Assessment of individual reliability indicators and rational service life of agricultural tractors

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Abstract. Nowadays, a case-by-case approach to optimizing and rationalizing the machine usage parameters is relevant. One of the ways to improve the efficiency of the machine and tractor fleet operation with regard to individual reliability indicators is to assess the rational tractor service life. According to the proposed model, the tractor is to be decommissioned when it ceases making a profit. Aiming to test the proposed model, ten 3 kN class tractors, operated in agricultural enterprises in the Vologda district of the Vologda region, have been under research for five years. As a result, it has been found out that all the tractors under study have different reliability and, consequently, different rational service life periods.

1. Introduction
Nowadays, a case-by-case approach to optimizing and rationalizing the machine usage parameters is relevant. The individuality in question is mainly due to the fact that machines, even of the same brand, are different in reliability [1-6]. During socialist ownership times, the unified planned standards set by the government were an impediment for fulfilling such tasks. At present, we do not have such a problem, and the current level of computer technology development makes it possible to solve these problems with the greatest confidence and in a short time. One of the ways to improve the efficiency of the machine and tractor fleet operation with regard to individual reliability indicators is to assess the rational tractor service life [3].

2. Theoretical studies
The proposed model provides the assessment of rational tractor service life during a limited period of monitoring, for example, from 3 to 5 years. The model includes coefficients that characterize the individuality of the tractor usage parameters in relation to similar parameters on average of the fleet:

\[ B(t) = \begin{cases} 
D(t) - A(t) - aC_{FR}(t) - bC_{FL}(t), & \text{if } 0 \leq T < T_D \\
D(t) - S - aC_{FR}(t) - bC_{FL}(t), & \text{if } T \geq T_D 
\end{cases} \rightarrow \max \tag{1} \]

where \( B \) – the profit made by a tractor since placed in service, \( D \) – the revenue made by a tractor since placed in service, \( A \) – depreciation costs from the date of the tractor operation, \( C_{FR} \) – failure repair costs on average of the tractor fleet, \( a \) – the coefficient characterizing the individuality of the dynamics of changes in the failure repair costs for an individual tractor, \( C_{FL} \) – fuel and lubricant costs on average...
of the tractor fleet, $b$ – the coefficient characterizing the individuality of the dynamics of changes in fuel and lubricant costs for an individual tractor, $t$ – amount of work, $T$ – the useful life of a tractor, $T_D$ – depreciation period, $S$ – the cost of a new tractor.

A nominal standard hectare is the amount of work, which equals to one-hectare plowing under the following conditions taken as standard:

- soil resistivity - 0.5 kg/cm² at a speed of 5 km/h;
- operating soil depth with plowing – 20-22 cm;
- agricultural background: the stubble field on medium strength soils on the bearing surface (medium loam) at the soil humidity up to 20-22%;
- flat surface topography (the slope angle is up to 1);
- correct (rectangular) land configuration;
- length of furrow – 800 m;
- altitude above sea level up to 200 m;
- there is no stoniness or any other obstacles.

Failure repair costs are determined in the following way:

$$ C_{FR} = \sum_{k=1}^{N} \left( \frac{vt_k}{ht_{kF}} \left( \frac{zT_{FRk}C_{TR}}{420} + gC_{SPk} \right) \right) = \sum_{k=1}^{N} qL_{kF} \left( \frac{zT_{FRk}C_{TR}}{420} + gC_{SPk} \right) $$

where $t_k$ – amount of tractor work for the k-year of operation on average of the tractor fleet, nominal standard hectares, $t_{kF}$ – amount of tractor work between failures in the k-year of operation on average of the tractor fleet, nominal standard hectares, $T_{FRk}$ – failure repair period in the k-year of operation on average of the tractor fleet, $C_{TR}$ – daily tariff rate of a mechanic-repairman, $C_{SPk}$ – the cost of a spare parts batch used for the failure repair in the k-year of operation on average of the tractor fleet, $L_{kF}$ – the number of failures for the k-year of operation on average of the tractor fleet; $v$, $h$, $z$, $g$, $q$ – the coefficients characterizing the individuality of the dynamics of changes, respectively, the amount of tractor work during the year, the amount of tractor work between failures, failure repair time, the cost of a spare parts batch used for the failure repair, the number of failures per year for a single tractor.

The formula (2) shows that failure repair costs directly depend on the reliability indicators.

According to the proposed model (1), it is advisable to take the tractor out of service when it ceases making a profit. To implement the model in production conditions, it is necessary to know the reliability of the whole tractor. To assess the reliability of the tractor, it is necessary to know the reliability of the individual components, determination of individual coefficients, etc.). However, there is some difficulty in assessing the reliability of the tractor, since it is difficult to determine the precise price of a production unit.

To solve this problem, it is proposed to assume that the profitability of a single tractor is equal to the average annual profitability of the whole enterprise. In this case, the income earned by the tractor during N years of operation can be determined in the following way:

$$ D = \sum_{k=1}^{N} t_k \left( C_{PU} + \frac{C_{PU} \times P_k}{100} \right), $$

where $C_{PU}$ – production unit cost, $P_k$ – profitability of the enterprise in the k-year of tractor service.

Determination of income in this way (taking into account the profitability of the enterprise) will make it possible to determine the rational tractor service life in a particular enterprise.

### 3. Experimental studies

Aiming to test the proposed model, ten 3 kN class tractors, operated in agricultural enterprises in the Vologda district of the Vologda region, have been under research for five years. As a result, it has been found out that all the tractors under study have different reliability (Table 1).
Table 1. Individual reliability indicators of tractors

| Sequence number of the tractor | Amount of work between failures $t_F$ (nominal standard hectares) | The number of failures for the year $L_Y$ | Failure repair period $T_{EF}$ (min) |
|-------------------------------|---------------------------------------------------------------|----------------------------------------|-----------------------------------|
| 1                             | 101                                                           | 19                                     | 148                               |
| 2                             | 105                                                           | 27                                     | 132                               |
| 3                             | 109                                                           | 14                                     | 90                                |
| 4                             | 71                                                            | 27                                     | 147                               |
| 5                             | 68                                                            | 16                                     | 193                               |
| 6                             | 89                                                            | 27                                     | 72                                |
| 7                             | 82                                                            | 25                                     | 65                                |
| 8                             | 131                                                           | 21                                     | 61                                |
| 9                             | 69                                                            | 25                                     | 92                                |
| 10                            | 73                                                            | 21                                     | 100                               |

The fact that if the tractors have individual reliability, then the dynamics of the failure repair, fuel and lubricant cost growth for each tractor is also individual, is confirmed by the dependences shown in Figures 1 and 2. The final result of the research is the dependencies shown in Figure 3.

The bends on the curves correspond to the end of the depreciation period. The maximum of the function $B(t)$ corresponds to the amount of work for the rational lifetime of the tractor $t_{opt}$, after which its operation becomes economically inexpedient because it ceases to be profitable. The values of $t_{opt}$ for each tractor under study are in the range of 26427-36247 nominal standard hectares, which corresponds to the optimal service life $T_{opt} = 13.3-18.3$ years.

During socialist ownership times, the following approach was in practice: if the tractor paid for itself (the amortization period was over), then it was not necessary to use it. But the studies have shown that the rational operation terms of the investigated tractors differ from the established depreciation terms. In the studied tractors, the former are higher than the latter by an average of 60%.

Figure 1. Dependence of failure repair costs on the amount of work (1, 3, 4, 8, 9, 10 are the sequence numbers of the tractors).
Figure 2. Dependence of fuel and lubricant costs on the amount of work (2, 8, 9, 10 are the sequence numbers of the tractors).

Figure 3. Dependence of the profits earned by the tractor, on the amount of work (1 – 10 are the sequence numbers of the tractors).

Thus, the expected economic effect of a rational strategy intended at decommissioning tractors in accordance with the developed model can be determined in the following way:

\[ E = \frac{B - B_D}{T_R - T_D} \]

where \( E \) – annual economic effect, \( B \) – the profit earned by the tractor by the end of a rational service life period, determined according to the developed model, \( B_D \) – the profit value earned by the tractor by the end of the depreciation period, \( T_R \) – rational tractor service life, determined by the developed model, \( T_D \) – depreciation period.

The expected annual economic effect in the agricultural enterprises of the Vologda region is on average 80 thousand rubles per a tractor.

4. Conclusion

The research connected with determination of the rational service life of individual tractors under real operation proves their individual dynamics in changing the operating costs. Each tractor has an
individual reliability. The present scientific work makes prerequisites for developing a mechanism that will allow implementing the proposed model on a wider production scale. It is a question of creating a computer program that will allow predicting the calendar period after which the operation of a specific equipment unit under specific conditions becomes economically inexpedient on the basis of periodical updating the information concerning operating costs and other data.

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