Technique and results of experimental studies of specific cost determination of tractors maintenance during implementation of different methods

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Abstract. Maintenance of tractors in the agricultural enterprises and country farms of the Irkutsk region is carried out by three ways: centralized; decentralized; combined. Each object is expressed by the specific cost of technical tinning in which maintenance-1 and maintenance-2 are considered, and on the decentralized and combined objects in addition – specific costs of maintenance-1 and maintenance-2. The technique of determination of specific cost of maintenance tractors provides obtaining numerical values of an indicator assessment of the choice means maintenance tractors. Results of experimental studies show that the mathematical expectation of specific cost of maintenance tractors by the centralized method has the minimum value (133 rub/engine hour) that is 24.8% less than mathematical expectation by the decentralized method and on 21.1% – by the combined method. This results from the fact that at the decentralized and combined methods the agricultural enterprises in addition have costs of acquisition maintenance unit, its contents and intended usage. When accounting working conditions of the operator in the field – at the decentralized and combined methods of expense also increase at the expense of additional costs respectively of 11.3% and 2.2%. at the combined method additional expenses are 4.8 times less, than at decentralized due to carrying out in field conditions only of maintenance-1.

1. Introduction

Nowadays, many types of research projects are conducted in the field of tractor maintenance - textbooks and teaching aids, dissertations and scientific reports, abstract collections, monographs, articles, theses, etc. This indicates that this area of knowledge is always relevant and in demand of practice [1].

In the article L K Ablin and V L Gnezdilov [2] give the rationale for the optimal zone of technical maintenance of tractors at the stationary maintenance point, taking into account the reduced costs (P) for the maintenance cycle, rubles / cycle –

\[ P = C_1 + C_2 + C_3 + C_4 + C_5 \rightarrow \min, \]

where \( C_1 \) – deductions on renovation for the maintenance cycle; \( C_2 \) – operating costs of the maintenance item per cycle; \( C_3 \) – transport costs per cycle; \( C_4 \) – loss of cash per cycle due to the tractor relocation to the maintenance station and the crop shortage during the move; \( C_5 \) – loss of funds due to tractor downtime on maintenance. For the maintenance cycle, the labor input of maintenance-2, maintenance-3 and the service station for the annual period of operation of the tractor is adopted.

Thus, the problem of choosing the means of maintenance is solved through the determination of the optimal radius of service for tractors [2]. A similar solution is given in the articles of L K Ablin and V
Gnezdilov [3, 4]. It should be noted that in the above mentioned works [2-4] a deterministic method is presented for calculating the choice of means of maintenance of the machine and tractor fleet.

In the article, R Khodabakhshian [5] gives this brief introduction to various preventive maintenance systems especially condition-based maintenance (CBM) techniques, selection of condition monitoring techniques and understanding of condition monitoring (CM) intervals, advancement in CBM, standardization of CBM system, CBM approach on agricultural machinery, advantages and disadvantages of CBM.

Authors A Rokhani, S Abdolahpur [6] make a forecast on the cost of repair and maintenance based on the artificial neural network (ANN) method, which has a significant impact on making the right economic decisions by controlling mechanisms, such as equipment replacement.

The article by C J A Ter Berg, G Leontaris, M van den Boomen et al. [7] covers the method for the determination of the optimal moment at which maintenance work should be performed with a quality guarantee. The proposed method utilizes Cooke’s classical model, which makes use of knowledge and experience of experts, which is estimated according to their performance in judging uncertainty, to assess this period. A bridge-based experiment shows that the proposed method has the potential to provide a means to effectively plan maintenance.

The search for publications on the choice of methods for maintenance of tractors does not give results, therefore this work is relevant.

From literary sources, it is possible to name two methods of technical maintenance of tractors in the spring-summer-autumn period of field mechanized work: centralized (all services are carried out at the technical maintenance point) and decentralized (technical maintenance-1 and technical maintenance-2 are performed in the field using a maintenance unit services, and maintenance-3 and seasonal technical services - at the hospital) [8]. These methods are widely used in the practice of technical maintenance of tractors, as well as in scientific research. However, it does not take into account the possibility of practical implementation of the combined method of technical maintenance of tractors (technical maintenance-1 at the tractor’s work site, and technical maintenance-2, technical maintenance-3 and seasonal technical maintenance at the hospital), and also the working conditions of the operator are not sufficiently taken into account and the quality of technical maintenance of tractors in the field.

Research objective – to determine the specific cost of maintenance of tractors for methods of maintenance.

The authors will take the maintenance methods behind objects of choice and find a mathematical description. All objects for choice conform to requirements of State Standard 20793-2009 on tractors maintenance [9]. Each object is expressed by the specific cost of maintenance in which are considered of maintenance-1 and maintenance-2, and on the decentralized and combined objects in addition – specific costs of maintenance-1 and maintenance-2.

Let’s submit mathematical descriptions of methods maintenance (objects’ for choice) in the following order [10):

1. Centralized: maintenance-1 and maintenance-2 carry out on point of maintenance where cars deliver under the own steam

\[
C_1 = \frac{L_{M1} C_{HW}}{\tau_{M1}} + \frac{L_{M2} C_{HW}}{\tau_{M2}} + \frac{I_{M1} S_{MP}}{\tau_{M1}} + \frac{I_{M2} S_{MP}}{\tau_{M2}} + \frac{2 R_0 S_T}{U_{HE} \tau_{M1}} + \frac{2 R_0 S_T}{U_{HE} \tau_{M2}} + \frac{L_{M1} U_{HE}}{\tau_{M1}} + \frac{L_{M2} U_{HE}}{\tau_{M2}} + \frac{2 R_0 U_{HE}}{V_{T \tau M1}} + \frac{2 R_0 U_{HE}}{V_{T \tau M2}}
\]

or after simple transformations

\[
C_1 = \frac{L_{M1} C_{HW} + I_{M1} S_{MP} + I_{M1} U_{HE}}{\tau_{M1}} + \frac{L_{M2} C_{HW} + I_{M2} S_{MP} + I_{M2} U_{HE}}{\tau_{M2}} + \frac{2 R_0 (S_T + U_{HE})}{V_T} \left( \frac{1}{\tau_{M1}} + \frac{1}{\tau_{M2}} \right) \tag{2}
\]

at \( L_{M1} > 0, L_{M2} > 0, I_{M1} > 0, I_{M2} > 0, C_{HW} > 0, S_{MP} > 0, \tau_{M1} > 0, \tau_{M2} > 0, R_0 > 0, V_T > 0, S_T > 0, U_{HE} > 0.\)
2. Decentralized: maintenance-1 and maintenance-2 on the place of operation tractors with use of the maintenance unit

\[ C_2 = C_{M1}^{MU} + C_{M2}^{MU} + C_{FMU}^{M1U} + C_{FMU}^{M2U} + C_{TMU}^{M1U} + C_{TMU}^{M2U} + \Delta C_{ASC}^{M1} + \Delta C_{ASC}^{M2} = \]

\[ = \frac{l_{M1} \cdot C_{HW}}{\tau_{M1}} + \frac{l_{M2} \cdot C_{HW}}{\tau_{M2}} + \frac{l_{M1} \cdot S_{MU}}{\tau_{M1}} + \frac{l_{M2} \cdot S_{MU}}{\tau_{M2}} + \frac{2 \cdot R_p \cdot S_a}{V_{AM1}} + \frac{2 \cdot R_p \cdot S_a}{V_{AM2}} + \frac{l_{M1} \cdot U_{HE}}{\tau_{M1}} + \frac{l_{M2} \cdot U_{HE}}{\tau_{M2}} + \Delta C_{ASC}^{M1} + \Delta C_{ASC}^{M2} \]

or after simple transformations

\[ C_2 = \frac{l_{M1} \cdot C_{HW} + l_{M2} \cdot C_{HW} + l_{M1} \cdot S_{MU} + l_{M2} \cdot S_{MU} + 2 \cdot R_p \cdot S_a}{\tau_{M1}} + \frac{l_{M1} \cdot U_{HE} + l_{M2} \cdot U_{HE}}{\tau_{M2}} + \Delta C_{ASC}^{M1} + \Delta C_{ASC}^{M2} \]  

(3)

at \( L_{M1} > 0, L_{M2} > 0, l_{M1} > 0, l_{M2} > 0, C_{HW} > 0, S_{MU} > 0, \tau_{M1} > 0, \tau_{M2} > 0, R_0 > 0, V_A > 0, S_A > 0, U_{HE} > 0, \Delta C_{ASC} > 0, \Delta C_{ASC} > 0. \)

3. Combined: maintenance-1 – on the place of work when using the maintenance unit; maintenance-2 – on point of maintenance

\[ C_3 = C_{M1}^{MU} + C_{M2}^{MU} + C_{FMU}^{M1U} + C_{FMU}^{M2U} + C_{TMU}^{M1U} + C_{TMU}^{M2U} + C_{DMU}^{M1U} + C_{DMU}^{M2U} + \Delta C_{ASC}^{M1} = \]

\[ = \frac{l_{M1} \cdot C_{HW}}{\tau_{M1}} + \frac{l_{M2} \cdot C_{HW}}{\tau_{M2}} + \frac{l_{M1} \cdot S_{MU}}{\tau_{M1}} + \frac{l_{M2} \cdot S_{MU}}{\tau_{M2}} + \frac{2 \cdot R_p \cdot S_a}{V_{AM1}} + \frac{2 \cdot R_p \cdot S_a}{V_{AM2}} + \frac{l_{M1} \cdot U_{HE}}{\tau_{M1}} + \frac{l_{M2} \cdot U_{HE}}{\tau_{M2}} + 2 \cdot R_0 \cdot U_{HE} + \Delta C_{ASC}^{M1} \]

(4)

\[ \text{or after simple transformations} \]

\[ C_3 = \frac{l_{M1} \cdot C_{HW} + l_{M2} \cdot C_{HW} + l_{M1} \cdot S_{MU} + l_{M2} \cdot S_{MU} + 2 \cdot R_0 \cdot U_{HE}}{\tau_{M1}} + \frac{2 \cdot R_0 \cdot U_{HE}}{\tau_{M2}} + \Delta C_{ASC}^{M1} \]

at \( L_{M1} > 0, L_{M2} > 0, l_{M1} > 0, l_{M2} > 0, C_{HW} > 0, S_{MU} > 0, S_{MT} > 0, \tau_{M1} > 0, \tau_{M2} > 0, U_{HE} > 0, R_0 > 0, V_A > 0, S_A > 0, V_T > 0, S_T > 0, \Delta C_{ASC}^{M1} > 0, \Delta C_{ASC} > 0, \)

where \( C_{M1}^{MU}, C_{M2}^{MU}, C_{FMU}^{M1U}, C_{FMU}^{M2U}, C_{TMU}^{M1U}, C_{TMU}^{M2U}, C_{DMU}^{M1U}, C_{DMU}^{M2U} \) – the specific expenses connected with idle times when carrying out maintenance-1 and maintenance-2 at point technical service and with use of the maintenance unit; \( C_{FMU}^{M1U}, C_{FMU}^{M2U}, C_{FMU}^{M1U}, C_{FMU}^{M2U} \) - the costs of the same types of service, connected with functioning point of maintenance and the maintenance unit; \( C_{FMU}^{M1U}, C_{FMU}^{M2U}, C_{FMU}^{M1U}, C_{FMU}^{M2U} \) - the specific costs on transportation of tractors up to point maintenance for performance of the same types of maintenance and also on transportation of the maintenance unit to the place of operation of machines respectively for carrying out maintenance-1 and maintenance-2; \( C_{M1}^{M1U}, C_{M2}^{M1U}, C_{M1}^{M2U}, C_{M2}^{M2U} \) - the specific expenses connected with idle times when carrying out maintenance-1 and maintenance-2 at point technical service and with use of the maintenance unit; \( C_{DMU}^{M1U}, C_{DMU}^{M2U} \) - the specific expenses connected with idle times because of transportation tractors on maintenance-1 and maintenance-2 to the place of service (to point of maintenance) and back; \( \Delta C_{ASC}^{M1}, \Delta C_{ASC} > 0 \) - the additional specific costs of maintenance-1 and maintenance-2, considering increase in labor input and also the expenses connected with losses from idle times of tractors; \( L_{M1}, L_{M1} \) - standard labor input of maintenance-1 and maintenance-2 according to tractor of the set brand, man-hour; \( l_{M1}, l_{M2} \) - the standard duration of maintenance-1 and maintenance-2 according to tractor of the set brand, hour; \( C_{HW} \) - the hour amount of compensation at adjuster (operator) taking into account all types of payments, rubles/hour; \( S_{MU} \) - specific cost of use of point maintenance and maintenance unit; \( \tau_{M1}, \tau_{M2} \) - periodicity of maintenance-1 and maintenance-2, engine hour; \( R_0 \) – radius of service, km; \( V_T \) - average transport speed of tractors and maintenance unit, km/h; \( S_T \) – operating costs on transportation of tractors, rubles/hour; \( U_{HE} \) – the hour expenses (losses from idle times of tractors) connected with idle time on maintenance and with moving of machines to point of maintenance and to the place of work, rubles/hour.

A generalized mathematical model is represented as the weighted specific average cost of maintenance when using at the same time several brands of tractors – on a formula
\[ C_c = \frac{C_i \tau_i + C_j \tau_j + C_k \tau_k + \ldots + C_m \tau_m}{\tau_i + \tau_j + \tau_k + \ldots + \tau_m}, \]

where \( C_c \) - the weighted specific average cost by methods maintenance, rubles/engine hour; \( C_i, C_j, C_k, \ldots C_m \) - the specific cost of maintenance i, j, k... to m-branches of tractors, rubles/engine hour; \( \tau_i, \tau_j, \tau_k, \ldots \tau_m \) - total operating time according to each of these brands of tractors, engine hour.

Thus, mathematical models (1)-(3) by the following methods of maintenance are received: centralized (on the basis of stationary objects of maintenance); decentralized (on the basis of mobile maintenance units) and on combined (maintenance-1 carry out on the place of their work with use of the maintenance unit, and maintenance-2 – in the central workshop).

2. Materials and methods of a research

The technique to determination of specific cost maintenance tractors at realization of various methods provides obtaining numerical values indicator of the choice \( C_{Oi} \) is means (i-subjects) maintenance of tractors. At the same time - the specific cost of maintenance-1 and maintenance-2 at realization \( C_{Oi} \) of object. This technique allows defining both taking into account additional expenses, and without their account (figure 1).

\[ \begin{aligned} &1. \text{To find data: } P_{MP}^E, P_{MP}^B, K_{MP}^E, K_{MP}^B, C_{MP}^{TR}, C_{MP}^{EN}, P_{MU}^T, P_{MU}^K, K_{MU}^E, K_{MU}^K, C_{MU}^{TR}, C_{MU}^{EN}, q_M(1)_i, q_M(1-2)_i, q_M(1-2-3)_i; \\
&L_1, L_2, L_3; \tau_1, \tau_2, \tau_3, \tau_G; N_i \\
\end{aligned} \]

\[ \begin{aligned} &2. \text{To calculate: } S_{qMP}^{Cent}, S_{qMP}^{Dec}, S_{qMP}^{Comb}, S_{qMU}^{Comb} \\
\end{aligned} \]

\[ \begin{aligned} &3. \text{To find data: } \delta, F_i, \\
&4. \text{To calculate: } R_i, \\
&5. \text{To find data: } C_{Hw}, G_{MT}, G_{TR} \quad \text{and } P_D, \\
&6. \text{To calculate: } S_I \\
&7. \text{To find data: } C_{HwU}, G_{MU} \quad \text{and } P_{MU} \\
&8. \text{To calculate: } S_A \\
&9. \text{To find data: } P_{TR}, C_{TR}, E_{TR}, E_{H}, \tau_{TR}; \\
&P_{AM}, C_{WAM}, E_{AM}, \tau_{AM}; C_{AMi}, C_{AMj}, C_{AMk}, \ldots C_{AMm}; n_{AMi}, n_{AMj}, n_{AMk}, \ldots n_{AMm} \\
&10. \text{To calculate: } l_{hl} \quad \text{no } l_{TR}, C_{WAM}, l_{AM} \\
&11. \text{To find: additional labor input} \\
&12. \text{To calculate } C_1, C_2, \quad \text{and } C_3 \text{ by each brand of the tractor} \\
&13. \text{To calculate } C_1, C_2, \text{and } C_3 \text{ by all brands of tractors} \\
&14. \text{To choose from } C_1, C_2, \text{and } C_3 \text{ such object which has the minimum value of specific cost of maintenance} \\
\end{aligned} \]

**Figure 1.** The flowchart of determination of specific cost of maintenance of tractors at realization various (\( C_1, C_2, \text{and } C_3 \)) methods of maintenance (the choice of objects by results of determination of maintenance cost).
Definition of an indicator of assessment of objects for choice taking into account additional expenses at maintenance in the field conditions is carried out in the following order (figure 1) [11].

1. Determination of the specific cost of use (rubles/hour) of point of maintenance on the centralized $S_{qMP}^{Cent}$ and combined $S_{qMP}^{Comb}$ maintenance and also the cost maintenance unit at the decentralized $S_{qMP}^{Decent}$ and combined maintenance $S_{qMU}^{Comb}$ counting on all parks of tractors.

2. The calculation of the specific cost ($C_1$, $C_2$, $C_3$) maintenance-1 and maintenance-2 without additional expenses in the field conditions $\Delta C_{ASC}^{M1}$ and $\Delta C_{ASC}^{M2}$ at the centralized, decentralized and combined service, and by each brand of the tractor – respectively on formulas (1), (2) and (3). It should be noted, that before carrying out the specified calculations define: radius of service, operating costs on transportation of tractors and the maintenance unit, losses behind hour of idle time of tractors at maintenance, losses when moving to point of maintenance.

3. On the basis of specific cost on paragraph 2 find the calculation of specific average cost of maintenance by all brands of tractors when using at the same time several brands of tractors on the basis of specific cost is shown on Figure 2 according to the formula (4).

Definition of an indicator of assessment of choice objects without additional expenses at maintenance of tractors in the field conditions is carried out in the order presented on Figure 1, but at the same time do not take into account paragraph 11.

3. Results and discussion

The results are received according to the technique represented on Figure 1. Besides, calculation of specific cost of maintenance of tractors was carried out on the personal computer in the programs: Excel and “Statistica”. Experimental data are obtained during observations of processes of maintenance in 43 agricultural enterprises of the Irkutsk region chosen in a random way. The specific cost of stationary and mobile means of maintenance tractors was determined by these enterprises and observations to working conditions of the operator in field are made. Then additional labor input on maintenance of tractors is revealed. Results this researches are the basis for determination to specific cost of maintenance tractors, by the methods of maintenance stated above.

Results of statistical processing of experimental data on the specific cost of maintenance tractors at realization these methods in the agricultural enterprises of the Irkutsk region are presented in the table in two options: taking into account and without working conditions of the operator in the field conditions. Let’s analyses them.

The mathematical expectation of specific cost maintenance tractors by the centralized method has the minimum value – 133 rubles/engine hour, that 24.8 and 21.1% are less than mathematical expectation respectively by the decentralized and combined methods (Table 1).

Results of the analysis to ratio of indicators mathematical expectation on methods of maintenance are presented in Figure 2. At the same time working conditions of the operator in the field were considered only at the decentralized and combined maintenance methods. In the analysis of the centralized method maintenance representation of indicators on demand «taking into account and without working conditions» does not make sense as working conditions at this method are standard or are close to them. Average values (mathematical expectation) of components of specific cost by realization of maintenance methods are given in Figure 2.

And the same agricultural enterprises of the Irkutsk region were taken into account, as at data processing at the specific cost of maintenance tractors. So, if to compare data on the decentralized method with centralized, and without working conditions, then almost all indicators of the decentralized method, except indicators $C^{TMU}$, $C^{TMU}$, on numerical values above of values to indicators of the centralized method (Figure 2).
Table 1. Results of processing experimental data on the specific cost maintenance tractors at realization of the methods maintenance

| 1 | Results of data processing by methods of maintenance (in numerator and a denominator – taking into account and without working conditions): |
|---|---|---|---|
| 1. Volume of observations \(N\), pieces. | centralized, \(C_1\) | decentralized, \(C_2\) | combined, \(C_3\) |
| 133 | 43 | 43 | 43 |
| 2. Mathematical expectation \(\bar{X}\) | 166 | 147 | 157 |
| 3. Average quadratic deviation \(S\) | 74.7 | 79.8 | 81.6 |
| 4. Coefficient of variation \(V\) | 0.56 | 0.48 | 0.51 |
| 5. Confidential borders: lower \(m_l\) | 60 | 66 | 80 |
| upper \(m_B\) | 54 | 460 | 518 |
| 6. Standard error \(\delta\), % | 1.1 | 1.3 | 1.3 |
| 7. Distribution law | Gauss | Gauss | Gauss |
| 8. Goodness-of-fit test \( \chi^2 \) | 0.21 | 0.14 | 0.18 |

The similar conclusion can be drawn also when comparing of the combined method with centralized. It should be noted that such comparison of numerical values during the analysis which is carried out by us is almost not possible further because each method of maintenance has the indicators.

Figure 2. Charts of specific cost of maintenance tractors on elements up to expenses at realization by centralized (Cent) decentralized (Decent) and combined (Comb) methods: a, b – in terms of money and in percentage.

Thus, by the centralized method these indicators concern mainly use point of maintenance, on decentralized – the unit of maintenance, and on combined – point of maintenance and the unit of maintenance. Therefore in this situation it is possible to tell that increase in specific cost at the decentralized method in comparison with centralized is caused by the high level of the specific costs of maintenance-1 and technical tinning-2 connected with functioning of the unit of technical tinning
\( (C_{FMU}^M) \): they make 95.0 rub/engine hour or 57.2% of the sum. At the combined method \( (C_{FMU}^{M1}, C_{FMU}^{M2}) \) – 92.4 rub/engine hour or 57.5%. This results from the fact that upon transition from the centralized method of maintenance to the decentralized or combined methods the agricultural enterprises in addition have costs of acquisition of the unit of maintenance, their contents and use to destination. When accounting working conditions of the operator in the field conditions – at the decentralized and combined methods of maintenance expenses at the expense of additional expenses \( (\Delta C_{ASC}^{M1}, \Delta C_{ASC}^{M2}) \) respectively also 3.9 rub/engine hour (2.2%) also increase by 18.8 rub/engine hour (11.3%). And at the combined method \( (\Delta C_{ASC}^{M1}, \Delta C_{ASC}^{M2} \text{ and } \Delta C_{ASC}^{M1}) \) additional expenses are 4.8 times less, than at decentralized due to carrying out in field conditions only maintenance-1. In conclusion it should be noted, that all provided figures belong to average values of indicators. Therefore in the conditions different from averages, there will be other values of specific cost of maintenance tractors and other allocation of costs determining this cost.

4. Conclusions

Thus, it is found that the population mean of specific cost of service tractors by the centralized \( X_{C1} \) method has the minimum value (133 rub / engine hour) that for 33 and 28 rub/engine hour (or for 24.8 and 21.1%) there are less population means of \( X_{C2} \) and \( X_{C3} \) – respectively by the decentralized and combined methods. This results from the fact that at the decentralized and combined methods the agricultural enterprises in addition have costs of acquisition of the maintenance unit, their contents and use to destination. When accounting working conditions of the operator in the field – at the decentralized and combined methods of maintenance expenses at the expense of additional expenses \( (\Delta C_{ASC}^{M1}, \Delta C_{ASC}^{M2} \text{ and } \Delta C_{ASC}^{M1}) \) respectively also 3.9 rub/engine hour (2.2%) also increase by 18.8 rub/engine hour (11.3%). And at the combined method \( (\Delta C_{ASC}^{M1}, \Delta C_{ASC}^{M2} \text{ and } \Delta C_{ASC}^{M1}) \) additional expenses are 4.8 times less, than at decentralized due to carrying out in field conditions only maintenance-1.

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