Method for Evaluation of the Economic Efficiency of Using Tractors in the Course of Implementation of a New Maintenance Method in Farms of the Omsk Region

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Abstract—Solution to the problem of improving the reliability of machine and tractor fleet in the production conditions of agricultural business is an important and urgent task for engineering department of agro-industrial complex. It can be solved by reducing the downtime of machines for maintenance using intensive methods for performing operations during low-stress period of field work, as well as outsourcing part of maintenance operations to specialized maintenance companies. Currently, one machine operator operates several machines and cannot perform maintenance and repair operations on time. Therefore, it is reasonable to outsource a part of complex maintenance and repair work to specialized companies. The article calculates maintenance costs at two levels: farm units of the agro-industrial complex and specialized maintenance enterprises. During forming a maintenance system at farms, dealer system can be implemented only in large ones with high profitability. Based on the studies, a method was developed for defining the economic efficiency of tractor operation in the course of implementation a new form of maintenance in the farms of the Omsk Region. The determination of the reduction of unit costs from the outsourcing of operations for complex technical maintenance during stressful period of field work by the farms of the Omsk Region to specialized enterprises have proved the effectiveness of the new concept of maintenance. Maintenance organization in cooperation with specialized centers will not only reduce the cost of equipment maintenance organization, but also increase the profitability of farm.

Keywords—machine-tractor unit, maintenance, dealer system, failure, profitability, operating time.

I. INTRODUCTION

Participants in the modern system of interaction and maintenance organization in agro-industrial sector are the following: agricultural producers as receivers of machines; performers of maintenance services as work performers during machine use; and manufacturers of machines as sellers of their products. Agricultural producers are the main ones in this scheme, and manufacturers of machines and maintenance performers are here to meet their needs what shows the priority of agricultural work in the system of interaction and maintenance organization [1].

In present-day conditions, it is reasonable to outsource the part of complex maintenance and repair work to dealer enterprises during long low-stress period; it guarantees higher quality of work than performed at a farm. The better the quality of preventive maintenance, the lower the percentage of sudden equipment failures during stressful period of sowing and harvesting [2]. Solution to the problem of machine downtime during failure handling and maintenance can be carried out by reducing the time for maintenance due to its intensification during low-stress period of field work [3].

II. RESEARCH METHODOLOGY

A. Objects and methods

Methods of mathematical modeling and statistical processing of results were used as basic research methods. Method of assessment the economic efficiency of tractor operation during implementing a new form of maintenance in the farms of the Omsk Region was considered. Farms with high revenue in the form of earnings can spend part of it on maintenance provided by dealer enterprises what will result in higher quality and volume of maintenance operations and will directly influence the reliability of equipment.

B. Research design

We have developed a method for calculating the share of maintenance that can be outsourced to a specialized maintenance enterprise based on determining the costs of Maintenance-2 and Maintenance -3 performed at farm (M) and at specialized maintenance enterprise (Z).

For this calculation, we need to find the costs of Maintenance-2 and Maintenance-3 performed at farm according to the formula

\[ M = \left( \frac{-t_{maj} + t_{maj} \cdot t_{omc}}{I_{ymnc} \cdot H_{omc}} + \frac{t_{maj} \cdot t_{p}}{I_{ymnc} \cdot H_{pr}} \right) \left( S_{1} + C_{2y} \right) \]  

where

- \( t_{maj} \) — duration of maintenance, h;
- \( t_{omc} \) — complexity of maintenance, man-hours;
- \( S_{1} \) — coefficient of economic efficiency of tractor operation in stressful period of field work;
- \( C_{2y} \) — cost of purchase and maintenance of specialized maintenance enterprise.

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where

- \( t_{maj} \) — duration of maintenance, h;
- \( t_{omc} \) — complexity of maintenance, man-hours;
- \( t_{omk} \) – duration of failure handling, h;
- \( t_p \) – duration of equipment repair, h;
- \( t_{sykno} \) – specific complexity of maintenance, man-hours/h;
- \( H_{omk} \) – time to failure, h;
- \( H_{pr} \) – time between repairs, h;
- \( S_t \) – cost of maintenance, RUR/h;
- \( C_{D} \) – cost of downtime per hour, RUR.

Costs of performing complex maintenance by specialized maintenance enterprises are calculated by the formula:

\[
Z = \left( \frac{t_{omk}}{t_{sykno} H_{omk}} + \frac{t_{omk}}{t_{pr} H_{pr}} \right) (S_t + C_{D}) + \frac{2R_f}{v_{np}} (C_{np} + C_{D}) \tag{2}
\]

where \( R_{gy} \) – radius of transportation of equipment for repair and maintenance, km;
- \( v_{np} \) – equipment transportation speed, km/h;
- \( C_{np} \) – cost of equipment transportation, RUR;
- Share of operations that can be outsourced to a specialized maintenance enterprise will be found by ratio

\[
\varphi_{fc} = 1 - \frac{Z}{M} \tag{3}
\]

For an example of calculating unit costs reduction from the outsourcing of complex maintenance during stressful period of agricultural work, three agricultural producers of the Omsk Region were taken; we conventionally named them Farm No.1, Farm No.2 and Farm No.3. The costs of Maintenance-2, Maintenance-3 and failure handling during stressful and low-stress periods of work for the main types of tractors working on these farms were defined; results are shown in Table 1.

**Table I. Calculation of costs for complex types of maintenance and failure handling as a result of outsourcing operations during stressful agricultural period**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Farm No.1</th>
<th>Farm No.2</th>
<th>Farm No.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs for M-2, M-3 and failure handling during stressful period, RUR</td>
<td>K-744</td>
<td>2782270</td>
<td>391955</td>
</tr>
<tr>
<td>John Deere 8420</td>
<td>265900</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total costs for M-3 during the low-stress period, thousand RUR</td>
<td>K-744</td>
<td>156850</td>
<td>41605</td>
</tr>
<tr>
<td>John Deere 8420</td>
<td>17450</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Evaluation of unit costs reduction for farms from the outsourcing complex types of maintenance during stressful agricultural period is based on the costs presented in Table 1. Calculation results are shown in Table 2.

**Table II. Calculation of the share of farm costs reduction from the outsourcing complex types of maintenance and failure handling during stressful agricultural period**

<table>
<thead>
<tr>
<th>Farm</th>
<th>Parameter</th>
<th>Cost reduction, RUR</th>
<th>Cost reduction share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm No.1</td>
<td>2906825</td>
<td>0.121</td>
<td></td>
</tr>
<tr>
<td>Farm No.2</td>
<td>350344</td>
<td>0.095</td>
<td></td>
</tr>
<tr>
<td>Farm No.3</td>
<td>3668340</td>
<td>0.133</td>
<td></td>
</tr>
</tbody>
</table>

In the course of this research, the features of MTF maintenance organization in farms depending on the following factors were established:
- \( F \) – area of arable land, ha;
- \( K_T \) – index of farm land ploughness;

\[
K_T = \frac{F}{F_1} \tag{4}
\]

where \( F_1 \) – total area of farm land, ha.
- \( \epsilon \) – density of mechanized work, conventional reference ha / ha of arable land;

\[
\epsilon = \frac{W_{sum}}{F} \tag{5}
\]

where \( W_{sum} \) – total operating time of tractors during a year, conventional reference ha;
- \( \zeta \) – machine supply, kW/100 ha of arable land;

\[
\zeta = \frac{100 \sum \tilde{N}_i}{F} \tag{6}
\]

where \( \sum \tilde{N}_i \) – total capacity of agricultural machines, kW.
- \( \xi \) – uneven loading of equipment for the i-th periods of use;

\[
\xi = \frac{W_i}{W_{sum}} \tag{7}
\]

where \( W_i \) – operating time of agricultural machinery for the considered i-th period.
- \( \rho_1 \) – compactness of land equal to the average radius of the farm, km;
- \( X_4 \) – the number of tractor drivers/machine operators per 100 ha of arable land;
- \( X_5 \) – skill level of tractor drivers/machine operators.

Studying MTF maintenance organization of farms with different types of farming with the help of mathematical models, it was found that the considered parameters influence the substantiation of agricultural machinery maintenance types as follows (Table 3).

**Table III. The impact of parameters on the conditions of MTF maintenance organization of the farms**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>F</th>
<th>K_T</th>
<th>( \epsilon )</th>
<th>( \zeta )</th>
<th>( \rho_1 )</th>
<th>X_4</th>
<th>X_5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \chi X ) %</td>
<td>39</td>
<td>5.4</td>
<td>2.7</td>
<td>9.8</td>
<td>7.5</td>
<td>3.2</td>
<td>7.2</td>
</tr>
</tbody>
</table>
The greatest impact on the efficiency of MTF maintenance organization is provided by: the area of arable land $\Pi_L = 39\%$, skill level of tractor drivers/machine operators $\Pi_X = 25.3\%$, machine supply $\Pi_M = 9.8\%$, uneven loading of equipment $\Pi_T = 7.5\%$, and the availability of tractor drivers/machine operators $\Pi_Y = 7.2\%$.

Based on the studies, it was established that MTF maintenance station should be organized in the place with the smallest radius of equipment transportation, and the material and technical base should be located at the enterprises with qualified specialists.

Maintenance of agricultural machinery should be organized out of season using annual maintenance planning. In the routine and preventive system, number maintenance depends on the operating time, not on the time of year and season [4].

Equipment maintenance organization in accordance with annual maintenance plan takes into account the peculiarities of agricultural production and ensures the timeliness and full performing of ongoing maintenance [5].

Figure 1 shows a graph of the dependence of revenue share that can be used to pay for equipment maintenance when it is outsourced to specialized enterprises on farm area.

![Graph of the dependence of revenue share](image)

Fig. 1. Dependence of revenue share on farm area

The analysis reveals that the larger the farm and the greater its profitability, the larger share can be used for outsourcing maintenance to specialized enterprises.

The calculation of maintenance share was carried out on the basis of Maintenance-2 parameters for Kirovets and John Deere-8420 tractors in the conditions of farms and specialized enterprises (SE) (Table 4).

<table>
<thead>
<tr>
<th>TABLE IV. DATA FOR MAINTENANCE-2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td><strong>Costs, RUR</strong></td>
</tr>
<tr>
<td>$T_{mof}$ – duration of maintenance, h</td>
</tr>
<tr>
<td>$S_c$ – cost of maintenance, RUR/h</td>
</tr>
<tr>
<td>$C_{tr}$ – cost of downtime per hour, RUR</td>
</tr>
<tr>
<td>$R_{e}$ – radius of equipment transportation for repair and maintenance, km</td>
</tr>
<tr>
<td>$v_{eq}$ – equipment transportation speed, km/h</td>
</tr>
<tr>
<td>$C_{eq}$ – equipment transportation cost, RUR</td>
</tr>
<tr>
<td>$l_{com}$ – complexity of maintenance, man-hours</td>
</tr>
<tr>
<td>$l_{spe}$ – specific complexity of maintenance, man-h/h</td>
</tr>
<tr>
<td>$H_{tot}$ – time to failure, h</td>
</tr>
</tbody>
</table>

In accordance with the method, the costs for Maintenance-2 of Kirovets and John Deere-8420 tractors were found for SE (Z) and the farm (M) (Table 5).

<table>
<thead>
<tr>
<th>TABLE V. COST OF MAINTENANCE-2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td><strong>Costs, RUR</strong></td>
</tr>
<tr>
<td>Share $\varphi$</td>
</tr>
</tbody>
</table>

The calculation for Kirovets and John Deere-8420 tractors showed that the share of Maintenance-2 operations that can be outsourced to a specialized enterprise was 0.715 and 0.401.

Figure 2 shows the dependence of the share of Maintenance-2 operations that can be outsourced to a specialized enterprise, from the radius from the farm to SE.

![Graph of the share of Maintenance-2 operations](image)

Fig. 2. Graph of the share of Maintenance-2 operations outsourced to SE as a function of radius

Based on the data obtained for four farms, the pattern of change, $\varphi = f(R)$ (Figure 3) was established in the form of the formula

$$\varphi = -0.0021 \cdot R + 0.9628$$

(8)

where R is the distance between SE and farm.

![Forecasting of the share of Maintenance-2 operations](image)

Fig. 3. Forecasting of the share of Maintenance-2 operations outsourced to SE as a function of radius

The critical value of radius for the outsourcing Maintenance-2 operations to SE was defined when the costs of farm tend to the costs of SE; it amounted to ($= 200 – 230$ km). When the radius increases above 450 kilometers, the costs of farm and SE become equal and the outsourcing of Maintenance-2 operations to SE makes no sense.
In the course of this research, the cost of performing Maintenance-3 in a farm was calculated (Table 6).

**TABLE VI. DATA FOR MAINTENANCE-3**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kirovets</th>
<th>John Deere-8420</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\overline{t}_{\text{med}}$ – duration of maintenance, h</td>
<td>8.3</td>
<td>16.55</td>
</tr>
<tr>
<td>$S_r$ – cost of maintenance, rubles / h</td>
<td>1120</td>
<td>1000</td>
</tr>
<tr>
<td>$C_{dt}$ – cost of downtime per hour, rubles.</td>
<td>2100</td>
<td>2100</td>
</tr>
<tr>
<td>$R_{eq}$ – radius of equipment transportation for repair and maintenance, km</td>
<td>135</td>
<td>0</td>
</tr>
<tr>
<td>$V_{eq}$ – equipment transportation speed, km/h</td>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>$C_{eq}$ – equipment transportation cost, RUR</td>
<td>1010</td>
<td>0</td>
</tr>
<tr>
<td>$t_{com}$ – complexity of maintenance, man-hours</td>
<td>26.5</td>
<td>28.5</td>
</tr>
<tr>
<td>$t_{spec}$ – specific complexity of maintenance, man-h / h</td>
<td>0.15</td>
<td>0.09</td>
</tr>
<tr>
<td>$H_{agg}$ – time to failure, h</td>
<td>210</td>
<td>160</td>
</tr>
<tr>
<td>$t_{otk}$ – duration of failure handling, h</td>
<td>6.95</td>
<td>29</td>
</tr>
<tr>
<td>$H_{otk}$ – time between repairs, h</td>
<td>3510</td>
<td>2510</td>
</tr>
<tr>
<td>$t_{eq}$ – duration of equipment repair, h</td>
<td>45</td>
<td>165</td>
</tr>
</tbody>
</table>

Results based on the calculation are shown in Table 7.

**TABLE VII. RESULTS OF COST CALCULATION FOR MAINTENANCE-3**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kirovets Maintenance-3</th>
<th>John Deere-8420 Maintenance-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs, RUR</td>
<td>67187.46</td>
<td>32263.3</td>
</tr>
<tr>
<td>Share $\phi$</td>
<td>0.79</td>
<td>0.64</td>
</tr>
</tbody>
</table>

The calculation for Kirovets and John Deere-8420 tractors showed that the share of Maintenance-3 operations that can be outsourced to a specialized enterprise was 0.79 and 0.64.

\[ \phi = -0.0008 \cdot R + 0.8775 \]  \( \text{(9)} \)

Fig. 5. Forecasting of the share of Maintenance-3 operations outsourced to SE as a function of radius

The critical value of radius for the outsourcing Maintenance-2 operations to SE was defined when the costs of farm tend to the costs of SE; it amounted to (~ 480–500 km). When the radius increases above 1,100 kilometers, the costs of farm and SE become equal and the outsourcing of Maintenance-3 operations to SE makes no sense.

Based on the analyzed data for specialized enterprises in the Omsk Region, it was found that the specialists travel using mobile technical maintenance units to conduct Maintenance-2 of machines at the distance of up to 250 km, and for Maintenance-3 – up to 500 km; this fact is confirmed by the calculations [6]. The farther the farm is from SE, the more expensive is maintenance, while service receiver and SE are in unequal partnerships, since the service receiver compensates for the cost increase [7].

The share of outsourced operations $\phi$ for complex types of maintenance to a specialized enterprise is determined from the savings resulting from outsourcing operations during stressful period.

\[ \phi = 1 - \frac{Z}{\sum \Theta} \]  \( \text{(10)} \)

where

\[ \sum \Theta \] – total savings of farm from outsourcing Maintenance-2 and Maintenance-3 operations during stressful period;

$Z$ – costs for Maintenance-2 and Maintenance-3 performed at SE.

Figure 6 shows the dependence of $\phi$ on the savings obtained during outsourcing of complex types of maintenance.

High cost savings during maintenance of equipment will allow farms to outsource the complex types of maintenance to specialized enterprises [8, 9].
III. SUGGESTIONS AND RESULTS

Based on the calculations performed, the following recommendations can be made: for $\phi \geq 0.5$ all operations on complex types of maintenance should be outsourced to a specialized enterprise; that will increase the reliability and efficiency of using tractors.

Support service of equipment at specialized enterprises increases its reliability and reduces the number of failures, while time between repairs increases by 40% (Figure 8), and the time to failure – by 30% (Figure 8) [10,11].

![Before technology implementation - After technology implementation](image1)

**Fig. 7.** $H_{otk}$ – time to failure, h

![Before technology implementation - After technology implementation](image2)

**Fig. 8.** $H_{p2}$ – time between repairs, h

IV. CONCLUSIONS

According to the research results, the following conclusions were made:

1. The following factors influence the efficiency of maintenance organization: the area of arable land $\Pi_F = 39.1\%$, skill level of tractor drivers/machine operators $\Pi_X = 25.2\%$, machine supply $\Pi_e = 9.7\%$, availability of tractor drivers/machine operators $\Pi_X = 7.3\%$, and irregular loading of MTF $\Pi_T = 7.6\%$.

2. The calculation of the share of operations that can be outsourced to specialized enterprises showed the following: when performing Maintenance-2 for Kirovets and John Deere-8420 tractors, the share will be 71.5% and 40.1%, respectively; when performing Maintenance-3, the share will be 79 and 64%, respectively.

3. Equations were obtained that make it possible to forecast the dependence of the share of operations on complex types of maintenance that can be outsourced to a specialized enterprise on the radius.

4. Outsourcing the share of operations on Maintenance-2 and Maintenance-3 to a specialized enterprise at $\phi \geq 0.5$ will increase the reliability and efficiency of using tractors, reduce the number of sudden failures, while the time between repairs increases by 40%, and time to failure – by 30%.

REFERENCES


