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Increasing the reliability of machines and the efficiency of their use in transportation processes in agro-industrial production using service logistics methods

The article considers the problem of increasing the reliability of machines and the efficiency of their use when transporting agricultural products. Increasing the reliability of machines at agro-industrial production enterprises is considered on the basis of improving the strategy of their technical maintenance and repair. At the same time, logistic service methods are used to provide the fleet of cars with the necessary spare parts.

The theoretical justification of the formation of the composition of spare parts at the enterprise, its limitations and the supply system is given. It is noted that in the processes of providing the necessary spare parts, the logistics center takes control. The main factors affecting the efficiency of spare parts supply organization have been identified. On the basis of the cost function, optimal management based on logistic models is considered. Comparative analysis proved the advantage of the developed system of technical maintenance and repair along with the existing planned preventive system. This is, first of all, an increase in the probability of trouble-free operation and the availability ratio of KamAZ vehicles and mobile agricultural and mobile agricultural machinery of the John Deere family.

machine reliability, transportation, agricultural production, service logistics, logistics control center, spare parts, technical condition, information support, maintenance

Formulation of the problem. When improving the system of technical maintenance and repair of machines (TM and R) and increasing their reliability and efficiency of functioning in agro-industrial production (AIP), it is important to use the methods of service logistics. These are primarily systems for the delivery of spare parts (SP), formation of the nomenclature of SP and the management of their stocks in the warehouses of waste disposal companies that use and service the park cars These questions relate to the service logistics of providing mobile agricultural machinery (MACM) while increasing their reliability and efficiency of use.

Analysis of recent research and publications. From the analysis of literary sources, it follows that the data in service logistics was conducted purely mathematically, since the theory of stock formation and management is one of the branches of applied mathematics [1,2]. To date, a description of the logic of stock movement and the methodology of modeling the state of the stock management system is given [3].

The content of the structure of the MACM is associated with large financial and management costs, but the efficiency of the enterprises that operate the MACM directly depends on it. The lack of necessary spare parts in the warehouse leads to the downtime of the equipment during its repair. But the excess volume of stocks also reduces the performance indicators of the enterprise. Parts stored in the warehouse may become unusable or illiquid. Both domestic and foreign scientists and practitioners dealt with issues of improving various aspects of stock management. Among them, a prominent place is occupied by the works of O.P. Antoniuk [4], V.V. Bilichenko [5], A.V. Bazhinova [6], O.P. Kravchenko [7,8], L.O. Litvyshka [9,10]. Abroad, Y. Liu, Z. Peng [11], Donald J. Bowersox [12], F. Zhao, Z. Tian, Y. Zeng [13] and others dealt with inventory management problems and related issues in service logistics. Scientists such as V.V. Lukinsky [1], A.P. Polyakov [14-19] and others. A number of methods and models characterizing the management of individual parts of the inventory system are proposed. However, in order to ensure effective management of the inventory of enterprises serving and operating MACM, a management model is needed that would systematically cover all sides of the issue related to inventory management and the specifics of this industry.

The improvement of the management system of the SP should be based on a logistic approach that ensures the unity of supply, production and sales, management of material resources [20-24].

A rule for choosing optimal stock management strategies and an algorithm for their adaptation in accordance with the changes in the parameters of the Poisson distribution of demand for SP as a function of the superposition of probability distributions are proposed, which makes forecasting the need for SP more universal. Seasonality of demand, age of the fleet of vehicles, and market conditions are the factors affecting the need for MACM in the SP. At that time, the method proposed by him for determining the need for SP based on the determination of the optimal size of the order according to the criterion of minimizing costs for stock storage based on the Wilson formula is ineffective. In practice, for the most part, the method of forecasting the need for SP MACM is based on building a trend, taking into account seasonal fluctuations. Logistic service methods are used in the improved maintenance and repair system by a team of scientists under the leadership of Professor V.V. Aulin [20-22, 25-28]. The works emphasize the effectiveness of this direction of research.

Setting objectives. The purpose of this work is to increase the reliability of machines and the efficiency of their use in AIP on the methods of service logistics, which is connected with the provision of the machine park with the necessary amount of SP and the logistics supply system itself.

Presentation of the main material. The system of management of supplies of the SP deals with MACM, dispersed among waste disposal enterprises in the territory of the region of operation. At the same time, they form a flow of failures and service needs, which form the incoming flow of requests to the logistics supply management system.

The main objects of the system of managing the supply of hazardous materials in the AIP are:

– MACM, which can be in one of three states: working, faulty, and a call is planned;

– the maintenance and repair system at the waste disposal enterprise, which provides service to the MACM, using logistics service methods.

The system of supply management of the public sector is considered as a closed system of mass service (SMS), in which processes occur that are caused by the combined action of random variables. During modeling, there is a need to determine the quantitative characteristics of the distribution laws of random variables, which are their parameters. Among them is the intensity of the incoming flow of appeals on the SP. Since this value can be determined through reliability indicators of the served MACM, it is of interest to study the dynamics of changes in this flow.

The random nature of the change in factors affecting the research parameters determines the choice of the research method and the assessment of the accuracy of the obtained results: to obtain reliable values of the parameters characterizing the random processes in the logistics service system, it is necessary to conduct experimental studies and generalize their results.

The PC application package provides a high-level interface for quickly creating discrete-event models using block diagrams.

The management of the supply of goods in the network of the service center is a complex model that combines the discrete-event and agent models, which describe models of objects that are different in nature. Modeling in this case requires the use of different approaches.

The construction of a discrete-event model requires the presence of a certain number of state variables characterizing it at the current moment of model time, as well as a list of planned events that must occur in the model. For such a model, the order in which events occurring in the model time will be processed is important. If any event happens sooner or later than was planned when building the model, the simulation results may be incorrect. In addition, as a general rule, the simulation environment should provide good repeatability of the simulation results.

As an agent in the model, an MACM unit, of a certain configuration and modification, operated at this waste disposal plant, acts as an agent. The model is implemented using a set of states in which the MACM is:

- a stable state of MACM performance with a certain mileage - state 1;

– failure of a unit, system, unit or part of MACM from group 1 with a certain mileage during the run-in period, which requires repair (non-working state of the machine) – state 2;

– failure of a unit, system, unit or part of MACM from group 2 with a certain mileage during the run-in period, which requires repair (non-working state of the machine) – state 3;

– failure of a unit, unit, system or part of MACM from group 3 with a certain mileage, operational..., requiring repair (inoperative state of the machine) – state 4;

– failure of a unit, system, unit or part of MACM from group 1 with a certain mileage during normal operation, which requires repair (non-working state of the machine) – state 5;

– failure of a unit, system, unit or part of MACM from group 2 with a certain mileage during regular operation, which requires repair (non-working state of the machine) – state 6;

– failure of a unit, unit or part of MACM from group 3 with a certain mileage during normal operation, requiring repair (non-working state of the machine) – state 7;

– the planned appeal of the AIP enterprise to the service center (SC) due to the failure of a node, system, unit or part of the MACM from group 1 at a certain mileage during the period of regular operation (operable condition of the machine, repair is planned) – state 8;

– a planned application of the waste disposal company to the SC due to the failure of a node, system, unit or part of the MACM from group 2 on a certain mileage during the period of regular operation (operable condition of the machine, repair is planned) – state 9;

– a planned appeal of the waste disposal company to the SC due to the failure of a node, system, unit or part of the MACM from group 3 on a certain mileage during regular operation (operable condition of the machine, repair is planned) – condition 10;

– expiration of the MACM service warranty and the car is removed from the model – state 11.

A synchronization algorithm is used to transfer model flows based on a logistic approach from a discrete-event model to an agent model. For each specific model, there is an algorithm that allows you to achieve the maximum efficiency of use, the quality of which depends on the gain as a result of synchronization.

Let us have a logistics service management center (LSC), from which batches of SP are distributed to waste disposal enterprises in the amount of q_{ij}, $i=\overline{1,N}$, $j-\overline{1,M}$, N – the total number of items in the batch of SP supplies. Deliveries are carried out in sets of the *i*- th name of the SP, which can be considered a generalized nomenclature.

The level of stock in the warehouses of the LSC point decreases in accordance with the intensity of service requests, which in turn correspond to λ_{ij} the intensity of failures of their parts, assemblies and aggregates at the j -th AIP enterprise, where MACM is operated and repaired.

On the basis of the value λ_{ij}, it is planned to apply for reclamation enterprises for the planned period t_p. After reaching the time τ-point of the realization of the delivery of batches, which depends on the distance of the j-th enterprise from the LSC of the LSC, as well as after the existing stock k_{ij} in the warehouses of the SC reaches the Z_{ij} value of the non-decreasing stock and the i-th nomenclature of the LSC at the j-th enterprise, the AIP LSC delivers in volume q_{ij} with the lowest costs g_{ij}. In conditions of random demand, the model does not include the periodicity of deliveries. Instead, the values of the total number of deliveries B for a certain period (year) are used.

With the help of planning requests of the j-th AIP enterprise, the stock of stored SP, which are replenished by the LSC, relative to the calculated intensity of failures and their details . Additional costs are associated with each such top-up. When minimizing costs for the storage period and fines are calculated based on the expected balance (deficit) until the end of the specified period (year). First of all, the LSC bears the costs S_{ij} of storing their SP, which are in the warehouse for the entire period and with the delivery of the volume of the batch g_{ij}.

Service requests are satisfied until their total volume (from the beginning of the planned period) does not exceed the initial stock. All the following requirements cannot be served immediately, which leads to the downtime of the MACM at the AIP enterprise, which operated it while waiting for maintenance and repair operations. The consequence of the downtime is lost profit for the enterprise and fines for the LSC.

The cost of the fine for the lack of the necessary spare parts in the LSC warehouse includes the excess of the costs of emergency delivery over the costs of ordinary and lost profit. The interest on their freezing due to a shortage of working capital is equal to:

$$d = \sum_{i=1}^{N} \sum_{j=1}^{M} \left(\frac{\lambda_{ij} B^2}{2g_{ij}} - \frac{1}{S_{ij}} \right). \quad (1)$$

The shortage of SP can lead to the loss of customers - waste disposal companies, if they decide to serve MACM in relation to LSC.

It is necessary to choose the moment, volume and structure of deliveries of batches of SP in such a way that the total costs of S for storage, delivery and penalty for shortage are minimal. Restrictions should be imposed on the operation of the company's warehouse: the maximum stock should not exceed the capacity of the warehouse, and its cost should not exceed a given amount. At the same time, the conditional minimum costs are determined by the formula:

$$S = (\tau - t_{\text{п}}) \cdot \sum_{i=1}^{N} \sum_{j=1}^{M} \lambda_{ij} \cdot s_{ij} \cdot k_{ij} + B \cdot \sum_{i=1}^{N} \sum_{j=1}^{M} g_{ij} \cdot q_{ij} + \sum_{i=1}^{N} \sum_{j=1}^{M} d_{ij} \cdot (N'_{ij} + q_{ij}) \cdot p_{ij} \to \min. \quad (2)$$

At the same time, there are the following restrictions:

$$\sum_{i=1}^{N} \sum_{j=1}^{M} S_{ij} - d_{ij} \sum_{i=s+1}^{\infty} p_i \geq 0; \quad (3)$$

$$\sum_{i=1}^{N} \sum_{j=1}^{M} d_{ij} \sum_{i=s+1}^{\infty} p_i \geq 0. \quad (4)$$

These restrictions are general conditions for the optimality of the stock N'_{ij}.

To ensure the minimum of the cost function under the conditions of the smallest deficit and the best values of efficiency indicators, it is necessary to calculate the optimal value of the delivery. Delivery must be made at a time equal to:

$$\tau_j = \sum_{i=1}^{N} \left(\left(\frac{q_{ij} + N'_{ij}}{\lambda_{ij}} - t_{\text{п}} \right) + g_{ij} \cdot B \right), \quad (5)$$

where the average idle time in waiting for the SP acts as an efficiency indicator Ej :

$$E_j = \sum_{i=1}^{N} \rho_{ij} / \Lambda_j , \quad (6)$$

where ρ_{ij} is the average number of applications for the replacement of the i-th defective part, node, system, or unit of the MACM in the SC for the j-th AIP enterprise; $\Lambda_j = \sum_{i=1}^{N} \lambda_{ij}$ – the total intensity of the flow of served applications according to the law of preservation of applications is equal to the intensity of the incoming flow.

The model of the system of provision of SP can be described in the form of a structure of functional relations between a varied composition of significant factors and initial parameters. In such a model, it is necessary to ensure the constancy of the reaction of "output" to "input", which must be in both static and dynamic equilibrium.

At the same time, three groups of factors are traditionally distinguished:

– which cannot be influenced;

– which can be influenced by influencing the target function;

– whose impact on the system is unknown or insufficiently studied.

Since the first and third group of factors refer to factors of the external environment and the probability of their occurrence is unknown, their fixed values are set in the model, which are not taken into account in the future. The objective function is defined as a dependence on the factors of the second group:

$$Y = f(x_1, x_2, ..., x_n). \quad (7)$$

The effectiveness of the organization of the supply of SP is determined on the basis of the indicator of the total costs for the organization of the supply of SP to ensure uninterrupted service during the warranty period. The value of the total costs for the organization of the supply and storage of raw materials in the warehouse was chosen as the objective function. The following can be attributed to the set of factors affecting this performance indicator:

x_1 – the period of early delivery of the control unit at the stage of full-time operation of the MACM during the warranty period;

x_2 – the optimal volume of delivery of the batch;

x_3 – the cost of warranty kits for MACM in relation to batches supplied to APR enterprises for MACM;

x_4 – warehouse area;

x_5 – the value of the irreducible reserve for each group of SP;

x_6 – method of delivery;

x_7 – the number of service posts in the DSC;

x_8 – the ratio of SP of each group to the total number (coefficient of grouping).

To arrange the factors according to the expected degree of influence on the efficiency indicator, the method of their ranking was used. For this, a questionnaire was used, which includes the optimization parameter, factors and levels of their variation.

From the diagram of ranks and medians of experts' opinions, it follows that the most significant factors are: x_1 – the period of early delivery of the equipment at the stage of regular operation of the warranty period; x_8 – the ratio of the number of each group to the total number in the batch; x_5 – the value of the non-reducible reserve for each group of SP; x_2 – is the optimal volume of parts for MACM supplied.

Optimal management based on logistic models consists in finding such optimal values

x_{opt1}, x_{opt2}, x_{opt5}, x_{opt8}, at which the values of the function $Y(x_1, x_2, x_5, x_8)$ are the total costs for the organization of delivery and storage The inventory in the company's warehouse will be minimal:

$$Y\left(X_1^*, X_2^*, X_5^*, X_8^*\right) \to \min . \quad (8)$$

If we conditionally rename the factors x_1, x_2, x_5, x_8 to X_1, X_2, X_3 *and* X_4, respectively , we have the function S (X_1, X_2, X_3, X_4), that is, the total costs of organization of delivery of spare parts (lots of parts) for maintenance and repair of the MACM. At the same time, the cumulative loss function is minimized:

$$S\,(X_1, X_2, X_3 X_4) = S_1 + S_2 + S_3 \to \text{min}, \quad (9)$$

where S_1 is the cost of storage of hazardous materials in the warehouse of the waste disposal company:

$$S_1 = 1/2 \cdot B \cdot \left(\tau - X_1\right) \cdot \sum_{i=1}^{N} \sum_{j=1}^{M} \lambda_{ij} \cdot h_{ij} \cdot \left(X_2 \cdot X_3\right), \quad 10)$$

where $X_1 = t_П$ is the point of delivery of the batch of SP; $X_2X_3 = k_{ij}$ – surpluses in the warehouse for each i -position of the SP.

S_2 – costs associated with the delivery of batches of MF to the warehouse:

$$S_2 = \sum_{i=1}^{N} \sum_{j=1}^{M} g_{ij} \cdot X_2 \cdot X_4, \quad (11)$$

where $X_2 \cdot X_4 = q_{ij}$ – the volume of the delivery batch of i- x items of the SP to the j -th waste disposal company where MACM is operated and serviced.

S_3 – the cost of the fine for the absence of the necessary items of the SP in the warehouse:

$$S_3 = \sum_{i=1}^{N} \sum_{j=1}^{M} d_{ij} \cdot (X_3 + X_2 \cdot X_4) \cdot p_{ij}, \quad (12)$$

where $X_3 = N_{ij}$ – the minimum stock of the *i-th* PPE in the warehouse of the j -th waste disposal company.

The use of such an improved maintenance and repair system gives the operator and service personnel more opportunities for rational use of the resource of nodes, systems and aggregates of MACM during operation, i.e. increased reliability and efficiency of use is observed. Of course, for the most effective control, it is necessary to carry out constant monitoring and correction of their technical condition. Due to the fact that with an improved maintenance and repair system, the complex of operations to maintain the operational condition of the MACM is performed according to its actual technical condition in non-regulated terms, and if necessary, the response to critical changes is more adequate. Of course, this gives advantages in solving the issue of the most optimal use of the resource of nodes, systems and aggregates by managing timely technological operations necessary in terms of type and volume. The obtained results of the study showed that diagnostic information does not always allow to objectively assess the technical condition of the unit's systems and the ranges of deviations of the values of the diagnostic parameters, which requires a demand for more specific information about the reasons for the sharp deterioration of the diagnostic parameters or the occurrence of failures of MACM nodes, systems and units.

The degree of ensuring the operational reliability of the MACM by the proposed maintenance and repair system, its effectiveness was evaluated in the AIP farms of the Kirovohrad region based on the determination of such reliability indicators as the probability of failure-free operation, availability coefficients and technical use. It was determined that the implementation of improved maintenance and on the basis of service logistics increases the probability of trouble-free operation of systems and units within 90...95%.

It was found that when the influence of the number of factors of a random nature increases, the probability of trouble-free operation of MACM decreases. The distribution of probabilities of trouble-free operation of MACM power units after performing certain technical actions with a planned preventive system (PPS) and an improved maintenance and repair system based on service logistics methods is shown in fig. 1-2.

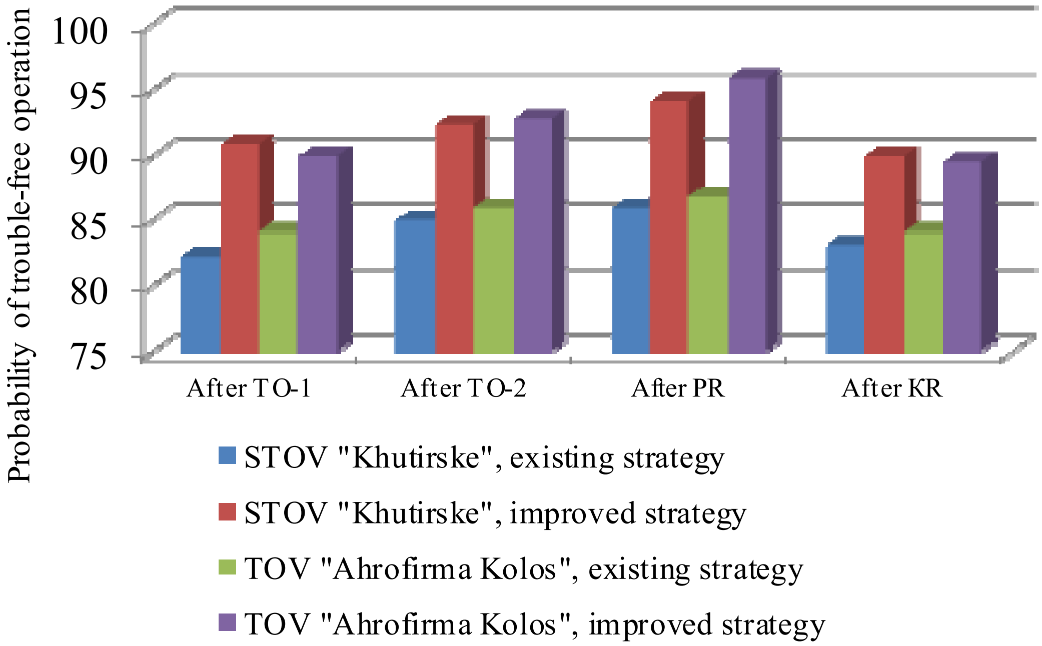

Figure 1 – Diagram of probabilities of trouble-free operation of KamAZ vehicles after performing certain technical measures with PPS and an improved maintenance and repair system based on service logistics methods

Sourse: obtained by authors

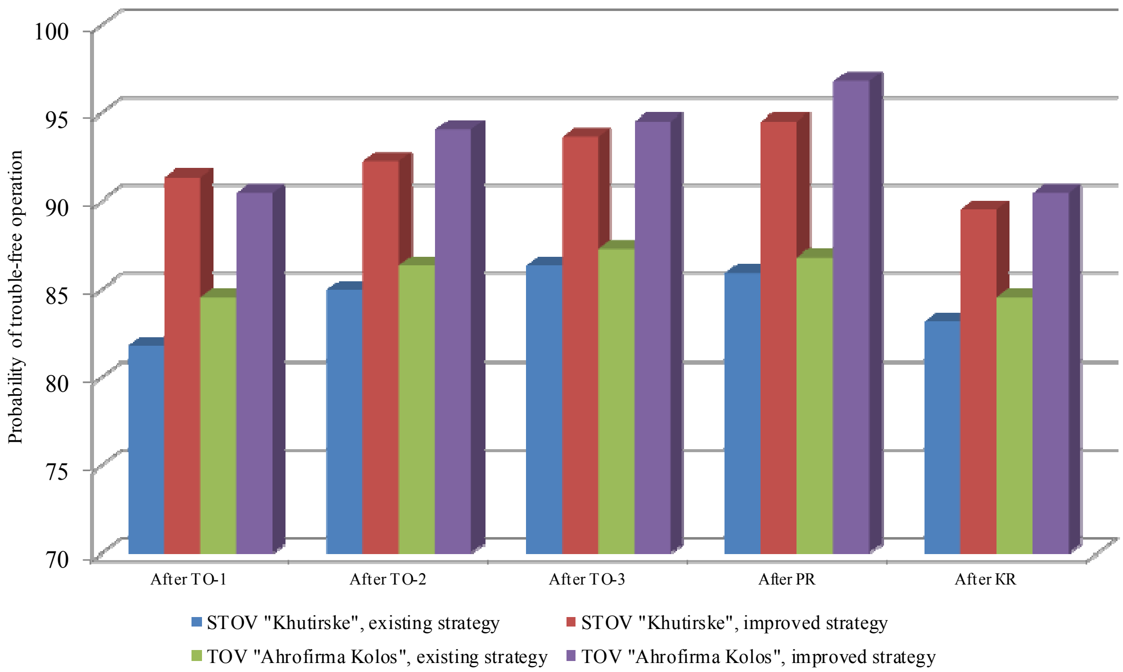

Figure 2 – Diagram of the distribution of probabilities of failure-free operation of the John Deere family of

MACM in the technical condition management system after performing certain technical actions at PPS and an improved maintenance and repair system based on service logistics methods

Sourse: obtained by authors

As evidenced by the results of carrying out technical actions with a change in the technical condition of the MACM, carrying out work to maintain it at a sufficient level and ensure the operability of the equipment correlates better with a higher probability. With PPS maintenance and repair, the probability of trouble-free operation of the MACM for all studied farms of the Kirovohrad region is lower by 6.7...14.3% compared to the improved maintenance and repair system using a logistics service.

It was found that the maintenance and repair systems can control the equilibrium state, which is heading towards the operational state. The implementation of technical actions helps to stabilize this state due to the "accumulation" of defects of various nature of occurrence and their implementation in the form of failures of specific elements of MACM [124], with minimal interference in the clearly defined exposure time according to a certain maintenance and repair system. Significant direct and indirect effects of factors on changes in indicators of operational reliability of MACM indicate a significant amount of underutilized potential resource.

The comparative results of the evaluation of readiness coefficients for two systems of maintenance and repair are shown in the table. 1.

Table 1 – Readiness coefficient of the researched vehicle park of waste disposal companies when using different maintenance and repair systems

AIP enterprise	Park of machines (MACM units), engines	Maintenance and repair systems	
		planned and preventive	improved
		The coefficient of readiness of the MACM park, K_R	
STOV "Khutorske"	cars of the KamAZ family (9)	0.63	0.78
	Tractors of the John Deer family (2)	0.67	0.81
TOV "Agrofirma Kolos"	cars of the KamAZ family (6)	0.69	0.82
	Tractors of the John Deer family (1)	0.71	0.84

Source: obtained by authors

At the same time, the readiness factor for the improved system is 1.12...1.32 times higher in comparison with the implementation of PPS maintenance and R.

It was found that for the "Khutorske" sewage treatment plant with PPS for different brands of MACM units, the average value of the readiness coefficient K_R varied between 0.63...0.67, and for the proposed one – 0.75...0.78; for the AIP company TOV "Agrofirmy Kolos", with PPS - 0.69...0.71, with the proposed one - 0.82...0.84.

There is a spread of availability coefficient values for diesel power units, which is determined by their initial and dynamic parameters: structural, technological, significant difference in working hours per unit of time, quality of service, fuel and lubricant materials used during operation, conditions and intensity of use. At that time, it should be noted that the human factor has a decisive influence on the readiness of MACM, both during production and maintenance.

The above shows that the use of the MACM technical condition management system to obtain information about the real technical condition in time makes it possible to adequately justify the extension of the service life to technical actions, to correct the nomenclature of the performed operations, to argue for a possible increase in the resource of the use of equipment, the coefficients of readiness and use.

Conclusions. 1. The information support of the system for managing the technical condition of MSHT units can be presented in the form of logistics flows, taking into account the flows of failures and spare parts during the implementation of an improved maintenance and repair system.

2. Information is obtained on the development of resource factors of influence, both in negative (destruction) and positive (restoration) directions.

3. The use of an improved technical condition management system for maintenance and repair on the basis of service logistics at APV enterprises of the Kirovohrad region allows us to talk about a certain adjusted structure of existing maintenance and repair systems.

4. With the optimal organization of modes of carrying out timely technical actions for the relevant nodes, systems and aggregates of MSHT, acceptable indicators of their reliability and efficiency of use are ensured.

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Підвищення надійності машин і ефективності їх використання в процесах перевезень у агропромисловому виробництві методами сервісної логістики

В статті розглядається проблема підвищення надійності машин і ефективності їх використання при перевезенні сільськогосподарської продукції. Підвищення надійності машин на підприємствах агропромислового виробництва розглядається на основі удосконалення стратегії їх технічного обслуговування і ремонту. При цьому використовуються методи логістичного сервісу при забезпеченні парку машин необхідною комплектацією запасних частин.

Дано теоретичне обгрунтування формування складу запасних частин на підприємстві, його обмеженість і система поставок. Зазначено, що в процесах забезпечення необхідними запасними частинами приймає логістичний центр управління. Виявлені основні фактори, що впливають на ефективність організації поставок запасних частин. На основі функції витрат розглядають оптимальне управління на основі логістичних моделей. Ці моделі дають оптимальне значення визначених факторів.

На основі моделювання сервісної логістики розроблена удосконалена система технічного обслуговування і ремонту машин, яка дає можливість істотно підвищені показники надійності. Це підтверджено дослідженнями на експериментальних підприємствах агропромислового виробництва. Парк машин на цих підприємствах в основному, задіяні у процесах перевезень сільськогосподарської продукції.

Порівняльним аналізом доведена перевага розробленої системи технічного обслуговування і ремонту поряд з діючою планово-запобіжною системою. Це передусім підвищення ймовірності безвідмовної роботи та коефіцієнта готовності автомобілів сімейства КамАЗ і мобільної сільськогосподарської і мобільної сільськогосподарської техніки сімейства John Deere.

надійність машин, перевезення, агропромислове виробництво, сервісна логістика, логістичний центр управління, запасні частини, технічний стан, інформаційне забезпечення, технічне обслуговування

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