Mathematical model of analytical approach of comparative analysis of productivity of agricultural machinery when using visualization technology

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Abstract. The article discusses options for increasing the productivity of agricultural machinery, and also reveals the relationship between increasing its productivity by reducing the time of maintenance when using elements of virtual reality. Also, the article presents a mathematical model and shows the solution to the problem of assessing the productivity of agricultural technical units, in particular, it is proposed to conduct an assessment based on a comparison of the time spent on performing work when using elements of virtual reality during maintenance and in the traditional form of its implementation.

1 Introduction

The study of the problem of productivity began in the middle of the 20th century as a component of equipment efficiency. Then the formula was obtained, the main elements of which are:

– A – availability;
– P – performance;
– Q – quality.

The combination of the above three terms gives the value of the overall equipment efficiency (OEE). The OEE indicator is actually a numerical characteristic of production losses. At the same time, the term "lean production" appeared, reflecting the desire to reduce losses due to an increase in the time of unscheduled shutdowns, a decrease in the speed of equipment and low-quality products[3]. In connection with the specific features of agricultural production, the organization of servicing agricultural machinery presents certain difficulties, since the complexity of the equipment, the large variety of sizes, size, complexity in operation, seasonality of work, extremely difficult working conditions are taken into account. All these features must be taken into account when studying the factors that can increase the productivity of equipment. The factors that increase its productivity include the following: training of qualified personnel capable of efficiently operating it, saving resources, ensuring the safety of use, increasing reliability. The existing service

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requires constant improvement, one of the options for which is the introduction of an information and digital environment. Information support and appropriate simulators allow solving many important tasks for the country's agro-industrial and economic complexes, in particular, to achieve the goal of increasing the productivity of an agricultural unit without innovation in the field of design solutions, augmented reality technologies can be used. They can be used in the organization of simulators or in the maintenance of agricultural machinery to increase its service life. By introducing IT technologies, you can train them to recognize objects, determine the relative sizes, shape, and for this it becomes necessary to create software for mobile platforms adapted for AR [1].

It is also important to correctly assess the quality of the work performed[2]. The productivity of each technical unit of agricultural machinery is one of the most important characteristics, therefore, its increase is a priority task when improving the performance of the machine, therefore, it is necessary to conduct research to determine its parameters. Moreover, by performance we mean its efficiency. The need to evaluate performance in this case is associated with the introduction of new technologies and methods, in particular, using IT and virtual reality, in a workflow that involves maintenance [12]. For agricultural machinery, this is of particular relevance due to the difficult operating conditions, which are often associated with weather conditions and service facilities [4]. Research in this area will make it possible to choose the correct and optimal solution when choosing one or another approach to the operation and method of technical support of an agricultural machine [5], which will make it possible to smooth out the following shortcomings in the organization and implementation of the planned work:

– insufficient qualification training of personnel carrying out operation and maintenance (maintenance) for a specific machine, which entails the choice of the wrong solution;
– lack of speed of operations during operation and maintenance;
– waste of time choosing the right solution.

2 Methods

Among the performance indicators, the reliability factor stands out, which directly depends on design solutions, workmanship, working conditions in the future and on the quality of maintenance during use and storage [6]. One of the solutions to the problem of increasing reliability is the timely performance of high-quality maintenance. It has been proven that it is it that is the guarantor of normal reliability indicators for performing a full list of operations. In particular, the system of technical inspection and repair of machines is of a preventive nature. The advantage of such a system is its planning, which makes it possible to determine in advance the timing of repair and maintenance operations and the funds, materials and number of performers required for this [7]. The use of modern technologies makes it possible to carry out maintenance by introducing virtual reality objects into the process, while significantly reducing the time and labor costs for its implementation, which in turn increases the productivity of the technical unit. For a quantitative analysis of the performance of a unit of agricultural machinery during operation, the authors developed an algorithm that allows comparing the results before using visualization methods and after, which made it possible to draw conclusions about the advisability of introducing such technologies [8]. We will analyze the data, relying on theoretical studies that allow us to identify the regularity of the results and draw conclusions about the productivity of agricultural machinery. To obtain the result, it is convenient to select the time interval in which the calculations will be performed. In the process of research, we will use the data obtained before and after the use of visualization technology, and then we will carry out a comparative analysis, on the basis of which we will draw the appropriate conclusions [13].

3 Results

Let's consider the main stages of building a mathematical model used for the comparative analysis of performance. Stopping the work of agricultural machinery is possible for three reasons

- unacceptable weather (seasonal) conditions;
- scheduled technical diagnostics and scheduled repairs;
- unscheduled repairs.

Weather conditions are uncontrollable factors, therefore, this type of equipment downtime cannot be influenced. Controlled human factors include technical diagnostics, scheduled repairs and unscheduled repairs [9]. One of the main problems during the use of a technical unit is to increase its productivity. This article explores the possibility of increasing productivity by reducing maintenance time. In particular, with a significant reduction in the downtime of the machine, which occurs, for example, during maintenance, there is a decrease in the time interval of the inoperative state of agricultural machinery, which leads to an increase in the time of productive operation [10]. Despite the fact that the technical unit retains the declared performance, in the created conditions the volume of work performed increases.

We will denote the observed time interval$[0;T]$. Let's break it down with dots t_i for intervals corresponding to the number of time intervals in each of which a certain operation is performed by an agricultural technical unit, the productivity of which is being investigated [14].

To estimate the volume of work performed, we introduce the coefficient k_i:

$$k_i = \frac{V_i}{V}, \tag{1}$$

V_i – volume of actually performed work for the investigated time interval $(0; t_i)$;

V – the entire scope of work assigned for a given unit of equipment.

For a full-fledged study, such a time period is of interest, which includes diagnostics of the technical condition of the machine [11]. We will analyze the data based on theoretical studies that allow us to identify a pattern and draw conclusions about the significance of previously obtained results.

Let be t_i - the time that a technical unit needs to spend to complete a specific task, here i – arbitrary number. Let's call $t_i$temporary factors .

With every factor t_i associated numerical coefficient k_i, and

$$0 \leq k_i \leq 1, \tag{2}$$

Let's find a quantitative relationship between the factors, their coefficients and the number $M(k,t)$.

To do this, we introduce the performance function

$$P = P(t_i), i = \overleftarrow{1, n}, \tag{3}$$

$t_i -$ factors that are variables in this representation (1).

For one factor, the formula for calculating P (t) takes the form:

$$P = kt, \tag{4}$$

k - coefficient showing the ratio of time t_i to the total amount of time T spent during the investigated time interval.

$$t_i \in [0; T], \tag{5}$$

then

$$T = t_1 + t_2 + \cdots t_i + \cdots + t_n = \sum_{i=1}^{n} t_i, \tag{6}$$

$$k = \frac{t_i}{T}, \tag{7}$$

Hence,

$$K = k_1 + k_2 + \cdots + k_i + \cdots + k_n, \tag{8}$$

Moreover,

$$K = \sum_{i=1}^{n} k_i = 1, \tag{9}$$

Since the number of factors can be different, it is necessary to consider them in aggregate. Let us introduce T - the set of values of the variable t, which takes the values of the time spent on a certain type of work of the agricultural machine, that is

$$T=\{t_1, t_2, \ldots, t_i, \ldots t_n\}, \tag{10(a)}$$

or

$$T=\{t_i\}_{i=1}^{n}, \tag{10 (б)}$$

We denote the sum of the products of coefficients and factors as M (k, t), then we get a formula showing the dependence of the value of M (k, t) on the amount of time spent t_i:

$$M(k,t) = \sum_{i=1}^{n} k_i t_i, \tag{11(a)}$$

or, if we write out formula (3) in expanded form

$$M(k,t) = k_1 t_1 + k_2 t_2 + \cdots + k_i t_i + \cdots + k_n t_n, \tag{11(б)}$$

$M(k,t)$ линейно зависит от t и k , следовательно, с возрастанием значений ее аргументов будет возрастать и значение $M(k,t)$.

Consider the geometric representation of the function P.

To do this, we introduce the sets:

$$T = \{t_i\} \text{ и } K = \{k_i\} \tag{12}$$

here $i = \overleftarrow{1,n}$,where n is the number of activities carried out by a technical unit during the investigated time interval.

Let's add the elements of these sets to the table 1.

Table 1. Parameters of the mathematical model.

<table>
<tr><td>T</td><td>t_1</td><td>t_2</td><td>…</td><td>t_{i-1}</td><td>t_i</td><td>$\mathbf{t_{i+1}}$</td><td>…</td><td>t_n</td><td></td></tr>
<tr><td>K</td><td>k_1</td><td>k_2</td><td>…</td><td>k_{i-1}</td><td>k_i</td><td>$\mathbf{k_{i+1}}$</td><td>…</td><td>k_n</td><td></td></tr>
<tr><td>M</td><td></td><td></td><td colspan="6">$\sum_{i=1}^{n} \mathbf{k_i\, t_i}$</td><td>M = const</td></tr>
</table>

The graphical representation of the function P will be built in the XOY coordinate system. On the OX axis we will mark the value of the factors x_i: $x_1, x_2, \ldots, x_n$, and on the axis OK value of coefficients k_i: $k_1, k_2, \ldots, k_n$, moreover, in such a way that

segment length $|OK_1| = k_1$,

segment length $|OK_2| = k_2$,
……………………………..
segment length $|OK_i| = k_i$,
………………………………
segment length $|OK_n| = k_n$,
end

$$|OK_1| + |K_1K_2| + \cdots + |K_{i-1}K_i| + \cdots + |K_{n-1}K_n| = 1, \tag{13}$$

that is

$$\sum_{i=1}^{n} |k_{i-1}k_i| = 1, \tag{14}$$

because

$$0 \leq |K_{i-1}K_i| \leq 1 \tag{15}$$

For a visual representation of the process, it is convenient to go to the graphical representation of the function. First, we construct the distribution function of the quantities t_i end K_i. This will be the function P, it will take the form of a step function (Figure 1).

Each step of this function will rise by an amoun $|k_{i-1}k_i|$, длина каждой ступеньки будет равна $|t_{i-1}t_i|$.

The graphic image will be built in the TOK coordinate system, with the OT and OK axes [15]. On the OT axis, we will plot the value of time intervals corresponding to a certain type of work of a given technical unit. The OK axis shows the values of the coefficients, with each subsequent value and coefficient k_i more than the previous $k_i < k_{i+1}$, and the same condition is fulfilled for t_i, that is $t_i < t_{i+1}$.

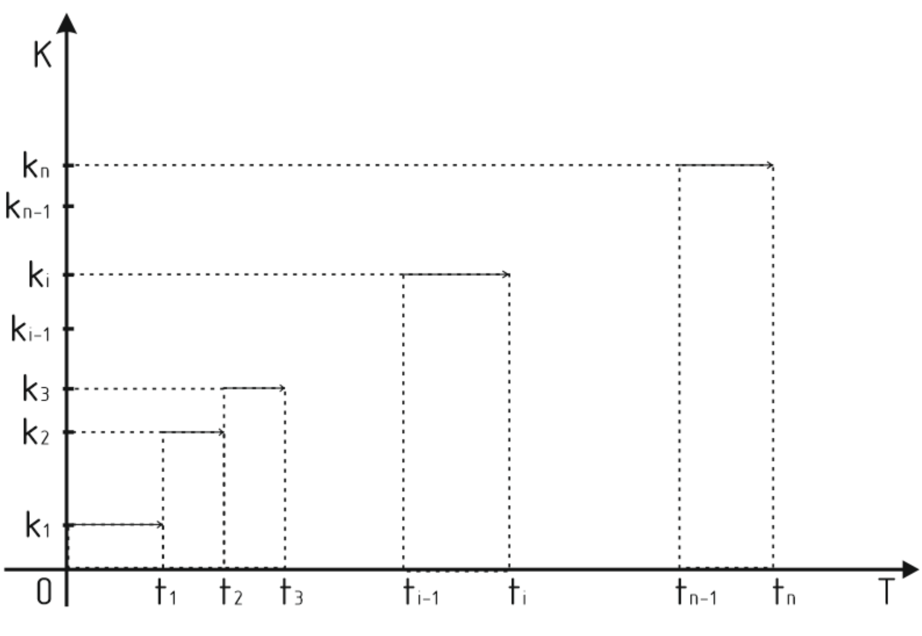

Fig.1. Graphical representation of a step function P (t) = f (t): OP – coefficient axis k_i; OT – time axis.

Figure 1 shows that the length of the resulting segment $|Ot_n|$ the more, the longer the length of each of the segments $|t_{i-1}t_i|$, that is, the total amount of costs increases if the values of each of the factors increase t_i.

From the distribution function of quantities t_i end k_i let's move on to a graphical representation of a diagram reflecting the geometric interpretation of P. Also, the constructed diagram will allow you to clearly see the principle of comparing performance for an element of agricultural machinery[16].

The diagram will be built in the TOK coordinate system. On the OT axis, we will plot time intervals, each of which will correspond to a certain work operation prescribed for the technical agricultural unit under consideration. The OK axis will mark the values of the coefficients k_i. Let us introduce the notation: $S_{V_i} -$ area of the i - th part of the diagram, corresponding to the i - th stage of the machine using virtual reality; S_{R_i} - area of the i - th part of the diagram corresponding to the i - th stage of the machine operation without the use of virtual reality.

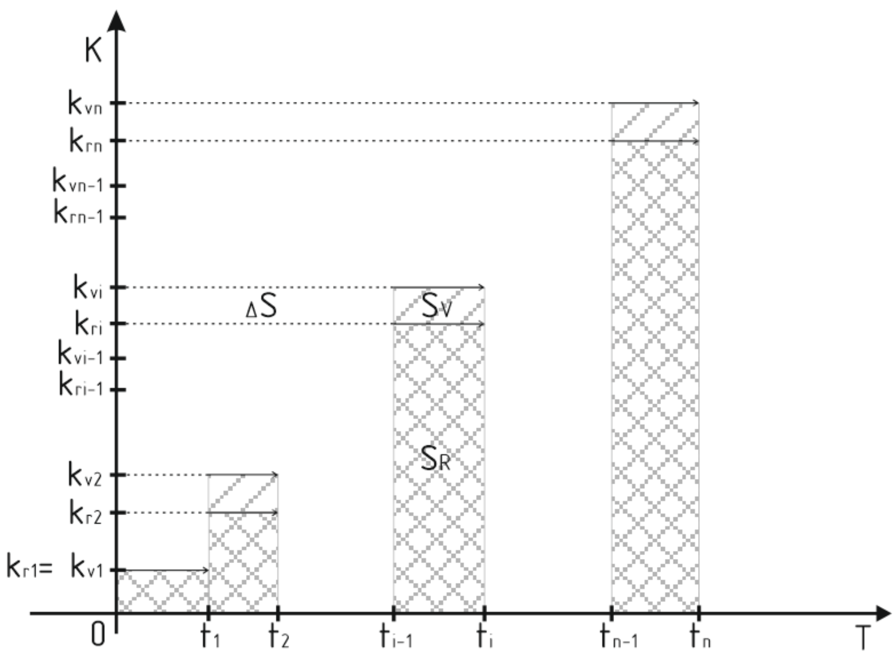

Fig. 2. Graphical representation of a diagram limited by a step function $P(t) = f(t)$: OK – coefficient axis k_i; OT – time axis; $S_{V_i} -$ area of the i - th part of the diagram corresponding to the i - th stage of the machine using virtual reality; S_{R_i} - area of the i - th part of the diagram corresponding to the i - th stage of the machine operation without the use of virtual reality.

From the distribution function of quantities t_i end k_i let's move on to the graphical representation of the diagram reflecting the geometric interpretation P. Also, the constructed diagram will allow you to clearly see the principle of comparing performance for an element of agricultural machinery [17].

The value P will be associated with the area S of the stepped figure describing the diagram in Figure 2, that is

$$P = S, \tag{15}$$

where

$$S = \sum_{i=1}^{n} S_i, \tag{16}$$

Here S_i – area of rectangles $t_{i-1}L_iM_it_i$ of which the area consists S the whole diagram, chart points L_i end M_i - are the intersection points of the lines $T = t_i$ end $K = k_i$.

Since we have condition (6), the area S is the larger, the greater the length of the resulting segment $|Ot_n|$, consisting in turn of segments $|t_{i-1}t_i|$.

Let ΔS be the difference between the areas of the figures S_V и S_R.

$$\Delta S = S_V - S_R, \tag{17}$$

If ΔS> 0, then when using digitalization elements, a technical unit has completed more production tasks than when organizing work by the classical method.

Therefore, the more factors k_i take on a greater value, the more P.

4 Discussion

Evaluation of the performance of an agricultural technical unit involves comparing the time characteristics before and after the introduction of virtual reality elements into the process, using a geometric interpretation. The geometric representation of productivity uses diagrams that demonstrate how the volume of work performed depends on the execution time, then, based on the ratio of the areas occupied by the diagrams, conclusions are drawn about the need to introduce certain new technologies. That is, it is possible to conduct research, both analytically and using a geometric interpretation of the process.

5 Conclusion

The proposed solution method allows you to make recommendations with maximum accuracy on the advisability of introducing new technologies, since the obtained formula ΔS = S_V-S_R allows you to compare the volumes of identical work performed at equal intervals of time under different conditions for one type of agricultural machinery. The paper presents an analytical solution to the problem of assessing the productivity of an agricultural technical unit, in particular, it is found that, provided that downtime is reduced by reducing it during maintenance and, accordingly, an increase in the time interval of the operational state, and a visual demonstration of the claimed method is shown.

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