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ENSURING THE EFFICIENCY OF THE SYSTEM OF TECHNICAL MAINTENANCE AND REPAIR OF TRANSPORT AND TECHNOLOGICAL MACHINES

MYKOLA HOLOTIUK[1], ANDRII SHYMKO[2], VICTOR MARTYNIUK[3], OLEKSANDR SHOVKOMUD[4]

Abstract

Current situation with the fleet of transport and technological machinery in Ukraine requires an individual approach to evaluating the effectiveness of its maintenance and repair system. The article is devoted to the issue of selecting the most effective option for the use of transport and technological machinery taking into account the specific conditions of its operation characterized by certain risks and uncertainties, and considering the real volumes and age structure of the fleet. Solving this problem requires substantiation of management models of maintenance and repair processes. It is necessary to provide scientifically based methods of managing the system of technical maintenance (TM) and repair of transport and technological machinery (RTTM) using specific methods of an individual approach to the technical and economic evaluation of the effectiveness of maintenance and RTTM processes which are adapted to the modern conditions of its operation.

The article presents the results of the research, which was carried out using the basics of system analysis, the theory of decision-making under the conditions of uncertainty, and the basics of multi-criteria analysis.

In the course of research, an analytical management model of the maintenance and repair system operation was formed that reveals the sequence of implementing the management methodology, which makes it possible to assess its state in successive discrete states, to promptly take into account the effect of external influencing factors and make corrections, which, in turn, allow increasing the validity of strategic decisions aimed at increasing the effectiveness. A numerical calculation was performed, which allowed us to conclude that the value of maintenance intervals has a significant impact on the indicator of effectiveness.

[1] Department of Construction, Road, Reclamation, Agricultural Machinery and Equipment, National University of Water and Environmental Engineering, Soborna Str., 11, 33028, Rivne, Ukraine, e-mail: m.v.holotiuk@nuwm.edu.ua, ORCID: 0000-0003-3661-4437

[2] Department of Construction, Road, Reclamation, Agricultural Machinery and Equipment, National University of Water and Environmental Engineering, Soborna Str., 11, 33028, Rivne, Ukraine.

[3] Department of Industrial Mechanical Engineering, Lutsk National Technical University, Lvivska St, 75, 43000, Lutsk, Ukraine, e-mail: martyniukviktor77@gmail.com, ORCID: 0000-0002-6914-2336.

[4] Department of Industrial Mechanical Engineering, Lutsk National Technical University, Lvivska St, 75, 43000, Lutsk, Ukraine, ORCID: 0000-0002-1702-8187.

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Adjusting this value makes it possible to optimize maintenance and repair processes.

Keywords: transport and technological machines; maintenance and repair system; efficiency; uncertainty; system approach

1. Introduction

Formulation of the problem. Transport and technological machinery (TTM) plays an important role in the operation of industrial enterprises and implementation of technological processes in agriculture. The TTM system performs transportation functions, as well as operations requiring the use of special machinery, which is equipped with technological equipment for various purposes. It should be noted that the TTM maintenance system has its own characteristics, i.e. sticking to the requirements of technological processes, for the restoration of which the technological machinery is used. In addition, TTM is often operated apart from the main bases. In order to increase the performance of TTM, it is necessary to carry out the measures aimed at maintaining and restoring its performance. Organization of the maintenance and repair system of TTM is the subject of research for many scientists [4, 11, 16]. At present, the planned preventive system for carrying out repairs and maintenance is widespread [5]. This system is based on the developed state and industry standards, and is characterized by planned technical repair services carried out with standardized periodicity.

Despite the prevalence of this system, its shortcomings should be mentioned. The measures aimed at restoring operational efficiency and the periodicity of the implementation are generalized and do not take into account the peculiarities of operation, climatic conditions that significantly affect the time of reaching the limit state of TTM.

In [15], it is emphasized that the periodicity of technical maintenance should be adjusted depending on the operating conditions and the level of TTM concentration in production.

The authors in [1, 14] also prove the need to adjust regulatory recommendations regarding maintenance periods. It is stated in the work that the structure of the fleet of cars is changing rapidly, new vehicle makes and models appear. In addition, the operating intensity varies throughout the year. These features must be taken into account when justifying the cycles of technical maintenance.

An analysis of the literature on the topic proves that simultaneously with the use of regulated normative documents for technical repair services, it is necessary to apply an individual approach to the organization of maintenance and repair systems.

This approach to the maintenance system organization will allow increasing the performance of the TTM fleet, adjust the periodicity of technical repair services, decrease costs and reduce machinery downtime.

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The most important elements of organizing the maintenance and repair system, which determine its efficiency, can be singled out:

- the site for performing technical repair services;
- the time for performing technical repair services (shift, inter-shift, lunch time);
- performers of technical repair services;
- frequency of services, number of service cycles;
- methods of machine repair.

Taking into account the design features of machines, their mobility, distance from production bases, road, material and technical conditions (availability of nearby production bases, mobile means of maintenance and repair), technical maintenance and repair of auto-tractor machinery can be carried out in stationary conditions, with the delivery of machines on its own or on a tow truck, to the place of machine operation with the help of mobile means of maintenance and repair.

The list of elements characterizing the efficiency clearly demonstrates the complexity of the maintenance and repair organization system (MROS).

To solve the main task of maintaining the technical condition of TTM, it is necessary to manage the process of maintaining their working capacity. The effectiveness of this process is determined by the MROS implementation strategy. This strategy requires the results of the analysis of the current state of the TTM fleet for the company development, as well as determining the reasons for the loss of operational efficiency. In addition, the TTM fleet consists of a wide range of machines.

It should also be noted that the efficiency of the MROS operation is influenced by cross-functional interactions of the enterprise departments providing technical maintenance and the staff professional level.

Taking into account the above, the analysis of the maintenance and repair system of transport vehicles for substantiating the ways of solving the problem of ensuring its efficiency requires a system approach.

The use of a system approach to the research allows taking into account the maximum possible number of factors affecting the functioning of MROS, and achieving the research purpose: provide the choice of the most effective options of using TTM and ensure carrying out technical maintenance and repair considering the real operating conditions and the overall service life of machines.

Reconstruction of the destroyed infrastructure in Ukraine requires the extensive use of TTM. Unfortunately, a significant amount of equipment has been destroyed. The structure of many large construction organizations, which own fleet of equipment, also underwent changes and partial destruction. TTM with not long service life is mainly involved in the operations related to the defense of the country. Therefore, worn-out machines have to be used to ensure the restoration activities. This state of affairs led to a decrease in the efficiency of their work.

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This, in turn, creates a need for improved repair and maintenance systems.

The results of research into the effectiveness of the use of technical means and repair services management are presented in the works of many authors [10, 18, 20]. The authors use the system analysis and mathematical modeling methods in their research.

The research is mainly based on the results of experimental indicators of technical operation of machines.

The situation with TTM fleet that currently exists in Ukraine requires an individual approach to evaluating the effectiveness of MROS, based on the method of solving multi-criteria problems under the conditions of uncertainty.

2. Research methods and methodology

The research was carried out using the basics of system analysis [17], the theory of decision-making under the conditions of uncertainty [2, 13], the basics of multi-criteria analysis [9, 12].

2.1. Fuzzy multi-criteria problem

To solve the problem of evaluating the MROS efficiency, an optimization criterion was chosen:

- working hours ($\mathrm{W_{hours}}$);
- specific costs for maintenance and repair (C);
- work intensity of operations ($\mathrm{W_{int}}$);
- duration of technical maintenance and repair intervals ($\mathrm{D_{TMR}}$).

It is difficult to get a solution to the problem taking into account all the criteria. MROS will be optimal if the following condition is fulfilled:

$$\begin{cases} F(W_1) = extrF(W); \\ \quad at\ W_1 \subset \vec{W}. \end{cases} \quad (1)$$

where $\vec{W}$ is a vector of optimization parameters to be controlled;
F is MROS performance indicator;
$extr$ is the procedure for finding the extremum F.

The content of the extremum search procedure is described by the correlation:

$$extr = \begin{cases} min, if\ we\ choose\ \mathrm{C}, \mathrm{W_{int}}, \mathrm{D_{TMR}}\ as\ W_1; \\ \quad max, if\ we\ choose\ \mathrm{W_{hours}}\ as\ W_1. \end{cases} \quad (2)$$

Costs C depend on the type of maintenance and on the time of the forced downtime.

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In order to analyze changes in the technical state of TTM, a discrete form of providing the indicators of MROS operation is used. For this, it is necessary to choose the value of the research period T_R = one year.

TTM maintenance is carried out regularly at certain time intervals depending on the engine hours that the machine has worked. To specify the research, a forklift truck, which is used for construction work, was accepted as a TTM object. The following technical maintenance requirements have been established for the loader (Figure 1): TM 1 – 100 engine hours; TM-2 – 1500 engine hours; TM_{month} – every month – 500 engine hours.

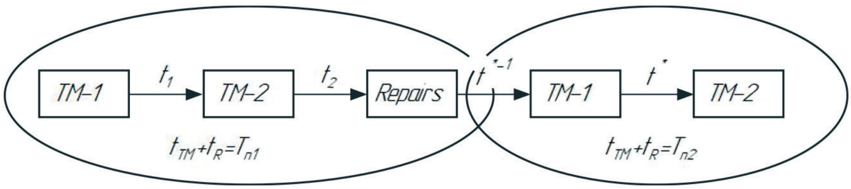

Fig.1. Scheme of discrete states: TM – technical maintenance; t_{TM} – machine downtime during maintenance, normal hours; t_R – downtime during repair, normal hours

$$\text{Downtime } t_{jTM} = \sum_{i=1}^{n} t_{ijTM} \cdot K_{ij}, \text{ hours} \quad (3)$$

where t_{ijTM} is the normative value of downtime during technical maintenance (TM);

K_{ij} is the number of TM services of the same type during the period of research.

If N number of machines of the same type are used to perform the work, then the formula for determining the duration of downtime during the i-th TM of all TTM of the same model for a discrete period will take the following form:

$$t_{jTM} = N \cdot TM_{ij} \cdot t_{ijTM}, \quad (4)$$

where TM_{ij} is the number of TM services of a certain type for the j-th TTM during the research period.

Within one discrete period, j-th TTM is characterized by the downtime period DP spent on repair works, in days:

$$DP_{jP} = \frac{t_{ij(P)} \cdot N_p}{EH}, \quad (5)$$

where $t_{ij(P)}/EH$ is an indicator of the work intensity of repair works, days/engine hours.

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N_p is the working time of TTM for a discrete period, machine hours. Taking into account the assumption that $t_{ij(P)}$ will differ for TTM with different operating periods, for a more accurate calculation we will use the specific value of the indicator $t_{ij(P)}$ of work intensity, for example $\frac{days\ (or\ hours)}{1500\ engine\ hours}$. The denominator is taken equal to the largest value according to the TM standard (15,000 engine hours for a loader). Considering the above, equation (5) will take the following form:

$$DP_{jP} = \frac{t_{ij(P)} \cdot N_{\text{П}}}{1500}, \frac{days}{engine\ hours}. \quad (6)$$

Specific work intensity of the j-th TTM:

$$t_{j(P)} = t_{j(P)} \cdot j_j, \quad (7)$$

where j_j is a conditional coefficient of transition from the maintenance period to the discrete period.

$$j_j = \frac{DP_{jP}^{P} + DP_{jP} + DP_{jP}^{`}}{\text{Т}_{\text{п}j}}, \quad (8)$$

where DP_{jP}^{P} is the time period (days or hours) when TTM performs work during a discrete period T_{DPj}

$DP_{jP}^{`}$ is the downtime period of j-th TTM during the maintenance period.

T_{DPj} is the number of days (hours) in a discrete period.

The total work intensity of the existing TTM fleet for a discrete period:

$$t_{DP} = \sum_{j=1}^{n} t_{j(P)}, \quad (9)$$

Allocating a specific time period to determine the values that evaluate the effectiveness of technical maintenance and repair allows for strategic management of TTM operation.

2.2. Methodology for assessing the performance of TTM states

Section 2.1. provides the list of MROS optimization criteria, which are subject to optimization, in order to ensure the efficiency of the MROS functioning. Accordingly, the optimization parameter is the MROS functioning performance for a certain (discrete) period.

The solution to the problem consists in determining such coefficients of relative importance C_{ij}, which ensure the maximum performance value. Fishburn method is used to determine the weighting coefficients [6, 8], which assess the n-th number of properties.

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To determine the level of performance, each parameter (optimization criterion) x_i $(i = 1, n)$ is matched with an estimate of its significance. After that, a system of weights is built in accordance with the following condition:

$$\begin{cases} \sum_{i=1}^{n} a_i = 1 \\ a_i \geq 0, i = 1, n \end{cases}, \tag{10}$$

where a_i is the weight of the i-th optimization criterion;

i is the criterion number;

n is the number of optimization criteria.

The criteria were placed in order of decreasing importance (in our research, it is the performance of MROS operation for a discrete period). After ranking, the weight indicators were determined using the Fishburn scale [6, 8].

$$a_i = \frac{2 \cdot (n-i+1)}{n \cdot (n+1)}. \tag{11}$$

Fishburn's rule (11) reflects the fact that there is no information about the level of criteria significance.

Provided that there is information about the limits of the criteria values, for example, $a_i \in \{\alpha_i - \beta_i\}$,, the following correlation is used:

$$\begin{cases} a_i = \alpha_i + \frac{1-\sum_{i=1}^{n} \alpha_i}{\sum_{i=1}^{n} (\alpha_i - \beta_i)} \cdot (\alpha_i - \beta_i); \\ i = 1, 2, \dots, n; \\ \alpha_i > \beta_i; \\ \sum_{i=1}^{n} \alpha_i \leq 1; \sum_{i=1}^{n} \beta_i \geq 1. \end{cases} \tag{12}$$

To recognize the level of membership of the selected indicators, it was necessary to obtain the membership function C_{in} (x), where x is the carrier, which is the domain of the function definition.

The larger C_{in} (x) is, the higher is the estimated degree of membership of the carrier element in a fuzzy set I.

The next step was the formation of nodal points (k_j), which determine the maximum of the membership function for each variable C_{ij} (x_{ij}).

In order to move on from a set of separate indicators to an aggregate operation efficiency indicator V_i, it is suggested to use a fuzzy multiple approach. This will make it possible to move on from verbal evaluation to the data in qualitative and quantitative presentation.

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An aggregate indicator in quantitative presentation is defined as follows:

$$q(V_i) = \sum_{j=1}^{P} k_j \sum_{i=1}^{n} a_i C_{ij}(x_{ij}), \tag{13}$$

where k_j denotes the nodal points (j = 1, 2,..., 5), a_i is the weight of the i-th factor in convolution (i = 1, 2, 3, 4);

C_{ij} (x_{ij}) is the value of the membership function of the j-th level relative to the current value of i-th factor, C_{ij} = {0.1;0.3; 0.5;0.7;0.9} [21].

The results of assessing the MROS functioning performance were carried out using a petal diagram. The construction of the diagram allows making management decisions, and is also a tool for adjusting goals.

The study of the MROS operation was conducted on the basis of the data provided by a private enterprise in Rivne. A team of experts made up of ten people, which included the enterprise head and its specialists, together with the three specialists of the "Oblavtodor" enterprise in Rivne, determined the economic performance of the MROS operation. The experts adopted a set of evaluating criteria in order to assess the level of the aggregate performance indicator. The value intervals for the fuzzy linguistic variables were chosen: very high, high, medium, low, and very low; as well a set of nodal points k_j = {0.1;0.3; 0.5;0.7;0.9} [21]. Ranking of criteria by the degree of their significance was performed. Expert opinion of the group members was formed by the method of centroid groups. Calculation of the multiple coefficient of rank correlation was performed under the condition of connected ranks ω. The coefficients were tested for significance using the Pearson criterion. The procedure of expert analysis is not considered in this article in detail, which is due to its wide coverage in literature [3, 19].

2.3. Concept of assessment of TTM MROS operation performance

It is possible to ensure the efficient functioning of TTM MROS under the condition that the maintenance organization system is adapted to the influence of the external environment and, as a result, changes in internal factors.

Taking into account what is stated in sections 2.1. and 2.2., we will generalize the suggested approaches to the analysis of the MROS operation performance and form a conceptual analytical model of a multi-criteria decision-making system in the TTM operation system with discrete states of technical maintenance and repairs (Table 1).

Tab. 1. Analytical model of MROS operation management

Stage name	Stage content
1	2
1. Preparation	1.1. Monitoring of the existing TTM fleet and determining the list of operations. 1.2. Evaluation of the requirements, restrictions and risks of the external environment. 1.3. Formation of the list of criteria for evaluating aggregated indicators to assess the performance of MROS operation (x).
2. Introduction of analytical procedures	2.1. Formation of analytical method for the extremum search – the conditions for ensuring the efficiency of MROS operation. 2.2. Calculation of the main indicators. 2.3. Formation of the term set for the selected criteria. 2.4. Determination of the significance (a_i) of the selected x_i of the TTM MROS operation performance using the expert evaluation method. 2.5. Determination of the eligibility levels of criteria $C_{ini}(x_i)$. 2.6. Calculation of the aggregate indicator of the efficiency of MROS functioning for various options of criteria ranking.
3. Analysis of results and justification	3.1. Analysis of the obtained results and the level of efficiency of TTM MROS functioning.

3. Research results

The parameters of the membership functions are defined according to [7] for the following linguistic variables: "Very low, Low, Medium, High, Very high". To describe a subset of the term set, a system of five appropriate membership functions is used:

- Membership function of the "Very low" term:

$$C_{in}(x) = \begin{cases} 1, & 0 \le x < 0.15 \\ 10 \cdot (0.25 - x), & 0.15 \le x < 0.25 \\ 0, & 0.25 \le x \le 1 \end{cases} \quad (14)$$

- Membership function of the "Low" term:

$$C_{in}(x) = \begin{cases} 0, & 0 \le x < 0.15 \\ 10 \cdot (x - 0.15), & 0.15 \le x < 0.25 \\ 1, & 0.25 \le x < 0.35 \\ 10 \cdot (0.45 - x), & 0.35 \le x < 0.45 \\ 0, & 0.45 \le x \le 1 \end{cases} \quad (15)$$

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- Membership function of the "Medium" term:

$$C_{in}(x) = \begin{cases} 0, & 0 \le x < 0.35 \\ 10 \cdot (x - 0.13), & 0.35 \le x < 0.45 \\ 1, & 0.45 \le x < 0.55 \\ 10 \cdot (0.65 - x), & 0.55 \le x < 0.65 \\ 0, & 0.65 \le x \le 1 \end{cases} \quad (16)$$

- Membership function of the "High" term:

$$C_{in}(x) = \begin{cases} 0, & 0 \le x < 0.55 \\ 10 \cdot (x - 0.55), & 0.55 \le x < 0.65 \\ 1, & 0.65 \le x < 0.75 \\ 10 \cdot (0.85 - x), & 0.75 \le x < 0.85 \\ 0, & 0.85 \le x \le 1 \end{cases} \quad (17)$$

- Membership function of the "Very high" term:

$$C_{in}(x) = \begin{cases} 1, & 0 \le x < 0.75 \\ 10 \cdot (0.75 - x), & 0.75 \le x < 0.85 \\ 0, & 0.85 \le x \le 1 \end{cases} \quad (18)$$

The results of ranking of the selected criteria and their membership according to Fishburn are shown in Table 2. As an example, there is given only the table that corresponds to the following solution search option $R_4 > R_3 > R_2 > R_1$, where R_i is the criteria ranking. The entire research considered various options for ranking the criteria, for example: $R_4 > R_3 > R_1 > R_2$; $R_4 > R_2 > R_3 > R_1$; $R_2 > R_3 > R_4 > R_1$, *etc.*

Tab. 2. Results of the performance criteria assessment

Criteria	Objective	Rank, R_i	Significance according to Fishburn
Working hours (x_1)	Max	4	0.1
Specific maintenance and repair costs (x_2)	Min	3	0.2
Work intensity (x_3)	Min	2	0.3
Duration of maintenance and repair intervals (x_4)	Max	1	0.4

The membership level matrix $q(V_i)$ is presented in Table 3.

Tab. 3. Matrix of membership levels $q(V_i)$ in a fuzzy set

Criterion	Membership Functions for the levels of economic performance				
	High q_1	Very high q_2	Medium q_3	Low q_4	Very low q_4
x_1	1	0	0	0	0
x_2	0	1	0	0	0
x_3	0	1	0	0	0
x_4	0	1	0	0	0

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The matrix columns are quality levels: high, very high, medium, low, and very low; terms are the performance assessment criteria; intersection – membership levels of qualitative levels.

An aggregate indicator for assessing the performance of MROS was determined according to (13). The results are shown in Table 4.

Tab. 4. Results of an aggregate indicator of MROS operation performance assessment

Nodal points K_j	Internal convolution $\sum_{i=1}^{n} a_i C_{ij}(x_{ij})$	Aggregate indicator $q(V_i)$
0.9	0.9	0.88
0.7	0.1	
0.5	0	
0.3	0	
0.1	0	

Similarly, the calculations were made for other cases of criteria ranking. The diagram (Figure 2) shows only some options.

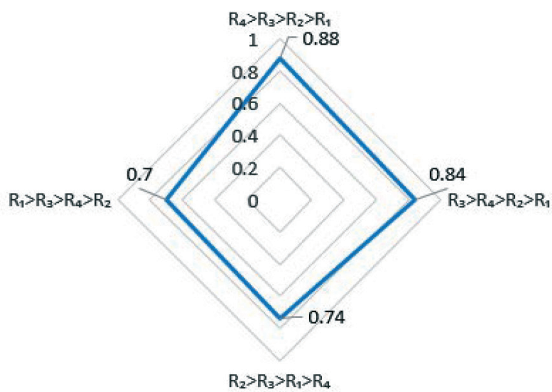

Fig. 2. Results of assessing the performance of MROS discrete states

4. Conclusions

Currently, the TTM fleet in Ukraine has significantly decreased against the background of a significant increase in the volume of works that require its use. In connection with this, the following problems arise: reduction of the resources and service life of TTM; increase in maintenance and repair costs. Solving these problems requires finding the ways to increase the MROS operation performance.

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In the course of research, an analytical management model of the MROS operation was formed, which reveals the sequence of implementation of the management methodology. The introduction of the methodology ensures the implementation of a multi-level assessment of the efficiency of MROS operation. The advantage of the suggested methods is the possibility of evaluating the state of MROS in successive discrete states, which will allow to quickly consider the effect of external influencing factors and make necessary corrections.

A numerical calculation was performed, which made it possible to obtain a performance indicator in the form of an average value weighted by all the criteria and their qualitative levels. The diagrams constructed on the basis of the calculation data prove the correctness of the selected criteria for assessing the performance of MROS operation and allow us to conclude that the duration of the MROS maintenance intervals has a significant impact on the performance indicator.

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