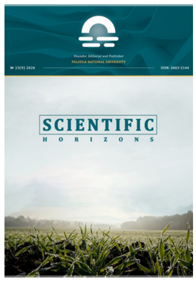
SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua

*Scientific Horizons*, 24(9), 55-62




UDC 631.3

DOI: 10.48077/scihor.24(9).2021.55-62

# Mathematical Models for Assessing the Reliability of Agricultural Machinery, Taking into Account the Influence of Military Factors in the Front-line Territory

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***Article's History***:
Received: 10.10.2021
Revised: 11.11.2021
Accepted: 15.12.2021

***Suggested Citation***:
Semenenko, L., Tarasov, O., Vasylenko, S., Cherep, V., & Polishchuk, V. (2021). Mathematical models for assessing the reliability of agricultural machinery, taking into account the influence of military factors in the front-line territory. *Scientific Horizons*, 24(9), 55-62.

**Abstract**. As the requirements for the quality of agricultural machinery and its working conditions increase, so do the demands on its maintainability, in particular its reliability. Failure for technical reasons or due to any external factors will result in the non-achievement of the goals set, and thus in a loss of performance. Today, as a rule, there is an insufficient level of reliability of agricultural equipment during operation, and this issue receives special attention in the territories that are located in the front-line zone in the east of Ukraine in the Donetsk and Luhansk regions. This is caused by both design solutions and imperfect models that are used during projecting. In addition, external factors that can significantly affect production activities are not taken into account. These include climatic conditions, natural disasters, personnel readiness, i.e. the human factor, as well as the factor of the consequences of an armed conflict. Therefore, the purpose of the article is to offer a mathematical model for assessing the reliability of agricultural machinery, taking into account the military factor in the front-line territory. The authors provide an analytical expression of the mathematical model for assessing the reliability of agricultural machinery, taking into account the influence of external military factors. This issue is gaining special attention in the front-line territories in eastern Ukraine, where a significant part of the acreage is also located. The proposed mathematical model, in contrast to the previous ones, will allow taking into account the wear and time-related deterioration of components of agricultural machinery, as well as external military factors (damage to equipment and personnel, damage due to collision with munitions, etc.). This mathematical model can be used to set the uptime requirements for agricultural machinery in a more reasonable manner and thereby increase its productive performance. During the research, methods of probability theory were used at the stage of determining the necessary probabilities of trouble-free operation of agricultural machinery, as well as methods of queuing theory, reliability theory of technical systems and mathematical modelling when determining the maintenance time of agricultural machinery samples for failure under various conditions of its application

**Keywords**: Weibull distribution, war, combat, simulation, meaning



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## INTRODUCTION

Technical systems, equipment and individual models of equipment in agriculture are becoming more and more complex. With the increase in requirements for the quality of agricultural machinery and its working conditions, as a result, the requirements for its maintainability, in particular for reliability, that is, the ability to perform tasks in a certain period of time with sufficient efficiency, increase. Failure of agricultural machinery for technical reasons or from any external factors (military, climate, etc.) will lead to the un-achievement of the goal set, which will negatively affect productivity and efficiency of work. Today, as a rule, there is an insufficient level of reliability during the operation of agricultural machinery samples [1; 2]. This is caused both by projecting decisions, as well as by the imperfection of the models that are used in their design and description of the process of their functioning under various operating conditions.

In addition, the influence of external factors that can significantly affect the production activities and the effectiveness of the final expected performance is not fully taken into account [3]. These include climatic conditions, natural disasters, the readiness of personnel, that is, the human factor, and in areas of military operations, that is, in front-line territories, one must not forget about the factors of external influence that are associated with the destruction of machinery during agricultural work, or collisions its consequences of hostilities in these areas (mines, ammunition, remnants of hostilities, war-torn territory, etc.) [4-7]. Today, when Ukraine is in a state of ongoing armed conflict, and part of the territory of Ukraine is the so-called front-line zone, in which there are quite large volumes of sown territories, that cannot be abandoned, then the problem of assessing the reliability of agriculture during the performance of tasks for sowing and harvesting crops from these territories, taking into account the effects of military factors, is a quite relevant and timely task of the present for agriculture of Ukraine and Ukraine as a whole [8].

The condition of any equipment changes over time, depending on the resource consumption, and under the influence of various external factors, if this is not taken into account during the design, there is a discrepancy between the required reliability of a sample of agricultural equipment and significantly low reliability, which is observed during the operation of this equipment, especially in areas close to the contact line with the enemy. This discrepancy increases if external factors are not taken into account, because a sample of equipment can also fail due to this component. This is exactly what is happening in practice, especially in the territories that are now considered front-line, but even with this status, these territories are also sown and agricultural products are harvested [9; 10].

The analysis of recent studies and publications on the issue of assessing the reliability of agricultural machinery shows that scientific tasks to ensure the reliability of serviced systems are addressed by researchers in a significant number of works. The greatest success was achieved for systems with an exponential law of duration distribution [9; 11; 12]. When applying the exponential distribution law, the process of functioning is considered through the prism of linear differential equations, which in turn are formed according to the process scheme when applying elementary formal mathematical rules. However, there are processes in which the duration is not subject to an exponential distribution, then it is difficult to describe these processes from a practical point of view and solve these equations in general, especially differential equations using frequent derivatives [13-15]. If it is necessary to solve such practical problems, statistical modelling methods are almost always used [16; 17].

In [1], a method for estimating the reliability indicator of equipment "probability of trouble-free switching on" of equipment in operation is considered. The application of the method is based on the use of operational observation data. The authors [2] outline the principles of constructing mathematical models, consider theoretical foundations of analytical and simulation modelling of technical systems functioning in the tasks of their reliability research. The authors in [3] research the application of the statistical modelling method for solving problems of reliability and operation of radio-electronic equipment. In [4], the general provisions of the methodology for system justification of reliability requirements for radio-electronic means of anti-aircraft missile systems are considered. Analytical methods for assessing the reliability of systems whose state is estimated by a homogeneous Markov process are provided by the authors in [9]. It should be noted that in the literature under consideration, when modelling the reliability of equipment, the influence of external factors that can significantly reduce its reliability is not taken into account. Therefore, the issue of assessing the reliability of agricultural machinery, taking into account the possible influence of external military factors, especially in the front-line territories, is an urgent task.

Therefore, the article is relevant because it offers a solution to this issue by clarifying the mathematical model of evaluating the reliability of agricultural machinery, taking into account the influence of external factors, which include climatic conditions, dangers associated with military operations (shelling, destruction, destruction of communications), the consequences of military operations (mining territories, the consequences of using ammunition to damage land and their residues on the sown land planes).

*The purpose of the study* is to offer a mathematical model for assessing the reliability of agricultural machinery, taking into account the influence of external military factors in the front-line territory.

## OPERATION OF AGRICULTURAL MACHINERY AND THE PROBABILITY OF ITS FAILURE: THEORETICAL ASPECTS

When agricultural machinery performs its intended tasks, it will be affected by two streams of events: failures due to limited technical reliability and failures due to the influence of various external factors. One of the main external factors in the front-line territories includes military factors that have a direct impact on equipment through the conduct of military operations or through the consequences left as a result of their conduct, as well as climatic factors that characterise the operating conditions of equipment. The discrepancy between the declared failure of a sample of agricultural machinery and that actually observed during its operation may be explained by an incorrectly accepted hypothesis when designing samples of equipment and determining the distribution of operating time before failure of equipment, especially without resource consumption since operation, time-related deterioration and wear components.

In this regard, it is advisable to model the reliability of a non-one-parameter (exponential) distribution of a random variable of time $\tilde{T}$ working hours to failure $P(t)=e^{-\theta \cdot t}$, as often accepted, and a more general, more flexible distribution, such as two-parameter ($\theta, \alpha$) by Weibull distribution, $P(t)=e^{-\theta \cdot t^{\alpha}}$($\theta$– scale parameter, $\alpha$ – a form parameter that takes into account the aging of equipment or takes into account the impact of external military and climatic factors).

During the operation of a sample of agricultural machinery, if any failures occur, its operability is restored by the repair authorities. Usually, the most time-consuming process is the process of eliminating failures caused by external military and climate factors. In the conditions of the production process, there is always a limit in the time and opportunities for timely restoration of the operability of agricultural machinery that has failed, this issue is especially relevant in front-line territories, where repair bodies and teams have a significant distance from the cultivated land. Therefore, it is justified to strive for the flow of failures of a sample of agricultural machinery due to limited technical reliability to be lower than the flow of failures due to the influence of military factors on the destruction of equipment due to combat operations or a collision with the residual effect of these operations, but this can only be achieved by increasing the average operating time for failure (to failure).

Taking into account all the above, it follows that agricultural machinery can fail if internal (limited technical reliability) and external (for example, climatic conditions, military operations) factors affect it separately or together. Then the probability of failure of a sample of equipment as a result of limited technical (own) reliability or due to external factors, as well as with the joint influence of the factors under consideration on its state, is determined as the probability of two compatible events [11]:

$$Q^0 = Q_H + Q_\beta - Q_H \cdot Q_\beta = 1 - P^0 \tag{1}$$

where $Q^0$ – the probability that two compatible and independent events will occur: failures of agricultural machinery as a result of external military or other factors and failures due to limited technical reliability, as well as failures in the implementation of both these events simultaneously; $Q_H$ – probability of failure of a sample of agricultural machinery due to limited technical reliability; $Q_\beta$ – the probability of failure of a sample of agricultural machinery due to the influence of external military or other factors; $P^0$ – probability of trouble-free operation of a sample of agricultural machinery under the influence of these events.

During the formation of the model proposed in the article, methods of probability theory were used at the stage of determining the necessary probabilities of trouble-free operation of agricultural machinery, as well as methods of queuing theory, reliability theory of technical systems and mathematical modelling when determining the maintenance time of agricultural machinery samples for failure under various conditions of its application (taking into account the effects of external factors and without them). The research also required solving exponential and logarithmic equations, which were solved by well-known algebraic and analytical methods. The study also used methods of operations research and methods of processing statistical information, as well as comparative analysis of the obtained practical recommendations.

## MODELING OF RELIABILITY OF AGRICULTURAL MACHINERY DUE TO EXTERNAL FACTORS

It is advisable to use Weibull distribution when modelling the reliability of agricultural machinery both at the design stage and during testing, which allows for a more correct calculation of the average operating time before failure, taking into account the ageing and wear of its components. At the same time, the failure of agricultural machinery due to external factors, such as military, climate, or others, can be considered practically independent of its condition, the condition of its components. In this case, the distribution of operating time before failure can be assumed to be exponential.

The probability of failure of a sample of agricultural machinery due to its limited technical reliability of agricultural machinery under the Weibull distribution of the random variable time of $\tilde{T}$ failure-free operation may be as follows:

$$Q_H(\tilde{T} < t) = 1 - e^{-\theta \cdot t^{\alpha}} = 1 - P_H(t) \tag{2}$$

And the probability of failure due to external factors (military, climate, etc.) in the exponential distribution of the random amount of time of trouble-free operation will be determined by:

$$Q_\beta(t) = 1 - e^{-\varepsilon \cdot t} = 1 - P_\beta(t) \tag{3}$$

where $\varepsilon$ – coefficient that takes into account external impact (the influence of military, climate and other factors of external influence); $P_1$ – probability of trouble-free operation of agricultural machinery over time of $t$ (h.) of continuous operation, taking into account limited technical reliability; $P_\beta$ – probability of trouble-free operation of agricultural machinery over time of $t$ (h.) of continuous operation, taking into account the influence of external military and climatic factors.

Substituting (2) and (3) in (1), the probability of failure of the sample of agricultural machinery due to limited technical reliability and external factors (climatic, military, etc.) during the time $t$ h. of continuous operation is obtained:

$$Q^0(t) = 1 - P_H \cdot P_\beta = 1 - e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} = 1 - P^0(t) \quad (4)$$

whence the probability of trouble-free operation in these conditions of use:

$$P^0(t) = 1 - Q^0(t) = P_H \cdot P_\beta = e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} \quad (5)$$

If a scale parameter $\theta=\frac{1}{T}$ is assumed, expression (5) can be rewritten as:

$$\boldsymbol{P^0(t) = e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} = e^{-\left(\frac{1}{T}\cdot t^{\alpha-1}+\varepsilon\right)\cdot t} \geq P_{nec}} \quad (6)$$

where $\boldsymbol{P}_{req}$ is probability of the necessary.

Whence, after logarithm, can be found the average value of the time spent before failure $T$ when assignment of certain values $\varepsilon$, $\alpha<1$, $t$ and $\boldsymbol{P}_{nec}$:

$$T \geq -\frac{t^\alpha}{\varepsilon \cdot t + \ln P_{nec}} = \frac{t^\alpha}{-\ln P_{nec} - \varepsilon \cdot t} \quad (7)$$

From formula (7) it is possible to find acceptable values of the coefficient that takes into account external influence $\varepsilon$ and calculate the operating time for failure of the sample of the agricultural machinery (before failure) $T$, for example, by the values of the form parameter $\alpha$=1.4, $t$=5 and different values of $\varepsilon$.

The obtained values $\varepsilon$ can be used not only to determine the average time $T$ before failure of agricultural machinery samples, but also to determine the possible number $\Delta N_\beta$ of decommissioned samples of machinery only due to external military or climatic factors during the time $t$ of continuous operation, for example, for future planning of the work of repair and restoration bodies. As already noted, using the model under consideration determines the time of $T$ trouble-free operation, when failures of agricultural machinery due to limited technical reliability will be much lower than failures due to external military and climatic factors. To do this, the ratio is introduced:

$$\frac{\Delta N_H}{\Delta N_\beta} \leq \sigma \quad (8)$$

where $\Delta N_H$ – the number of agricultural machineries disabled only due to limited technical reliability; $\Delta N_\beta$ – the amount of agricultural equipment disabled only due to external factors (climate and military).

As it is known,

$$\Delta N_\beta = Q_\beta \cdot (1 - Q_H) \cdot N_0 \quad (9)$$

$$\Delta N_H = Q_H \cdot (1 - Q_\beta) \cdot N_0 \quad (10)$$

where $N_0$ – the number of agricultural machineries in production.

A certain number of samples of agricultural machinery $\Delta N_{H\beta}$ can be disabled both due to limited technical reliability, and simultaneously due to external military and climatic factors:

$$\Delta N_{H\beta} = Q_H \cdot Q_\beta \cdot N_0 \quad (11)$$

Obviously, with the increase in the average time to failure of agricultural machinery, the number of $\Delta N_H$ disabled due to only limited technical reliability will decrease. Given that the probability of an event that is associated with the occurrence of a quantity $\Delta N_{H\beta}$, significantly lower compared to the probabilities of occurrence of values $\Delta N_H$, $\Delta N_\beta$, and also taking into account that the work of repair and restoration bodies will be mainly associated with the restoration of technical readiness of agricultural machinery disabled due to the influence of external military and climatic factors, can be considered $\Delta N_{H\beta} \approx 0$.

Substituting the values of (9) and (10) in (8), can be obtained:

$$\frac{\Delta N_H}{\Delta N_\beta} = \frac{e^{-\left(\varepsilon - \frac{1}{T}\cdot t^{\alpha-1}\right)\cdot t} - e^{-\varepsilon \cdot t}}{1 - e^{-\varepsilon \cdot t}} \leq \sigma,\ \varepsilon \neq 0 \quad (12)$$

where:

$$\boldsymbol{e^{-\left(\varepsilon - \frac{1}{T}\cdot t^{\alpha-1}\right)\cdot t} \leq e^{-\varepsilon \cdot t} + \sigma \cdot (1 - e^{-\varepsilon \cdot t})} \quad (13)$$

The logarithm of this expression, gives the value of the $T$ operating time before the failure of the equipment during $t$ its continuous operation:

$$T \geq \frac{t^\alpha}{\varepsilon \cdot t + \ln\left[e^{-\varepsilon \cdot t} + \sigma \cdot (1 - e^{-\varepsilon \cdot t})\right]},\ \sigma > 0 \quad (14)$$

Equation (13) is the essence of the mathematical model. In order for the units of measurement to match, equation (13) should be written as follows:

$$T \geq \frac{1 + \alpha^{1.604\cdot\alpha} \cdot (t-1)}{\varepsilon \cdot t + \ln\left[e^{-\varepsilon \cdot t} + \sigma \cdot (1 - e^{-\varepsilon \cdot t})\right]} \quad (15)$$

since when $\alpha<1$ expression $t^\alpha \approx 1+\alpha^{1.604\cdot\alpha}\cdot(t-1)$.

In order to determine the limit values of the coefficient of accounting for external military and climatic factors $\varepsilon$ expressions (7) and (13) are equated:

$$\frac{t^{\alpha}}{\varepsilon \cdot t + ln\ [e^{-\varepsilon \cdot t} + \sigma \cdot (1 - e^{-\varepsilon \cdot t})]} = -\frac{t^{\alpha}}{\varepsilon \cdot t + ln\, P_{nec}} \quad (16)$$

where:

$$\varepsilon \cdot t + ln\ P_{nec} = -\varepsilon \cdot t - ln\ [e^{-\varepsilon \cdot t} + \sigma(1 - e^{-\varepsilon \cdot t})] \quad (17)$$

or:

$$2 \cdot \varepsilon \cdot t = -ln\ P_{nec} - ln\ [e^{-\varepsilon \cdot t} + \sigma(1 - e^{-\varepsilon \cdot t})] \quad (18)$$

If this transcendental equation is to be solved with respect to $\varepsilon$, because to reach a certain value $\sigma$ is possible, given not only $T$, but also one or another amount of generalised relative hourly losses $\varepsilon$, then we get:

$$\varepsilon = \frac{1}{2 \cdot t} \cdot (1 + \sigma - ln\, P_{nec} - \sqrt{(1 + \sigma - ln\, P_{nec})^2 + 4 \cdot ln\, P_{nec}}) \quad (19)$$

where $\sigma$=0:

$$\varepsilon = \frac{1}{2 \cdot t} \cdot (1 + \sigma - ln\, P_{nec} - \sqrt{(1 + \sigma - ln\, P_{nec})^2 + 4 \cdot ln\, P_{nec}}) = \frac{1}{2 \cdot t} \cdot (1 - ln\, P_{nec} - \sqrt{(1 + ln\, P_{nec})^2}) < -\frac{ln\, P_{nec}}{t} \quad (20)$$

which can also be obtained from (7).

If equation (18) is solved with respect to $\sigma$, then this value will be expressed as $\varepsilon$ as follows:

$$\sigma = f(\varepsilon) = -(1 - \varepsilon \cdot t) - \frac{1 - \varepsilon \cdot t}{\varepsilon \cdot t} \cdot ln\, P_{nec} = (1 - \varepsilon \cdot t) \cdot (-1 - \frac{ln\, P_{nec}}{\varepsilon \cdot t}) > 0 \quad (21)$$

Thus, further calculations can be performed using the following functions: $\varepsilon=f(\sigma)$ or $\sigma=f(\varepsilon)$.

Next acceptable values $\varepsilon$ can be calculated depending on $\sigma$ and $P_{nec}$ and unlike previously obtained permissible values $\varepsilon=-\frac{ln\ P_{nec}}{t}$, but taking into account the value $\sigma$, which is achieved by setting $P_{nec}$, $\varepsilon$, $t$. After that the final calculations of the values $T$ are made for the set $\sigma$, $P_{nec}$, $t$ = 5 hours.

Next, it is desirable to check the operability of the proposed mathematical model for assessing the reliability of agricultural machinery, taking into account the influence of external military factors, without taking into account time-related deterioration and wear of agricultural machinery, that is, $\alpha$=1, and without taking into account the conditions of external influence, that is, $\varepsilon$=0, when it is not affected by military or climatic factors. Then the probability of trouble-free operation of a sample of agricultural machinery can be calculated as:

$$P^0(t) = e^{-(\theta \cdot t^{\alpha-1} + \varepsilon) \cdot t} = P(t) = e^{-\theta \cdot t} = e^{-\frac{1}{T} \cdot t} \quad (22)$$

By setting $P(t) \geq P_{nec}$ the value of the average operating time $T_{av}$ before failure will be found under the condition: $T_{av} \leq -\frac{t}{ln\ P(t)}$.

## THE RESULTS OF CALCULATIONS OF THE PROPOSED MATHEMATICAL MODEL

Preliminary calculation results are shown in Table 1, obtained in accordance with the proposed mathematical model under pre-defined conditions, and correctly reflect the situation with determining the average operating time $T_{av}$ before failure without taking into account time-related deterioration and wear of agricultural machinery ($\alpha$=1) in the process of its operation in the military and without taking into account the influence of the external military and climatic factors ($\varepsilon$=0). So, for $t$=5 hours required to achieve $P_{nec}$=0.95 value $T_{av}$ makes up 98 h≈100 h.

***Table 1**. The value of the average operating time of agricultural machinery before failure (h) without taking into account the influence of external military and climatic factors at α=1, ε=0*

| Continuous operating time of agricultural machinery | Possible values $P(t) = e^{-\frac{1}{T} \cdot t} = P_{nec}$ | | | | |
|---|---|---|---|---|---|
| | 0.6 | 0.7 | 0.8 | 0.9 | 0.95 |
| $t$=1 hour | 2 | 3 | 5 | 10 | 20 |
| $t$=2 hours | 4 | 6 | 9 | 19 | 39 |
| $t$=3 hours | 6 | 8 | 13 | 28 | 58 |
| $t$=4 hours | 8 | 11 | 17 | 38 | 78 |
| $t$=5 hours | 10 | 14 | 22 | 47 | 98 |
| $t$=7 hours | 14 | 20 | 31 | 66 | 136 |
| $t$=10 hours | 20 | 28 | 45 | 95 | 195 |

Next, it is worth considering another special case of determining the reliability indicators of agricultural machinery based on the proposed method of mathematical modelling of its reliability taking into account time-related deterioration and wear of components ($\alpha$>1), but without taking into account external factors ($\varepsilon$=0). In this case, the probability of no-failure operation is determined by:

$$P^0(t) = e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} = P(t) = e^{-\theta \cdot t^{\alpha}} = e^{-\frac{1}{T}\cdot t^{\alpha}} \quad (23)$$

Given the condition that $P(t) \geq P_{nec}$ the value of the average time of operation $T_{av}$ before failure will be found from:

$$T_{av} \geq -\frac{t^{\alpha}}{ln\ P(t)} = -\frac{1+\alpha^{1.604\cdot\alpha}\cdot(t-1)}{ln\ P(t)} \quad (24)$$

Value $T_{av}$ (h) depending on the possible $P_{nec}$ and time $t$ (h) of continuous operation, as well as, for example, by the parameter $\alpha$=1.4 (which takes into account, for example, resource costs of about 70%) are shown in Table 2.

***Table 2.*** *Value of the average operating time of agricultural machinery before failure (h), taking into account time-related deterioration and wear of components (α>1), but without taking into account the influence of the external military and climatic factors (ε=0), α=1.4 and ε=0*

| Continuous operating time of agricultural machinery | Possible values $P(t) = e^{-\frac{1}{T}\cdot t^{\alpha}} = P_{nec}$ | | | | |
|---|---|---|---|---|---|
| | 0.6 | 0.7 | 0.8 | 0.9 | 0.95 |
| $t$=1 hour | 2 | 3 | 5 | 10 | 20 |
| $t$=2 hours | 5 | 7 | 12 | 25 | 51 |
| $t$=3 hours | 9 | 13 | 21 | 44 | 91 |
| $t$=4 hours | 14 | 20 | 31 | 66 | 136 |
| $t$=5 hours | 19 | 27 | 43 | 90 | 186 |
| $t$=7 hours | 30 | 43 | 68 | 145 | 297 |
| $t$=10 hours | 49 | 70 | 113 | 238 | 490 |

And finally, in the most general case, taking into account time-related deterioration and wear of components ($\alpha$>1), as well as external climatic and military factors ($\varepsilon \neq 0$), the probability of trouble-free operation of agricultural machinery will be determined by:

$$P^0(t) = e^{-(\theta \cdot t^{\alpha-1}+\varepsilon)\cdot t} = e^{-\left(\frac{1}{T}\cdot t^{\alpha-1}+\varepsilon\right)\cdot t} \quad (25)$$

Given the condition that $P(t) \geq P_{nec}$ the value of the average time of operation $T_{av}$ before failure will be found from:

$$T_{CP} \geq -\frac{t^{\alpha}}{\varepsilon\cdot t + ln\ P_{nec}} = -\frac{1+\alpha^{1.604\cdot\alpha}\cdot(t-1)}{\varepsilon\cdot t + ln\ P_{nec}} \quad (26)$$

the following condition must be met $\varepsilon < \frac{-ln\ P_{nec}}{t}$.

However, to fulfill the condition $\varepsilon < \frac{-ln\ P_{nec}}{t}$, we take, for example, $\varepsilon$=0.0063 and calculate the value $T_{av}$ depending on the previous values $P_{nec}$ and $t$, which are shown in Table 3. Missing data in Table 3 cells at $P_{nec}$=0.95 indicate an unrealised technical value $T_{av}$>1000 hour per $t$=7 and non-fulfilment of the condition $\varepsilon < \frac{-ln\ P_{nec}}{t}$ at $t$=10.

***Table 3.*** *Value of the operating time of agricultural machinery before failure, taking into account time-related deterioration and wear of components (α>1), as well as the influence of external climatic and military factors (ε≠0) at α=1.4, ε=0.0063*

| Continuous operating time | Possible values $P(t) = e^{-\left(\frac{1}{T}\cdot t^{\alpha-1}+\varepsilon\right)\cdot t} = P_{nec}$ | | | | |
|---|---|---|---|---|---|
| | 0.6 | 0.7 | 0.8 | 0.9 | 0.95 |
| $t$=1 hour | 2 | 3 | 5 | 10 | 22 |
| $t$=2 hours | 5 | 8 | 13 | 28 | 68 |
| $t$=3 hours | 9 | 14 | 23 | 54 | 144 |
| $t$=4 hours | 14 | 21 | 35 | 87 | 267 |
| $t$=5 hours | 20 | 29 | 50 | 129 | 481 |
| $t$=7 hours | 33 | 49 | 85 | 249 | – |
| $t$=10 hours | 56 | 86 | 157 | 592 | – |

## CONCLUSIONS

In the article, the authors consider the current issue of improving a mathematical model for assessing the reliability of agricultural machinery, taking into account the influence of the external military and climatic factors in the front-line territory in the east of Ukraine.

The mathematical model proposed by the authors, unlike the previous ones, will allow taking into account wear and time-related deterioration of components of equipment samples, as well as external factors (climate, military, etc.). Thus, according to the results of a numerical experiment, without taking into account time-related deterioration and wear of equipment components, the operating time before failure is $T$=100 hours. Using this mathematical model without taking into account external factors – about $T$=200 hours. Additional consideration of external factors makes it necessary to bring the operating time before failure to about $T$=500 hours that provides a probability of trouble-free operating of at least 0.9-0.95. It is believed that with the help of the proposed mathematical model, it is possible to set more reasoned requirements for the reliability of agricultural machinery samples, thereby increasing their productive work in high-risk areas (front-line zones).

The direction of further research is the introduction of the developed model into the design system of individual samples of agricultural equipment, which will perform tasks related to the cultivation of agricultural territories in the front-line zones in the territories of Donetsk and Luhansk regions. Samples that will be used in these areas will need to have certain technical features of their operation in order to increase the level of trouble-free operation.

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# Розвиток математичних моделей оцінювання безвідмовності техніки сільського господарства з урахуванням впливу зовнішніх воєнних факторів у прифронтовій території

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**Анотація**. Із підвищенням вимог до якості техніки сільського господарства та умов її роботи, як наслідок, зростають вимоги до її надійності, зокрема до безвідмовності. Відмова з технічних причин або від будь-яких зовнішніх факторів призведе до недосягнення поставленої мети, а й значить до зниження продуктивності роботи. На сьогодні переважно спостерігається недостатній рівень безвідмовності техніки сільського господарства під час експлуатації, особливої уваги це питання набуває на територіях, які знаходяться у прифронтовій зоні на сході України в Донецькій та Луганській областях. Це викликано як конструкторськими рішеннями, так і недосконалістю моделей, які застосовуються під час проектування. Крім того, не враховуються зовнішні фактори, які суттєво можуть вплинути на виробничу діяльність. До них можна віднести кліматичні умови, стихійні лиха, підготовленість персоналу, тобто людський фактор, а також фактор наслідків збройного конфлікту. Тому метою статті є запропонувати математичну модель оцінювання безвідмовності техніки сільського господарства з урахуванням воєнних факторі у прифронтовій території. Автори наводять аналітичний вираз математичної моделі оцінювання безвідмовності техніки сільського господарства з урахуванням впливу зовнішніх воєнних факторів. Особливої уваги це питання набуває на прифронтових територіях на сході України, де знаходиться також значна частина посівних площ. Запропонована математична модель, на відміну від попередніх, дозволить врахувати зношення, старіння комплектуючих зразків техніки сільського господарства, а також зовнішні воєнні фактори щодо ураження техніки та персоналу, пошкодження її унаслідок зіткнення з боєприпасами тощо. За допомогою даної математичної моделі можна більш аргументовано задавати вимоги з безвідмовності зразків техніки сільського господарства, тим самим підвищити їх продуктивну роботу. Під час дослідження було використано методи теорії ймовірностей на етапі визначення необхідних ймовірностей безвідмовної роботи сільськогосподарської техніки, а також методи теорії масового обслуговування, теорії надійності технічних систем та математичного моделювання під час визначення часу обслуговування зразків сільськогосподарської техніки на відмову за різних умов її застосування

**Ключові слова**: розподіл Вейбулла, війна, бойові дії, моделювання, значення