The object of this study is the process of distribution of damaged weapons and military equipment of various types among specialized repair and restoration units.

The problem being solved is the lack of adaptability of the existing scientific and methodical apparatus to the expedient distribution of damaged weapons and military equipment of various types among specialized repair and restoration units.

An algorithm for the expedient distribution of damaged weapons and military equipment among specialized repair and restoration units is proposed, which is based on the method of non-linear programming (the method of two functions). The essence of the developed algorithm is to take into account the non-linearity of objective functions of both the consumer and the resource.

A feature of the developed algorithm of expedient distribution is taking into account the heterogeneity of both damaged weapons and military equipment, as well as the specificity of repair and restoration units.

The scope of practical application of the proposed algorithm is management processes in military hostilities during combat operations.

The procedure for appointing specialized repair and restoration units for the restoration of damaged weapons and military equipment has been improved.

The peculiarity of the proposed procedure is that it is based on the distribution of damaged weapons and military equipment not only on the basis of the capacity of certain repair and restoration units but also taking into account their compliance. The specified procedure makes it possible to select those repair and restoration units that could allow for an increase in the level of restoration of damaged weapons and military equipment by 20 %.

The scope of practical application of the improved procedure is the management processes of the technical support system of troops when planning measures to restore damaged weapons and military equipment

Keywords: optimal distribution, restoration of weapons and military equipment, method of two functions

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DEVISING A SCIENTIFIC-METHODICAL APPARATUS FOR THE APPROPRIATE DISTRIBUTION OF DAMAGED WEAPONS AMONG SPECIALIZED REPAIR AND RESTORE UNITS

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1. Introduction

The results of analysis of recent military conflicts proved the important role of management processes related to ensuring the stability of the functioning of a group of troops (forces). A feature of modern military conflicts is the increasing dependence of the results of the operation not only on fire, maneuver, and shock capabilities [1–4] but also on the capabilities

of ensuring stability. Stability means the ability to function of a group of troops (forces) under the influence of negative factors, in particular, the influence of the enemy.

The main measures to enable stability of the functioning of a group of troops (forces) are the formation of reserves [1, 3], protection from the influence of the enemy [2, 3], repair and restoration of weapons and military equipment (WME) [4]. Taking into account the essence of these measures, it is necessary to note that the formation of reserves and protection against the influence of the enemy are measures that are organizationally combined with the command of the tactical and operational levels. In addition, the influence of these processes is noticeable directly during the conduct of hostilities. It is clear that these processes dynamically adapt to the conditions in the practical plane and attract more attention of scientists in the theoretical plane. However, it should be noted that the repair and restoration of WME is no less, and sometimes a more important process.

The results of analysis of recent military conflicts [5–7], and especially of the Russian-Ukrainian war, indicate certain problems associated with the repair and restoration of military equipment. In particular, the problem is the increase in the range of WME in the troops, correspondingly, the increase in the number of approaches to the repair and restoration of WME. This problem is due to the fact that when the capabilities of a separate repair and restoration body increase, the number of specialists and equipment of this body increases and, accordingly, the size of the body itself increases. This leads to a decrease in maneuverability and the ability to camouflage, and an increase in maintenance costs. Also, this can lead to the possibility of downtime of individual elements of this body, or their incomplete loading.

At the same time, a possible solution to this problem could be the formation of separate highly specialized teams. This could provide greater opportunities for masking and mannerism. However, there is a significant problem associated with the management processes of such a system of repair and restoration of WME. In particular, the issue is related to the appropriate distribution of damaged WME among highly specialized repair and restoration units. Solving this problem would ensure the necessary level of stability of the functioning of the grouping of troops (forces) and significantly reduce the losses and costs associated with the repair and restoration of WME.

Thus, the management processes of complex systems of military purpose have a problem related to the need for appropriate distribution of damaged WME among highly specialized repair and restoration units and the lack of a corresponding adapted methodical apparatus. Therefore, taking into account the urgent need to restore and repair damaged WME and the difficulty of expedient distribution of such WME among relevant units, overcoming this problem is urgent.

2. Literature review and problem statement

In paper [8], an improved methodology for evaluating the WME restoration system is proposed, which is based on taking into account the probability and intensity of detection of damaged WME samples. The proposed approach makes it possible to determine the capabilities of the repair and restoration units of the mechanized brigade in carrying out repair work and to substantiate the rational structure of the WME restoration system for the required military unit. However, this approach takes into account only a certain grouping of troops (mechanized brigade), and also does not make it possible to carry out an appropriate distribution of damaged WME among the relevant units.

In work [9], the method of forecasting the volume of losses of WME in an operation (battle) is highlighted. This method is based on taking into account the influence of the initial ratio of the combat potential of the parties and the level of personnel of the troops (forces). The specified method allows taking into account the influence of the degree of protection of the troops, the degree of enemy fire damage, and operational damage. However, the proposed method does not allow determining the types of WME for its further distribution among individual repair and restoration units.

In study [10], a mathematical model for evaluating the effectiveness of the operation of the WME recovery system is proposed, which is based on a semi-Markov model of operation of the WME recovery subsystem. The proposed model makes it possible to determine the time of the WME recovery subsystem in the appropriate state, the time of operation until the moment of transition to the next state. However, the specified model does not take into account the state of appropriate distribution of the damaged WME among the relevant units.

In paper [11], a method of modeling the process of the operation of the system of restoration of WME of a group of troops is proposed, which is based on the method of aggregated modeling. The proposed method makes it possible to display the structure of processes, in particular, maintenance, deployment and readiness for use, provision of the necessary material resources, restoration of the operational efficiency of WME in the event of combat damage. However, the proposed method does not take into account the process of expedient distribution of the damaged WME among individual repair and restoration units.

In work [12], an analysis of the development of mobile means of maintenance and repair of military automobile equipment was carried out. The proposed analysis was carried out on the basis of a comparison of the modern fleet of mobile vehicles for the maintenance and repair of military vehicles. It was established that the tactical and technical characteristics of mobile maintenance and repair equipment do not ensure the effective restoration of military vehicles in full under modern conditions. It was established that this is connected with the increase in the range of samples of military automotive equipment, the moral and physical aging of mobile means of maintenance and repair. However, the work did not investigate the need for separate specialized repair and restoration units by types of WME for further distribution of damaged WME among them.

In [13], a methodical approach to substantiating the composition of the repair and restoration units of an operational group of troops in a defense operation is proposed. The proposed methodical approach is based on the solution of the optimization problem of integer nonlinear programming to minimize the costs of repair and restoration of WME. However, the proposed approach is based on the assumption that all repairable units are the same, which makes it impossible to use it in the appropriate distribution of damaged WME among specialized units.

Paper [14] presents an overview of approaches related to the restoration of damage in battle. These approaches are based on previous research projects conducted for the US Department of Defense, including reports on the experience of repairing damage to WME during Operation Desert Storm. This work examines the importance of combat damage

recovery, the challenges it poses, and the challenges and actions associated with improving combat damage recovery capabilities. However, the paper does not consider approaches to the expedient distribution of damaged equipment among specialized repair and restoration units.

Paper [15] discusses the possibilities of developing the temporary repair system and its corresponding integration into the maintenance system of individual armies of the North Atlantic Alliance. The work proposes an approach to involve a complex spare parts supply system in temporary repairs using optimization methods to determine the optimal stock and time required for spare parts supply. However, the approach proposed in the paper regarding the optimal distribution of spare parts is appropriate in cases of a relatively small range of WME. At the same time, approaches regarding the use of specialized repair and restoration units have not been considered.

Paper [16] describes the organizational and technical conditions associated with the implementation of a system of expedient repairs of military equipment. Also, the paper considers the processes of unification and adjustment of equipment in design and production chains, proactive diagnostics, procedural conditioning, training, technology, and temporary repairs. However, the paper does not consider the process of distributing damaged WME according to their range among repair and restoration units.

Study [17] reports a systematized procedure for making optimal decisions regarding the management of assessment and restoration of damaged WME. The approach is based on statistical data collected in real combat operations. In this study, three mathematical decision-making models for the operational management of the restoration of damaged WME are considered. Solutions to the problems of optimized deployment, task allocation, and selection of resource formation schemes are presented. However, the study did not consider cases with a relatively large number of WME and the appropriateness of the proposed model in this case.

Therefore, our review of literature on the restoration of military equipment damaged during hostilities reveals that available studies consider cases of a relatively small number of military equipment, consider different types of military equipment as homogeneous. That is, the unsolved problem of the theoretical plan is the lack of adaptability of the existing scientific and methodological apparatus to the expedient distribution of damaged WME of various types among specialized repair and restoration units.

3. The aim and objectives of the study

The purpose of our study is to devise a scientific and methodological apparatus for the expedient distribution of damaged WME of various types among specialized repair and restoration units to increase the degree of realization of the capabilities of these units. This will make it possible to reduce the time for the restoration of damaged WME and improve the efficiency of repairing and regenerating units.

To achieve the goal, the following tasks were set:

– to develop an algorithm for the appropriate distribution of damaged WME among specialized repair and restoration units;

– to improve the procedure for appointing specialized repair and restoration units for the restoration of weapons and military equipment.

4. The study materials and methods

The object of this study is the process of distribution of damaged WME of various types among specialized repair and restoration units.

The main hypothesis assumes that the distribution of damaged WME of different types among specialized repair and restoration units, which takes into account the heterogeneity of both WME samples and repair and restoration units, makes it possible to increase the efficiency of the functioning of these units.

The main assumption adopted in the research: the number of types of specialized repair and restoration units corresponds to the number of groups of types of WME, taking into account the design features of WME by certain developers. That is, groups of types of WME should be further divided into subgroups according to structural features.

The main simplification adopted in the work is as follows: the distribution of damaged WME among specialized repair and restoration units occurs discretely, that is, at a certain point in time.

The work uses approaches from the theory of mathematical programming, in particular the method of nonlinear integer programming «method of two functions» [18–20].

The essence of the «method of two functions» is to find the optimal solution to problems where the constraints are integer constraints, which are described by nonlinear objective functions of both the consumer and the resource. The main idea of the method is that the problem of nonlinear programming is transformed into a sequence of problems of linear programming, where at each step one of the two functions approximating the function of nonlinear programming is optimized. That is, this optimization of one of the two functions maximizes the suitability function of a certain type of resource to meet the needs of a certain consumer (F) [18–20]:

$$F=\sum_{\gamma=1}^{S}\Theta_{\gamma}\left(1-\prod_{j=1}^{N}\left(1-\omega_{\gamma j}\right)\right), \tag{1}$$

where γ is the resource number indicator; S is the number of resource sources; Θ is the coefficient of importance of a certain resource source; j – indicator of the consumer number of a certain type; N is the number of consumers of a certain type; ω is the probability of satisfying the consumer's need with a certain type of resource.

The main limitation: in one step, one consumer is assigned to one resource source, and the resource number indicator takes on values from 1 to N:

$$\sum_{\gamma=1}^{S}\vartheta_{j\gamma}=1, j=1.....N, \tag{2}$$

where ϑ is an indicator of assigning a certain consumer to a certain source of resources.

Basic conditions: the components of the assignment matrix $\|\vartheta^0\|$ take on values 1 or 0, the probability of not hitting the target is between 0 and 1, the coefficient of importance of the target is greater than 0:

$$\left.\begin{array}{l}\vartheta_{j\gamma}\in\{1,0\},\\ 1\geq\left(\varepsilon_{j\gamma}=1-\omega_{j\gamma}\right)\geq 0,\\ \Theta_{\gamma}>0.\end{array}\right\}\begin{array}{l}j=1...N,\\ \gamma=1...S.\end{array} \tag{3}$$

The general procedure for applying the method of two functions includes several stages.

At the first stage, the normalized shares of the importance coefficients of each resource source are calculated [20]:

$$R_\gamma^{(t)} = \frac{\Theta_\gamma^{(t)}}{\sum_{\gamma=1}^{S} \Theta_\gamma^{(t)}}, \quad (4)$$

where t is the calculation step number; S is the number of resource sources at a certain step of calculations.

At the second stage, one determines the $\Delta_{k_t\gamma_t} = \max_{k,\gamma} \Delta_{k\gamma}$, $a_\gamma^0 = \prod_{j=1}^{N} \varepsilon_{j\gamma}$, $\gamma = 1...S$, elements of the current matrix of values of the degree of correspondence of a certain source to a certain consumer $\| \Delta_{kl}^{(t)} \|_{NS}$ according to formula (5) [18–20]:

$$\Delta_{k\gamma}^{(t)} = R_\gamma^{(t-1)} \omega_{kl} - \sum_{\gamma}^{S} \frac{R_\gamma^{(t-1)} \omega_{k\gamma}}{\varepsilon_{k\gamma}} a_\gamma^{(t-1)}, \quad (5)$$

where $N^{(t)}$ is the set of consumer numbers not assigned to the t-th step of calculations; k is the number of consumers at a certain step of calculations.

The next stage is associated with fixing a certain consumer to a certain source of resources ($\vartheta_{k_t l_t} = 1$) according to the condition. At the next stage, the current value of the objective function F_t^+ (6) is calculated [19, 20]:

$$F_t^+ = F_{t-1}^+ + \Delta F_{k_t\gamma_t}, \quad (6)$$

where $F_0^+ = 0$.

At the next stage, the new values of the normalized shares of the importance coefficients $R^{(t)}$ (7):

$$F_0^+ R_\gamma^{(t)} = \begin{cases} R_\gamma^{(t-1)}, \\ R_\gamma^{(t-1)} \varepsilon_{k_t\gamma}, \end{cases} a_\gamma^{(t)} = \frac{a_\gamma^{(t-1)}}{\varepsilon_{k_t\gamma}},$$

and the product of the probabilities of customer dissatisfaction $a_\gamma^{(t)}$ (8) are calculated [18–20]:

$$R_\gamma^{(t)} = \begin{cases} R_\gamma^{(t-1)}, \\ R_\gamma^{(t-1)} \varepsilon_{k_t\gamma}, \end{cases} \quad (7)$$

$$a_\gamma^{(t)} = \frac{a_\gamma^{(t-1)}}{\varepsilon_{k_t\gamma}}. \quad (8)$$

Repetition of these stages takes place until the moment of full distribution of consumers, completion of resources, or achievement of the required value of the objective function.

In our study, the Microsoft Excel 2010 programming environment (USA) was used for calculations. The simulation system «JCWME» (USA) was applied to simulate combat operations and the process of damage to WME. A personal computer based on an Intel core i5-2xxx processor, 4Gb DDR3 RAM, HDD 500Gb (Taiwan) was used for data calculation.

5. Results of devising a scientific and methodological apparatus for the expedient distribution of damaged weapons among specialized repair and restoration units

5. 1. Development of an algorithm for the appropriate distribution of damaged weapons and military equipment among specialized repair and restoration units

Taking into account the peculiarities of the distribution of damaged WME among specialized repair and restoration units, it should be noted that WME have their own characteristics depending on the type, kind of troops, and manufacturer. Moreover, repair and restoration units are also adapted to perform a certain list of works. Therefore, the most expedient approach to the distribution of damaged WME among repair and restoration units is to take into account these features. In other words, both the damaged WME and the repairing and restoration units are described by non-linear functions.

Methods of nonlinear integer programming, in particular the method of two functions, are most suitable for finding the optimal distribution, taking into account the nonlinearity of the functions of both the consumer and resource.

The method of two functions makes it possible to take into account not only the benefit from assigning a certain sample of WME to the most appropriate repair and restoration body but also to take into account the loss from not assigning it to other units. Thus, the main element that is taken into account when appointing a sample of WME is the difference between the gain when assigned to a certain body and the volume of gains when assigned to other units.

In general, the input data for the proposed algorithm are capacity coefficient of the repair and restoration body (Θ); the number of repairing and restoration units (S); the number of types of damaged WME (N), and the number of samples by these types (k). Also, the input data includes the set value level of the objective function (F_{set}).

Moving on to the consideration of the stages of distribution of damaged WME among specialized repair units, it should be noted that at the first stage it is necessary to determine the capabilities of each of the specified units. This will make it possible not to overload the units and minimize the recovery time of damaged WME. It is proposed to determine the capabilities of each body through the normalized shares of workload of a certain repair and restoration body by adapting formula (4):

$$R_\gamma = \frac{\Theta_\gamma}{\sum_{\gamma=1}^{S} \Theta_\gamma}, \quad (9)$$

where γ is the number indicator of the repair and restoration body.

At the second stage, it is necessary to determine the suitability of each of the repair and restoration units for the restoration of a certain type of WME samples. It is expedient to determine this adaptability through the probability of repair of a certain sample of WME by a certain repair and restoration body (ω). It is advisable to summarize the results in a table for convenient use of these data ($\| \omega_{kl} \|_{NS}$).

At the third stage, it is necessary to determine the first matrix of gains (t=0) using the corresponding calculation dependence (5) adapted to the conditions of the problem:

$$\Delta_{k\gamma} = R_\gamma \omega_{k\gamma} - \sum_{\gamma}^{S} \frac{R_\gamma \omega_{k\gamma}}{\varepsilon_{k\gamma}} a_\gamma, \quad (10)$$

where a_γ is the product of the probabilities of not restoring the damaged WME; ε_k is the probability of non-restoration of a damaged sample of the k-type WME by the γ-th repair and restoration body.

At the fourth stage, it is necessary to determine the maximum value of winnings when assigning a certain damaged sample of WME to a certain repair and restoration body ($\Delta_{k\gamma} \to \max$).

At the fifth stage, it is necessary to enter in the matrix of assignments ($\Delta_{k\gamma} \to \max$) the corresponding sample of the WME intended for a specific repair and restoration body.

At the sixth stage, it is necessary to determine the calculation of the new values of the load share of a certain repair and restoration body (R) (9), the product of the probabilities of customer dissatisfaction (a_γ) (8) and build the next matrix of gains $\|\Delta_{k\gamma}\|_{NS}$ (10).

At the seventh stage, it is necessary to determine the current value of the objective function of ensuring the restoration of damaged WME by available specialized repair and restoration units (F) (1).

At the eighth stage, it is necessary to check the fulfillment of the condition of reaching the set level of the value of the objective function:

$$F_t \geq F_{set}, \quad (11)$$

where t is the calculation step number.

If the condition is met, the distribution stops, if the condition is not met, steps one through eight are repeated until condition (11) is met.

The general view of the structural and logical scheme of the algorithm for the expedient distribution of damaged weapons and military equipment among specialized repair and restoration units is shown in Fig. 1.

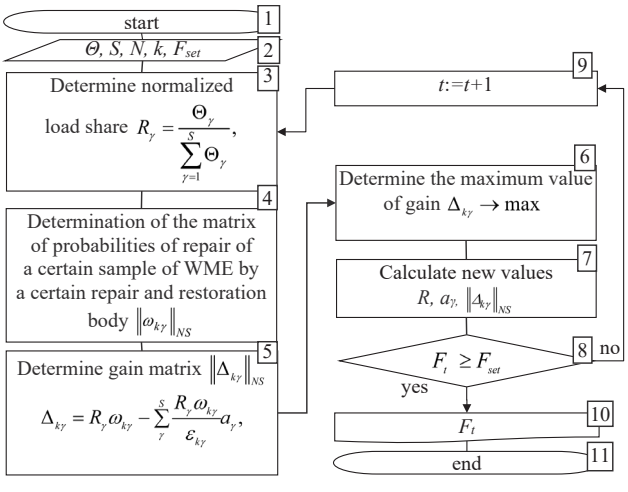

Fig. 1. General view of the structural and logical scheme of the algorithm for the expedient distribution of damaged weapons and military equipment among specialized repair and restoration units

In the specified algorithm, the most important thing is that owing to the determination of normalized shares of workload on repair and restoration units (module 3), it is possible to determine the degree of utilization of their capabilities. It is also necessary to pay attention to the fact that the distribution of damaged WME is carried out based on the application of the method of two functions (modules 4–7), which ensures optimal distribution of damaged WME among specialized repair and restoration units.

5. 2. Improvement of the procedure for the appointment of specialized repair and restoration units for the restoration of weapons and military equipment

The general characteristic of the existing procedure for the appointment of specialized repair and restoration units for the restoration of weapons and military equipment is based on the unification of the specified units for the restoration of a wide range of munitions. This was appropriate in the case when the range of WME is limited to existing samples and will not change during the armed conflict.

Also, a feature of the existing procedure for appointing specialized repair and restoration units for the restoration of weapons and military equipment is the focus on the degree of damage [21]. This allows for the distribution of damaged equipment according to clear criteria and relatively quickly. However, the specified procedure leads to a quantitative increase and a qualitatively different filling of existing units with equipment. This somewhat complicates the functioning of the existing system under the conditions of hostilities and significantly increases the cost of restoring the WME [22]. Therefore, the transformation of the system of repair and restoration of WME is taking place in the direction of the creation of specialized repair and restoration units. However, the existing criterion of the degree of damage does not allow rational distribution of damaged WME.

At the same time, the technological cycle of WME recovery is divided into operations of certain stages, which ensures bringing the WME sample into a workable state with bringing the main parameters to the established standards [23]. That is, taking into account the specified cycle, it can be stated that certain specialized repair and restoration units have different degrees of suitability for the restoration of this or that sample of WME. In other words, certain units can restore the WME sample only to a minimally functional state, other units can provide a greater number of restored functions of the WME sample, others – full recovery. That is, it is necessary to take into account the heterogeneity of both WME samples and repair-restore units in the existing procedure.

Thus, in order to improve the procedure for appointing specialized repair and restoration units for the restoration of WME, it is proposed to introduce a tabular method of applying the method of two functions. The general form of implementation of the tabular method is given in Table 1.

The input data for the specified technique (Table 1) is a set of probabilities of restoration of damaged WME by a certain repair and restoration body (Table 2).

The results of the calculations, in particular regarding the assignment of the repair and restore body according to a certain sample of damaged WME, are proposed to be entered in the appropriate matrix of assignments ($\|\vartheta_{j\gamma}\|_{NS}$) (Table 3).

In order to check the suitability of the proposed improved procedure for the appointment of specialized repair and restoration units for the restoration of damaged WME, it is suggested we consider an example. The initial data is the conduct of a defensive operation by an operational-tactical grouping of troops under conditions of direct contact with the enemy. The number of repair units, S=5. By types: repair of automobile equipment of domestic production – 1, production of partner countries – 1; repair of artillery weapons of domestic production – 1, production of partner countries – 1; repair of armored vehicles of domestic production – 1. Capacity coefficient of the repair and restoration body: Θ_1=2, Θ_2=1, Θ_3=2, Θ_4=1, Θ_5=2. Number of types of damaged WME, N=5. By types: automotive equipment of domestic production, automotive equipment of partner countries, artillery weapons of domestic production, artillery weapons of partner countries, armored vehicles of domestic production. Moreover, automobiles of domestic production (GAZ-66), n_1=3; automobiles of partner countries (DAF YAZ-2300) n_2=2. Artillery weapons of domestic production (BM 21) n_3=1, artillery weapons produced by partner countries (M777) n_4=2. Armored vehicles of domestic production (T-64BM «Bulat») n_5=2. The set level of restoration of the damaged WME (value of the objective function), F_{set}=0.96.

Table 1

Tabular technique of the improved procedure for the appointment of specialized repair and restoration units for the restoration of damaged samples of WME

Step number	Damaged WME		Number of the repair and restoration body			Maximum value of the function for each type of weapons and military equipment	Assigned repair and restoration body according to the type of weapons and military equipment	Maximum value of the objective function
			1	.....	S			
	Type	Number	Capacity factor					
			$\Theta_1^{(0)}$	...	$\Theta_\gamma^{(0)}$			
			Normalized fraction of the coefficient					
			$R_1^{(0)}$	...	$R_\gamma^{(0)}$			
1	1	n_1	$\Delta_{1,1}^{(1)}$	...	$\Delta_{1,\gamma}^{(1)}$	$\max\limits_{1,\gamma}\Delta_{1,\gamma}^{(1)}$	$\vartheta_{k\gamma}^{(1)}$	$\max\Delta_{k\gamma}^{(1)}$
	...	...	...	...	...	...		
	N	n_k	$\Delta_{k,1}^{(1)}$	...	$\Delta_{k\gamma}^{(1)}$	$\max\limits_{k\gamma}\Delta_{k\gamma}^{(1)}$		
	$R^{(1)}$		Normalized fraction of the coefficient in the first step of calculations			Current objective function value		
			$R_1^{(1)}$	...	$R_\gamma^{(1)}$	$F^{(1)}=\max\Delta_{k\gamma}^{(t)}$		
t	1	n_1	$\Delta_{1,1}^{(t)}$	...	$\Delta_{1,\gamma}^{(t)}$	$\max\limits_{1,\gamma}\Delta_{1,\gamma}^{(t)}$	$\vartheta_{k\gamma}^{(t)}$	$\max\Delta_{k\gamma}^{(t)}$
	...	...	...	...	...	...		
	N	n_k	$\Delta_{k,1}^{(t)}$	..	$\Delta_{k\gamma}^{(t)}$	$\max\limits_{k\gamma}\Delta_{k,\gamma}^{(t)}$		
	$R^{(t)}$		Normalized fraction of the coefficient at t step of calculations			Current objective function value		
			$R_1^{(t)}$	...	$R_\gamma^{(t)}$	$F^{(t)}=F^{(t-1)}+\max\Delta_{k\gamma}^{(t)}$		

Table 2

Probability of restoration of damaged WME by a certain repair and restoration body ($\omega_{k\gamma}$)

Type of damaged WME	Number of damaged WME samples	Number of the repair and restoration body, (S)		
		1	...	S
1	n_1	ω_{11}	...	$\omega_{1\gamma}$
...	...	...	...	...
N	n_k	ω_{k1}	...	$\omega_{k\gamma}$

Table 3

Matrix of assignments of specialized repair and restoration units for restoration of damaged samples of WME

Number of the damaged sample of WME	Number of the repair and restoration body, (S)		
	1	...	S
1	$\vartheta_{1,1}$	...	$\vartheta_{1,\gamma}$
...	...	...	...
n_k	$\vartheta_{k,1}$	...	$\vartheta_{k,\gamma}$

The corresponding probabilities of restoration of the damaged WME by a certain repair and restoration body ($\omega_{k\gamma}$) are given in the table (Table 4).

Applying the proposed improved procedure for the appointment of specialized repair and restoration units for the restoration of damaged WME using the tabular method (Table 1) yielded the following results (Table 5).

Table 4

Probability of restoration of damaged WME by a certain repair and restoration body under the conditions of conducting a defense operation

Type of damaged WME	Number of damaged WME	Number of the repair and restoration body				
		1	2	3	4	5
GAZ-66	3	0.99	0.7	0.4	0.3	0.4
DAF YAZ-2300	2	0.6	0.98	0.3	0.5	0.3
BM 21	1	0.5	0.4	0.99	0.7	0.4
M777	2	0.1	0.2	0.7	0.99	0.5
T-64BM	2	0.3	0.2	0.3	0.5	0.98

According to the results of the improved procedure for the appointment of specialized repair and restoration units for the restoration of damaged WME using a tabular method (Table 5), a table of appointments of specialized repair and restoration units for the restoration of damaged WME samples was formed (Table 6).

Analysis of our results reveals that with the available forces and means it was possible to achieve the established level of restoration of damaged WME (objective function value), F_{set}=0.96 at the eighth step. At the same time, the capacities of the existing repair and restoration units will not be enough to restore two damaged samples of anti-tank weapons, in particular: the T-64BM «Bulat» battle tank and the M777 light towed howitzer. That is, the application of the improved procedure makes it possible not only to carry out an appropriate distribution but also to determine the need for additional repair and restoration units.

Table 5

Improved procedure for the appointment of specialized repair and restoration units for the restoration of damaged WME

No.	Type of damaged WME	Number of samples	Number of the repair and restoration body					Maximum function value	Assigned repair and restoration body		Maximum value of the objective function
			1	2	3	4	5				
			Capacity Factor								
			2	1	2	1	2				
			Normalized shares								
			0.25	0.13	0.25	0.13	0.25				
1	GAZ-66	3	0.25	0.07	0.08	0.02	0.08	0.25	0	0	0.25
	DAF YAZ-2300	2	0.14	0.12	0.06	0.05	0.06	0.14	0	0	
	BM 21	1	0.11	0.04	0.25	0.07	0.09	0.25	3	3	
	M777	2	0.01	0.01	0.16	0.12	0.11	0.16	0	0	
	T-64BM	2	0.03	–	0.03	0.01	0.24	0.24	0	0	
2	Normalized shares		0.25	0.13	0.00	0.13	0.25	Results			
	GAZ-66	3	0.25	0.07	–	0.02	0.08	0.25	1	1	0.49
	DAF YAZ-2300	2	0.14	0.12	–	0.05	0.06	0.14	0	0	
	BM 21	–	0.12	0.05	0.00	0.09	0.10	–	0	0	
	M777	2	0.01	0.01	–	0.12	0.11	0.12	0	0	
	T-64BM	2	0.03	–	–	0.01	0.24	0.24	0	0	
3	Normalized shares		0.00	0.13	0.00	0.13	0.25	Results			
	GAZ-66	2	0.00	0.07	–	0.02	0.08	0.08	0	0	0.74
	DAF YAZ-2300	2	–	0.12	–	0.05	0.06	0.12	0	0	
	BM 21	–	0.00	0.05	0.00	0.09	0.10	–	0	0	
	M777	2	–	0.01	–	0.12	0.11	0.12	0	0	
	T-64BM	2	–	–	–	0.01	0.24	0.24	5	5	
4	Normalized shares		0.00	0.13	0.00	0.13	0.01	Results			
	GAZ-66	2	0.00	0.07	–	0.02	–	0.07	0	0	0.86
	DAF YAZ-2300	2	–	0.12	–	0.05	–	0.12	0	0	
	BM 21	–	0.00	0.05	0.00	0.09	0.00	–	0	0	
	M777	2	–	0.01	–	0.12	–	0.12	4	4	
	T-64BM	1	–	–	–	0.01	0.00	0.01	0	0	
5	Normalized shares		0.00	0.13	0.00	0.00	0.01	Results			
	GAZ-66	2	0.00	0.07	–	–	–	0.07	1	2	0.93
	DAF YAZ-2300	2	–	0.05	–	–	–	0.05	0	0	
	BM 21	–	–	0.03	–	–	–	–	0	0	
	M777	1	–	0.01	–	–	–	0.01	0	0	
	T-64BM	1	–	–	–	–	–	–	0	0	
6	Normalized shares		0.00	0.06	0.00	0.00	0.01	Results			
	GAZ-66	1	0.00	0.02	–	–	–	0.02	1	2	0.95
	DAF YAZ-2300	2	–	0.01	–	–	–	0.01	0	0	
	BM 21	–	–	0.01	–	–	–	–	0	0	
	M777	1	–	–	–	–	–	–	0	0	
	T-64BM	1	–	–	–	–	–	–	0	0	
7	Normalized shares		0.00	0.04	0.00	0.00	0.01	Results			
	GAZ-66	–	0.00	0.01	–	–	–	–	0	0	0.95
	DAF YAZ-2300	2	–	0.00	–	–	–	0.00	2	2	
	BM 21	–	–	0.00	–	–	–	–	0	0	
	M777	1	–	–	–	–	–	–	0	0	
	T-64BM	1	–	–	–	–	–	–	0	0	
8	Normalized shares		0.00	0.03	0.00	0.00	0.01	Results			
	GAZ-66	–	0.00	0.00	–	–	–	–	0	0	0.96
	DAF YAZ-2300	1	–	0.00	–	–	–	0.00	2	2	
	BM 21	–	–	0.00	–	–	–	–	0	0	
	M777	1	–	–	–	–	–	–	0	0	
	T-64BM	1	–	–	–	–	–	–	0	0	

Table 6

Table of assignments of specialized repair and restoration units for restoration of damaged samples of WME

WME type	Number of WME	Number of the repair and restoration body				
		1	2	3	4	5
GAZ-66	3	1	2	–	–	–
DAF YAZ-2300	2	–	2	–	–	–
BM 21	1	–	–	1	–	–
M777	2	–	–	–	1	–
T-64BM	2	–	–	–	–	1

For comparison, it is appropriate to consider the existing procedure for the allocation of the appointment of specialized repair and restoration units for the restoration of damaged WME. According to the existing procedure, the distribution takes place in accordance with the specifications of the repair and restoration body and taking into account its workload. Moreover, the load factors are obtained by summarizing the existing experience regarding the restoration of the corresponding WME. The general distribution can be represented in the form of a table (Table 7).

Table 7

Table of assignments of specialized repair and restoration units for restoration of damaged samples of WME according to the existing procedure

WME type	Number of WME	Number of the repair and restoration body					The degree of utilization of the capabilities of repair and restoration units
		1	2	3	4	5	
Load factor		0.25	0.13	0.25	0.13	0.25	
GAZ-66	3	1/0.2	–	–	–	–	0.2
DAF YAZ-2300	2	–	2/0.1	–	–	–	0.1
BM 21	1	–	–	1/0.14	–	–	0.14
M777	2	–	–	–	1/0.12	–	0.12
T-64BM	2	–	–	–	–	1/0.2	0.2
Total							0.76

At the same time, the application of the existing procedure for the appointment of specialized repair and restoration units for the restoration of damaged WME (Table 7) will lead to the non-recovery of 4 samples of WME (in addition, two GAZ 66 trucks will also not be restored). It is advisable to represent the general increase in the degree of utilization of the possibilities of repair and restoration units in the form of a chart (Fig. 2).

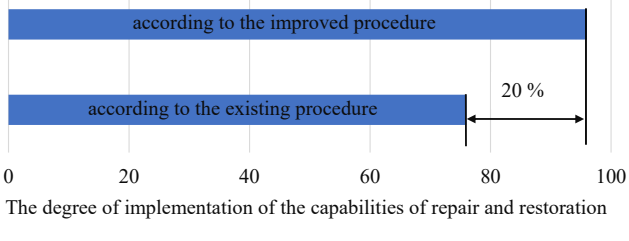

Fig. 2. Comparative analysis of the implementation of the possibilities of repair and restoration of units under the existing and improved procedure

A comparative analysis of the degree of utilization of the capabilities of repair and restoration units under the existing and improved procedure reveals that the degree of utilization of the capabilities of repair and restoration units under the existing procedure is 0.76. That is, the increase in the degree of restoration of the damaged WME, in the case of using the improved procedure, is 20 %.

6. Discussion of results of devising a scientific and methodological apparatus for the expedient distribution of damaged weapons among specialized repair and restoration units

An algorithm for the expedient distribution of damaged WME among specialized repair and restoration units is proposed ((9) to (11), Fig. 1). It has been established that its application could significantly simplify management processes regarding the distribution of damaged WME and, accordingly, would ensure stability of the operation of the troops. This is explained by the fact that the proposed algorithm provides clear criteria for the distribution of damaged WME, taking into account both the possible gain in the case of assignment and loss in the case of non-assignment (10). The application of this algorithm will make it possible to achieve the established level of restoration of damaged WME (value of the objective function) (11). This is explained by the fact that specialized repair and restoration units will receive those samples of damaged WME that most correspond to their specialization.

The essence of the developed algorithm for the expedient distribution of damaged WME among specialized repair and restoration units is the application of the nonlinear programming method to describe the functions of both the consumer and resource (5).

Moreover, samples of damaged WME act as a consumer, and repair units act as a resource (1).

Also, the proposed algorithm makes it possible to increase the degree of adaptability of the existing forces and means of restoration and repair to the restoration of damaged WME. This is explained by the fact that specialized repair and restoration units will receive those samples of damaged WME that most correspond to their specialization.

A feature of the developed algorithm of expedient distribution is taking into account the heterogeneity of both the damaged WME and the specificity of the repair and restore units. In contrast to studies [2, 5, 10, 11], in which simplifications are adopted regarding the homogeneity of repair and restoration units, the proposed algorithm takes into account their heterogeneity.

The specified feature of the developed algorithm solves the problem associated with the impossibility of appropriate distribution of a relatively large range of damaged WME. This makes it possible to adapt the existing scientific and methodological apparatus to the expedient distribution of damaged WME of various types among specialized repair and restoration units.

With regard to the limitations of the developed algorithm, it should be noted that the distribution of damaged WME must be carried out in stages, although in fact the

process of damage to WME occurs continuously. The specified limitation will not significantly affect the efficiency of distribution, this is explained by the fact that after damage, WME is grouped at the collection points of damaged WME where the degree of damage is assessed. Accordingly, the distribution of WME among the repair and restoration units takes place in stages, even according to existing approaches.

The shortcomings of the developed algorithm include the dependence of the appropriateness of the distribution on the accuracy of input data. At the same time, as one of the main elements of the input data, the probability of restoration of a certain sample of WME by a certain repair and restoration body can be determined in advance. In addition, the use of available technological cards for assessing the degree of damage to anti-aircraft guns according to the appropriate range of anti-aircraft guns, taking into account the type, kind of troops, and the manufacturer will simplify the determination of input data.

The development of the algorithm for the appropriate distribution of damaged WME among specialized repair and restoration units could be continued in the direction of the application of dynamic programming methods. This will significantly expand the limits of application of the proposed algorithm and make it possible to take into account dynamic changes in the combat situation.

The procedure for appointing specialized repair and restoration units for the restoration of the damaged WME has been improved (Tables 1–3). The essence of the improvement consists in the construction of a matrix of appointments of specialized repair and restoration units for the restoration of damaged WME samples (Table 3) based on taking into account the probabilities of restoring damaged WME by a certain repair and restoration body (Table 2). The specified procedure makes it possible to choose such a repair and restoration organ that will allow one to restore damaged WME with the maximum possibility, given the accepted conditions (Table 1). According to the conditions adopted within the example (Table 4), it is possible to achieve the established level of restoration of damaged WME, $F_{set}=0.96$, at the eighth step (Table 5). In contrast to the existing procedure, when $F_{set}=0.76$, the proposed one makes it possible to recover two more samples (Table 6). This is explained by the fact that the proposed procedure makes it possible to take into account the various capabilities of repair and restoration units.

A feature of the proposed procedure is that it is based on the distribution of damaged WME not only on the basis of the capacity of certain repair and restoration units but also taking into account their compliance (Table 5). In contrast to studies [3, 4, 6–9], in which only the capacity of repair and restoration units is taken into account. Also, this will make it possible to maximize the amount of recovered WME (Table 6).

The proposed procedure solves the problem regarding the adaptation of the existing scientific and methodological apparatus to the expedient distribution of damaged WME of various types among specialized repair and restoration units. This makes it possible to increase the degree of implementation of the capabilities of the repair and restoration units during the restoration of damaged WME.

The limitation of this procedure is the fact that the degree of restoration of damaged WME depends on the degree of adaptability of the specialized repair and restoration body to the restoration of such a sample of WME (Table 5).

The disadvantage of the improved procedure is the discreteness of the distribution of damaged WME among specialized repair and restoration units. However, it should be noted that further development of the procedure with the use of dynamic nonlinear programming approaches will make it possible to eliminate this shortcoming. It is proposed to devote further research to this.

7. Conclusions

1. An algorithm for the expedient distribution of damaged weapons and military equipment among specialized repair and restoration units has been proposed. It has been established that its application could significantly simplify the management processes regarding the distribution of damaged weapons and military equipment and, accordingly, would ensure stability of the functioning of the troops. A feature of the proposed algorithm is taking into account the heterogeneity of both damaged weapons and military equipment, as well as the specificity of repair and restoration units. In contrast to existing research. A distinctive feature of this algorithm is the lack of simplification regarding the homogeneity of repairable units and damaged weapons and military equipment. The proposed algorithm makes it possible to carry out an expedient distribution of a relatively large range of damaged weapons and military equipment. It also makes it possible to adapt the existing scientific and methodological apparatus to the expedient distribution of damaged weapons and military equipment of various types among specialized repair and restoration units. The scope of application of the proposed algorithm is management processes during the organization of comprehensive support during combat operations.

2. The procedure for appointing specialized repair and restoration units for the restoration of damaged weapons and military equipment has been improved. The essence of the improvement is the construction of a matrix of appointments of specialized repair and restoration units for the restoration of damaged samples of weapons and military equipment based on taking into account the probabilities of their restoration by this body. The specified procedure makes it possible to select such repair and restoration units that will make it possible to increase the level of restoration of damaged weapons and military equipment by 20 %. The peculiarity of the proposed procedure is that it is based on the distribution of damaged weapons and military equipment not only on the basis of the capacity of certain repair and restoration units but also taking into account their compliance. A distinctive feature of the improved procedure is taking into account the degree of adaptability of repair and restoration units to the repair of certain weapons and military equipment. The scope of application of the improved procedure is the processes of managing the system of technical support of the troops while planning measures to restore damaged weapons and military equipment.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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