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Modelling the performance of repair and restoration bodies in combat conditions

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Abstract. Today, when the Russian Federation has launched a full-scale war against Ukraine, the most important and urgent task of maintaining equipment in a combat-ready state is to find ways to improve the efficiency of the system of its maintenance and repair, i.e., the productive work of repair and restoration bodies in a combat situation. The success of the armed forces on the battlefield will depend on the effective work of the repair and maintenance bodies.

The purpose of this study is to model the production activity of repair and restoration bodies taking into account combat operations. The study was conducted on the example of the self-propelled gun of the Buk-M1 anti-aircraft missile system.

To solve this problem, the method of analytical modeling with the use of probability theory is used, which allows a comprehensive consideration of all approaches to solving this issue.

The article discusses the reasons why military equipment can fail. This is due to limited technical reliability, due to fire from the enemy during hostilities, or due to the combined effect of both of these factors. The article provides a variant of finding the number of equipment that is out of service due to each of these reasons. The author considers how the achieved value of the average uptime of a self-propelled gun will affect the nature of its damage, how the value of time between failures will change, taking into account losses (failures) as a result of limited technical reliability, compared to the value of relative losses due to enemy fire. It is proved that with an increase in the average operating time before the failure of a self-propelled gun, the number of vehicles that are disabled due to limited technical reliability alone will decrease. The correlation between the number of vehicles that failed due to limited technical reliability and the number of self-propelled guns that failed due to enemy fire is proposed. The values of the probability of failure-free operation and the probability of equipment failure for both of these cases are estimated. Knowing the expected value of the repair fund, it is possible to model the performance of repair and restoration bodies taking into account the combat situation. Taking into account the ratio between the number of equipment that failed due to limited technical reliability and the number of equipment that failed due to combat damage allows to increase the efficiency of the system of restoration of self-propelled guns damaged in combat operations, improve the planning of production activities of repair and restoration bodies, i.e., increase the overall combat capability of a military formation, for example, in the process of repelling an air attack on troops (objects).

The materials of the article are of practical value for predicting the work of repair and restoration bodies in the conditions of hostilities.

Keywords: modeling, technical reliability, combat situation, probability of failure.

Introduction

In peacetime, the failure of weapons and military equipment in the Armed Forces of any state

is largely due to the length of time it has been in service, as the samples experience deterioration in the technical condition of elements and materials due to their aging and wear. In wartime, damage to equipment in a combat situation is added. Before the war began, the Armed Forces of Ukraine were equipped with almost all types of weapons and military equipment, but more than 60% of the equipment had been in service for more than 15 years. Military equipment can fail for various reasons: due to limited technical reliability, due to enemy fire during combat operations, or due to the combined effect of both factors. This study was conducted on the example of the Buk-M1 self-propelled rocket launcher (SRL). An analysis of the current technical condition of the SRL showed that there are quite frequent failures due to limited technical reliability. The task of the relevant repair and restoration bodies will be to timely restore the technical readiness of disabled SRLs, and this task will be more difficult to solve in relation to equipment that has failed because of enemy fire, and therefore repair and restoration bodies will be mainly engaged in the restoration of these SRLs. Therefore, the most important and urgent task in today's warfare environment to maintain equipment in a combat-ready state is to find ways to improve the efficiency of its maintenance and repair system, i.e., the productive work of repair and restoration bodies in combat conditions.

The issues of improving the system of maintenance and repair of weapons and equipment are reflected in numerous literatures of both theoretical and applied nature. Startsev V. V. et al. (2022) discusses methods for assessing the effectiveness of the restoration of ground-based samples of the Air Force of Ukraine both as part of a group of troops and in military units and individual units. The authors in (Openko P. V. et al., 2021) use the methodology for assessing the possibility of eliminating combat damage and restoring the suitability of weapons and equipment to calculate the effectiveness of the restoration of anti-aircraft missile system combat assets. The authors in (Doska O. M. et al., 2020) determine the performance indicators for the restoration of anti-aircraft missile weapons. Modelling can play a crucial role in improving production activities and supporting combat operations of repair and restoration bodies. By using mathematical and computational models to simulate various scenarios, it becomes possible to identify potential bottlenecks, optimize workflows, and allocate resources more efficiently, according to scientists (Mair J. et al., 2023) and authors in (National Defense Authorization Act for Fiscal Year, 2023).

Materials and Methods

During wartime, maintenance and repair organizations face several unique challenges that can significantly impact their ability to support military operations. These challenges may include limited resources, time constraints, and unpredictable operating conditions. In order to effectively solve these problems, it is important to understand the specific needs and requirements of repair and recovery agencies during combat operations. This will help to identify opportunities to improve operations and support combat operations.

Efficient production activities are crucial to sustainment of combat operations, as they allow repair and restoration authorities to repair damage quickly and effectively of equipment and infrastructure caused by the conflict. To achieve this efficiency, it is necessary to optimize production processes and workflows, minimize downtime and ensure efficient resource allocation. This requires a deep understanding of the specific challenges and requirements faced by repair and maintenance organizations during hostilities, as well as the ability to quickly adapt to changing circumstances.

Modelling plays an important role in improving production activities and supporting the combat operations of repair and restoration agencies. By using mathematical and computational models to simulate various scenarios, it becomes possible to identify potential bottlenecks, optimize workflows, and allocate resources more efficiently. This can help maintenance and repair facilities make more informed decisions about resource allocation and prioritization, ultimately leading to more efficient and effective operations. In addition, by incorporating data from previous combat situations, models

can be refined and improved over time, leading to even greater efficiency and effectiveness in supporting military operations.

Modelling the production activities of repair and restoration facilities can help ensure that they have the necessary resources to fulfil their tasks. By considering factors such as the number of weapons and equipment in need of repair, the types of equipment required, and the availability of spare parts, a model can be developed that accurately predicts resource demand. This, in turn, can help ensure that the right equipment and supplies are available when needed, minimizing delays and downtime.

Another important aspect of modelling production activities in repair and restoration organizations is maximizing efficiency. By developing models that consider combat experience, repairs and remanufacturing can be conducted in a way that minimizes downtime and maximizes the quality of work. This can include developing models that consider factors such as the types of repairs required, the availability of skilled personnel, and the types of equipment needed. In this way, maintenance and repair facilities can ensure that they are operating at maximum capacity even in the most critical situations, which is exactly what happens in a combat environment.

In addition to minimizing downtime and maximizing efficiency, modelling production activities in the maintenance and repair facility can also help minimize delays in critical situations. By using mathematical and computational models to simulate different scenarios, it becomes possible to identify potential bottlenecks, optimize work processes and allocate resources more efficiently. This may include developing models that consider factors such as the types of equipment needed, the availability of spare parts, and the time required to complete repairs. In this way, repair and restoration authorities can ensure that they are able to respond quickly and effectively to critical situations while minimizing the impact on the fighting.

Military equipment can fail for various reasons: due to limited technical reliability, due to enemy fire during combat operations, or due to the combined effect of both factors. The probability of a complete group of incompatible events will be calculated as follows (O. Wentzel, 2006):

$$P(t) = P(t)_1 + P(t)_2 + P(t)_3 + P(t)_4, \quad (1)$$

where $P(t)_1$ is the state of the equipment sample, taking into account only the technical component;

$P(t)_2$ - the state of the equipment sample, taking into account only the enemy's fire impact;

$P(t)_3$ is the state of the equipment under the combined influence of both of these factors;

$P(t)_4$ - the state of the sample equipment if no factors affect it.

In turn, we can write down that

$$P(t)_1 = P(t)_H \cdot (1 - P(t)_\beta), \quad (2)$$

$$P(t)_2 = P(t)_\beta \cdot (1 - P(t)_H), \quad (3)$$

$$P(t)_3 = P(t)_H \cdot P(t)_\beta, \quad (4)$$

$$P(t)_4 = (1 - P(t)_H) \cdot (1 - P(t)_\beta), \quad (5)$$

where $P(t)_H$ is the probability of IED failure due to only limited technical reliability;

$P(t)_\beta$ - the probability of IED failure due to only enemy fire

Substituting expressions (2)-(5) into (1), we obtain:

$$P(t) = P(t)_H \cdot (1 - P(t)_\beta) + P(t)_\beta \cdot (1 - P(t)_H) + P(t)_H \cdot P(t)_\beta + (1 - P(t)_H) \cdot (1 - P(t)_\beta) =$$
$$= P(t)_H - P(t)_H \cdot P(t)_\beta + P(t)_\beta - P(t)_\beta \cdot P(t)_H + P(t)_H \cdot P(t)_\beta + 1 - P(t)_\beta - P(t)_H +$$
$$+ P(t)_H \cdot P(t)_\beta = 1$$

Thus, the result indicates that all IED states have been considered, since the probability of a complete group of incompatible events is equal to one.

Next, we need to investigate how the state of the SRL will change when the factors act in different combinations. If we exclude the state of the equipment sample when no factors affect it, the probability of SRL failure can be written down according to the probability addition theorem:

$$P^0(t) = P(t)_1 + P(t)_2 + P(t)_3, \quad (6)$$

Substituting expressions (2)-(4) into (6), we obtain:

$$\begin{aligned} P^0(t) &= P(t)_H \cdot (1 - P(t)_\beta) + P(t)_\beta \cdot (1 - P(t)_H) + P(t)_H \cdot P(t)_\beta = \\ &= P(t)_H - P(t)_H \cdot P(t)_\beta + P(t)_\beta - P(t)_H \cdot P(t)_\beta + P(t)_H \cdot P(t)_\beta = \\ &= P(t)_H + P(t)_\beta - P(t)_H \cdot P(t)_\beta \end{aligned} \quad (7)$$

It is advisable to model the reliability of an SRL without taking into account the conditions of the combat situation using the Weibull-Gnedenko distribution, which allows for a more correct account of the aging and wear of its components [13]:

$$P(t)_H = e^{-\theta \cdot t^\alpha}, \quad (8)$$

where *t is the* time of continuous operation of the SRL (h);

θ - is the Weibull distribution parameter, which in this case determines the intensity λ ($\lambda = \frac{1}{T}$, 1/h) of SRL failures due to limited technical reliability;

T - is the value of the average operating time before SRL failure, taking into account all factors affecting its condition (hours);

α - is a parameter that considers the aging and wear and tear of SRLs during operation in the military.

The probability of an SRL failure due to enemy fire, for example, with an exponential distribution of a random variable of uptime, will be:

$$P(t)_\beta = e^{-\varepsilon \cdot t}, \quad (9)$$

where ε is the generalized (inferred) value of the relative hourly combat losses of equipment because of enemy fire.

Substituting (8) and (9) into (7), we obtain an expression for calculating the probability of SRL failure during its continuous operation, considering both factors:

$$P^0(t) = e^{-(\theta \cdot t^{\alpha-1} + \varepsilon) \cdot t} = e^{-\left(\frac{1}{T} \cdot t^{\alpha-1} + \varepsilon\right) \cdot t} \geq P_{ПОТР}, \quad (10)$$

where $P_{ПОТР}$ is the required (desired) value of the probability of SRL failure, considering both limited technical reliability and enemy fire.

If the value of ε is known, it is possible to determine the number of ΔN_β disabled SRLs only due to enemy fire during the time of continuous operation of the equipment for future planning of the work of repair and restoration bodies. This number can be determined as follows:

$$\Delta N_\beta = Q_\beta \cdot (1 - Q_H) \cdot N_0, \quad (11)$$

where N_0 is the number of SRLs in the unit before the start of hostilities;

Q_H - the probability of SRL failure due to limited technical reliability;

Q_β - the probability of failure of weapons and military equipment due to the influence of the enemy alone.

At the same time, SRLs can fail during hostilities due to limited technical reliability. In this case, the number of equipment that failed during the time of continuous operation only for this reason is determined as follows:

$$\Delta N_H = Q_H \cdot (1 - Q_\beta) \cdot N_0, \quad (12)$$

A certain number of IEDs $\Delta N_{H\beta}$ can be disabled both due to limited technical reliability and simultaneously because of fire impact on them by the enemy:

$$\Delta N_{H\beta} = Q_H \cdot Q_\beta \cdot N_0. \quad (13)$$

The issue of modelling the production activity of repair and restoration bodies becomes important. In this case, it is necessary to determine to what extent this performance can be predicted depending on the nature of SRL damage. Or, in other words, how will the achieved value of the average SRL uptime affect the maintenance of the SRL in a technically ready condition, how will the value of *T* change, taking into account losses (failures) as a result of limited technical reliability, compared to the value of relative losses due to enemy fire.

Suppose that when planning the value of the time *T* before SRL failure, it is assumed that the value of ΔN_H should be σ times less than the value of ΔN_β, that is, that the following ratio (according to $\varepsilon \neq 0$) is fulfilled:

$$\frac{\Delta N_H}{\Delta N_\beta} = \frac{Q_H \cdot (1 - Q_\beta)}{Q_\beta \cdot (1 - Q_H)} = \frac{\left(1 - e^{-\frac{1}{T} \cdot t^\alpha}\right) \cdot e^{-\varepsilon \cdot t}}{\left(1 - e^{-\varepsilon \cdot t}\right) \cdot e^{-\frac{1}{T} \cdot t^\alpha}} = \frac{1 - e^{-\frac{1}{T} \cdot t^\alpha}}{1 - e^{-\varepsilon \cdot t}} \cdot e^{-\left(\varepsilon - \frac{1}{T} \cdot t^{\alpha - 1}\right) \cdot t} = \frac{e^{-\left(\varepsilon - \frac{1}{T} \cdot t^{\alpha - 1}\right) \cdot t} - e^{-\varepsilon \cdot t}}{1 - e^{-\varepsilon \cdot t}} \leq \sigma, \quad (14)$$

from

$$e^{-\left(\varepsilon - \frac{1}{T} \cdot t^{\alpha - 1}\right) \cdot t} \leq e^{-\varepsilon \cdot t} + \sigma \cdot (1 - e^{-\varepsilon \cdot t}), \quad (15)$$

By logarithmizing this expression, we obtain the value of the time *T* before the SRL fails under the given conditions of use of the equipment during continuous operation at $\sigma > 0$:

$$T \geq \frac{t^\alpha}{\varepsilon \cdot t + \ln\left[e^{-\varepsilon \cdot t} + \sigma \cdot \left(1 - e^{-\varepsilon \cdot t}\right)\right]}, \quad (16)$$

It is at this value of *T that* the condition $\frac{\Delta N_H}{\Delta N_\beta} \leq \sigma$ will be fulfilled.

Results and Discussions

The calculation of the operating time before SRL failure is shown in Table 1.

Table 1 shows that, for example, fire damage will predominate at $\sigma = 0{,}2$. Therefore, the repair teams must be prepared to eliminate failures due to enemy fire.

As we can see, with an increase in $P_{ПОТР}$ for any value of σ , *the required value of T* increases, which is natural. With a decrease in σ , i.e., with a decrease in ΔN_H for any value of $P_{ПОТР}$, the required value of *T* should increase, which is also expected. The calculations show that the value of the SRL repair fund due to enemy fire is 1.6 times higher than the value of the SRL repair fund formed as a result of the limited technical reliability of equipment.

Researchers of the National Defense Academy of Ukraine in their works, namely (Khazanovych O. I., 2004) and (Polyakov A. P., 2004), consider the role and place of the maintenance and repair system in the system of technical support of troops from different perspectives, analyse the peculiarities of its functioning.

Table 1. Time between failures for a given ratio σ , required (desired) value of the probability of failure and continuous operation time

Possible meanings for σ	Possible values $P_{ПОТР}$				
	0,6	0,7	0,8	0,9	0,95
1	33 $(\ )\varepsilon = 0{,}0450$	49 $(\ )\varepsilon = 0{,}0325$	81 $(\ )\varepsilon = 0{,}0211$	95 $(\ )\varepsilon = 0{,}0010$	186 $(\ )\varepsilon = 0$
0,5	45 $(\ )\varepsilon = 0{,}0597$	68 $(\ )\varepsilon = 0{,}0435$	116 $(\ )\varepsilon = 0{,}0282$	264 $(\ )\varepsilon = 0{,}0137$	362 $(\ )\varepsilon = 0{,}0050$
0,45	47 $(\ )\varepsilon = 0{,}0619$	73 $(\ )\varepsilon = 0{,}0451$	125 $(\ )\varepsilon = 0{,}0293$	280 $(\ )\varepsilon = 0{,}0142$	469 (481) $(\ )\varepsilon = 0{,}0062$
0,4	50 $(\ )\varepsilon = 0{,}0643$	77 $(\ )\varepsilon = 0{,}0468$	134 $(\ )\varepsilon = 0{,}0303$	307 $(\ )\varepsilon = 0{,}0147$	643 $(\ )\varepsilon = 0{,}0073$
0,3	59 $(\ )\varepsilon = 0{,}0700$	93 $(\ )\varepsilon = 0{,}0509$	161 $(\ )\varepsilon = 0{,}0328$	381 $(\ )\varepsilon = 0{,}0159$	744 $(\ )\varepsilon = 0{,}0077$
0,2	76 $(\ )\varepsilon = 0{,}0771$	122 $(\ )\varepsilon = 0{,}0558$	221 $(\ )\varepsilon = 0{,}0359$	952 $(\ )\varepsilon = 0{,}0190$	1082 $(\ )\varepsilon = 0{,}0085$

The option of determining the number of spare parts required to compensate for combat damage to weapons and military equipment in repair bodies of different levels is provided in (Maltsev V. A. et al., 2015). The problem of the procedure for restoration, repair, modernization, increase of the installed resource and extension of the service life (storage) of weapons, military and special equipment is addressed in the Resolution of the Cabinet of Ministers of Ukraine (2018). The authors (V. Shuienkin et al., 2010) consider the problems of logistics support of troops in combat conditions. Scientists (M. A. Tkachuk et al., 2018) consider mathematical models when changing the state of elements of combat vehicles and technological systems for their manufacture; (H. S. Zalevskyi et al., 2019) propose a methodology for assessing the effectiveness of logistics support tasks of military units of the Air Force of the Armed Forces of Ukraine in an armed conflict.

However, these papers rather indirectly deal with the calculation of the repair fund, considering the combat situation.

Conclusion

Thus, knowing the expected value of the repair fund, it is possible to model the production activities of repair and restoration bodies considering the combat situation. Taking into account the ratio between the number of equipment that has failed due to limited technical reliability and the number of equipment that has failed due to combat damage makes it possible to choose the value of the average operating time before equipment failure, which makes it possible to increase the efficiency of the system for restoring SRLs damaged in combat, to improve the planning of production activities of the repair and restoration bodies used for this purpose, that is, to increase the overall combat capability of a military formation, for example, in the process of warfare. Given the value of σ , it is possible to calculate the required time to failure.

The subject of further research may be the consideration of other factors that affect the productivity of repair and restoration bodies. This may include personnel training, the financial component, and the use of impersonal repair in the military.

Recommendations

The materials of the article are of practical value for predicting the work of repair and restoration bodies in combat conditions for specialists of the Command of the Logistics Forces of the Armed Forces of Ukraine.

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