_x \sqrt{2\pi}} \int_{(X_s - X)}^{(X_p - X)} e^{-\frac{(X_p - X)^2}{2\sigma_x^2}} d\tau \left[ \exp\left( \frac{(X_p - X)}{a} \right) - \exp\left( \frac{(X_p - \tau - X)}{a} \right) \right]
\]

However, it should be determined that the risk of incorrectly determining the state of a node or aggregate with a probability $P(x)$ is fraught with the fact that there is actually no failure, and according to the readings of diagnostic devices it is there, and there is a need for a more detailed study of the condition of the node or aggregate of the tractor and possibly disassembling it. This situation leads to additional costs of time and money in diagnosing, although this happens in an unstressed field work [4, 5]. Therefore, the first components of the dependencies in formulas (16) and (17) should be considered as the likelihood of additional costs when performing work during scheduling maintenance of tractors, and the second component as the likelihood of the risk of failure in the upcoming field work period, which usually does not taken into account.

To implement the obtained dependencies, it is necessary to know the distribution functions of the main tractor components and assemblies technical parameters – the key ones, and there are not so many of them that determine the performance of the tractor [6]. Values of permissible and limiting parameters are determined from the results of the experiment. The standard deviations of measurement errors are determined on the basis of the maximum measurement error $e = 3\sigma_e$.

The experimental data determine the of the variation coefficients value of the Weibull distribution, $(V)$ by the coefficient $(V)$ determine the differential

\[
f(x) = \frac{6}{\alpha} \left( \frac{x}{\alpha} \right)^{\alpha-1} e^{-\left( \frac{x}{\alpha} \right)^{\alpha}} \text{ or integral } F(x) = 1 - e^{-\left( \frac{x}{\alpha} \right)^{\alpha}} \text{ functions, then implement the dependencies }
\]

(16) and (17), setting the integration limits, based on specific conditions: degree of deterioration of the tested components and assemblies of the tractor (resources), duration of the upcoming field work period, and others [7].

In the practical implementation of the models obtained, it is possible to obtain the resource values of individual tractor units based on the specific operating conditions using mathematical processing of the Excel Analysis Package [8]. (Fig. 3).
Figure 3. Regression analysis results obtained using the Excel Analysis Package

The resulting mathematical models can be processed in publicly available programs in order to obtain an algorithm for planning a technical service system for a particular enterprise of the agro-industrial complex and managing the processes of maintenance and repair of the fleet with the lowest predicted costs and saving the unit life during the overhaul period [9, 10].

4. Conclusion
Based on the above, we can draw the following conclusions:

1. In order to ensure trouble-free machines operation during the stressful agricultural period, it is necessary to determine the level of technical maintenance of equipment sufficient to prevent sudden failures and to perform the necessary maintenance and repair operations for the units outside the stressful period of agricultural production.

2. To take into account the influence of the probabilistic characteristics of technical parameters maintenance and diagnostics processes on the expediency criterion value, mathematical dependencies of the tractor units and assemblies technical condition parameters were obtained for expanding parameters values as a result of wear (16), and dependencies for the narrowing values of tractor components technical parameters under wear (17).

3. Mathematical models are processed in publicly available programs. As a result, an algorithm for planning the system of technical service and managing the processes of maintenance and repair of agricultural enterprises fleet has been obtained.

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