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Methods for Forecasting Costs for Technical Impacts of Vehicles and Determining Cost Rate

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Abstract

The article defines the basic norms of car maintenance, the frequency of maintenance, the life of the product before repair, the step of grouping maintenance operations and the current labor costs for maintenance. Information is given about the grouping of TSK by main operations.

Keywords: *Hardening, Adjustment, Diagnostics, Reliability, Spare Parts, Labor Costs, Technological Requirement, Standard, Node, Mechanism, Combination, Failure.*

1. Introduction

The Transport and Road Complex (TDK) is one of the main national economic structures of the economy of the Uzbekistan, providing satisfaction of the country's needs in road, rail, river, sea and air transportation. At the same time, TDK has a significant impact on the state of the environment – atmospheric air, reservoirs, soil, vegetation and wildlife.

Traffic accidents in cities and on the roads of Uzbekistan are one of the most serious socio-economic problems. As a result, about 1,000 people die in Uzbekistan, more than 2,850 people are injured, and about 200 people remain disabled.

Safety traffic on motor transport is provided according to the scheme "car-driver-road-environment" (AVDS), therefore, the weakening or unsatisfactory condition of one of the links in this chain will always be a prerequisite for the commission of a traffic accident,

The composition of the country's fleet is dominated by vehicles with a low initial technical level and unsatisfactory technical condition in operation. This has a noticeable impact on the level of road traffic accidents in the country, which is an order of magnitude higher than the corresponding indicator of economically developed countries [1-2].

Drivers of motor vehicles continue to have a decisive impact on the accident rate in the country.

The operational condition of federal highways is at a low level. According to official statistics, due to the unsatisfactory condition of streets and roads, on average, every ninth traffic accident is connected.

Therefore, the concept of reliability – the preservation of the quality of the functioning of the object in time – can be attributed to each of the elements of the AVDS system, naturally, taking into account their inherent features.

In this regard, this tutorial attempts to consider the features of the functioning of all elements of the AVDS system, their impact on the quality of functioning, including reliability and its indicators.

The authors express their gratitude to their colleagues who helped in the formation of this manual.

A standard is a quantitative or qualitative indicator used to streamline the decision–making and implementation process.

By appointment, the standards are divided into:

- regulatory properties of products (reliability, performance, load capacity, weight, dimensions);

- regulating the condition of products and materials (values of technical condition parameters, density, viscosity, content of components and impurities);

- regulating resource provision (capital investments, consumption of materials and spare parts, labor costs);

- regulatory technological requirements (defining the procedure for carrying out certain maintenance and repair operations);

By level, the standards are divided into:

- national (state standards, national standards of technological design of ONTP, consumption rates of spare parts, etc.);

- interpectoral (regulations on maintenance and repair of rolling stock);

- industry (standard technological and methodological guidelines, industry standards);

- intra-industry and economic (quality standards of TO and R, standards of enterprises).

The standards are used in determining the level of performance of cars and fleet, planning the scope of work, the number of performers, the need for a production base.

The most important standards of technical operation include:

- frequency of maintenance;

- product life before repair;

- the labor intensity of the and P;

- consumption of spare parts and operational materials.

The standards are determined on the basis of data on the reliability of products, material consumption, duration and cost of maintenance and repair work. Let's consider the most common methods of determining the standards of technical operation [3-5].

2. Materials And Methods

This The frequency of maintenance is the standard operating time (in kilometers or hours of operation) between two consecutive homogeneous maintenance works. During maintenance, two main methods are used to bring the product to the required technical condition.

With the first method (by operating time), a certain periodicity is established, according to which the product is restored to the level set by the technical documentation when the set operating time is reached.

With the second method (according to the technical condition parameter), at a given frequency, the technical condition is first monitored and a decision is made to carry out preventive technical actions, i.e. bringing the technical condition of the product to the set level. Thus, in general, the operation consists of two parts – control and executive.

The expediency of using one or another method of conducting maintenance (with or without control) is determined by the ratio of costs for eliminating and preventing failures, for the control and executive parts of the operation, variation of random variables and other factors [8].

Methods for determining the frequency of maintenance are divided into:

a) the simplest (prototype analogy method);

b) analytical, based on the results of observations and the main laws of the TEA;

c) simulation based on simulation of random processes.

Determination of the frequency of maintenance by the method of analogies and clarifications

The periodicity (as well as the list of works) in accordance with this method is assigned by comparing with prototypes or previous models at this plant and then specified as a result of factory, interdepartmental tests and operational experience. Since the indicators of the operational manufacturability of cars were not normalized for a long time during the design, when making recommendations, the desire to insure their products prevailed over the factories, which led to the appointment of a minimum periodicity (and a maximum list of operations), multi-stage maintenance systems, sharply differing recommendations for the maintenance of structurally homogeneous components and mechanisms of cars from different factories and caused great difficulties in organization of the technological process at motor transport enterprises [10-11].

Naturally, this method can be recommended only as an indicative one for preliminary, mainly factory tests, as well as when assigning initial modes.

Determination of the frequency of maintenance by changing the appearance of the node, mechanism, connection, material

According to the appearance and nature of the contamination of the rolling stock, the frequency and volume of cleaning and washing operations are determined when the car is operating under these operating conditions (road conditions, season, etc.). The appearance and location of the lubricant in the bearing friction units (lubrication stratification, its discharge) is one of the criteria indicating the need to replace the lubricant. This method is used to determine the frequency of replacement of engine oils (drip test), lubrication of friction units of cars through oil presses, performing a number of fastening operations. This method has limited application and gives only approximate results.

Determination of the frequency of maintenance according to the acceptable level of reliability

Dispersion is characteristic of the parameters of the change in the technical condition. If you assign the frequency of maintenance taking into account the full range of possible parameter values, it will be too low, and the content of the work itself will be unstable. The assignment of periodicity, based on the average value of the parameter, leads to the fact that about half of the cases of failures and malfunctions occur earlier than the established periodicity. The proposed method for determining the periodicity according to the acceptable level of reliability provides for the determination of the periodicity, provided that the probability of failure or malfunction of the previously established periodicity will be less than the stipulated level.

The probability of uptime

$R_Д \{x_i \le l_0\} = \gamma,$ i.e. $l_0 = x_\gamma,$ (1)

$x_i -$ where is the time to failure;

$R_Д -$ acceptable probability of uptime;

$\gamma = 1 - F;$

$l_0 -$ the frequency of the;

$x_\gamma -$ gamma – percent resource.

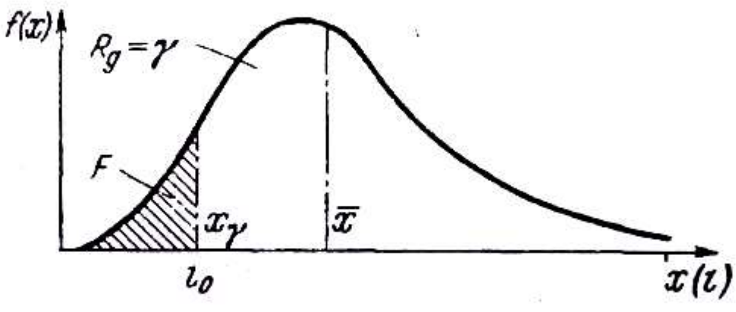

Figure 1-Determination of the frequency of maintenance by the acceptable level of reliability

For aggregates and mechanisms that ensure traffic saf $R_Д = 0{,}9 - 0{,}98;$ for other components and assemblies $R_Д = 0{,}85 - 0{,}90.$

The frequency determined in this way is significantly less than the average time to failure and is associated with it as follows:

$l_0 = \beta L$, (2)

$\beta -$ where is the coefficient of optimal periodicity, taking into account the type of distribution curve, the coefficient of variation and the confidence level of probability;

$L -$ average time to failure.

The smaller the variation of the random variable, the greater the frequency of maintenance, all other things being equal, can be assigned. More stringent safety requirements reduce the rational frequency of maintenance (Table 1.).

Table 1. – Coefficients of rational frequency at different values of the permissible probability of failure-free operation and the coefficient of variation of the resource

$P_Д$	Coefficient of variation of the resource			
	0,2	0,4	0,6	0,8
0,85	0,80	0,55	0,40	0,25
0,95	0,67	0,37	0,20	0,10

Note the conditions conducive to the use of this method:

- the economic consequences of failure and malfunction of this connection, node, mechanism are not paramount;

- the mass of objects, in which the specific influence of each on the operation of the machine, mechanism, connection is relatively small;

- the practical impossibility of fixing a sequential change in the state of each object by time or mileage.

The most widespread use of this method has been found to establish the frequency of maintenance (control and tightening) of fasteners. The method can also be applied to other components, aggregates and mechanisms in the case of a preliminary assessment of the frequency of maintenance for their correction, as well as when rationing the resource [15].

Determination of the frequency of maintenance by the permissible value and the regularity of changes in the technical condition parameter

The change of a certain parameter of the technical condition of a group of cars occurs in different ways (curves 1-7 Figure 2). On average, for this group, the trend of parameter change is characterized by curve 4, which allows determining the average operating time when, on average, the entire set of products reaches the permissible value of the technical condition parameter. This average operating time corresponds to the average intensity of the parameter change. At the same time, products with a greater intensity of changes in the technical condition parameter will reach the limit state earlier, and, consequently, a failure will be recorded for them at the assigned maintenance frequency corresponding to the average operating time. Such a service system is irrational, therefore, a frequency is assigned at which the probability of failure will not exceed a given risk value F, for example, F = F2.

This case corresponds to a greater intensity of change in the technical condition parameter than the average, called the maximum permissible:

$$a_Д = \bar{a}\mu, \quad (3)$$

$\bar{a}$ -where is the average intensity of the change in the technical condition parameter obtained from the distribution curves;

$\mu -$ the maximum intensity coefficient, which takes into account the type of distribution curve, the coefficient of variation and the confidence level of probability.

The coefficient is influenced by the degree of risk, variation and type of distribution law.

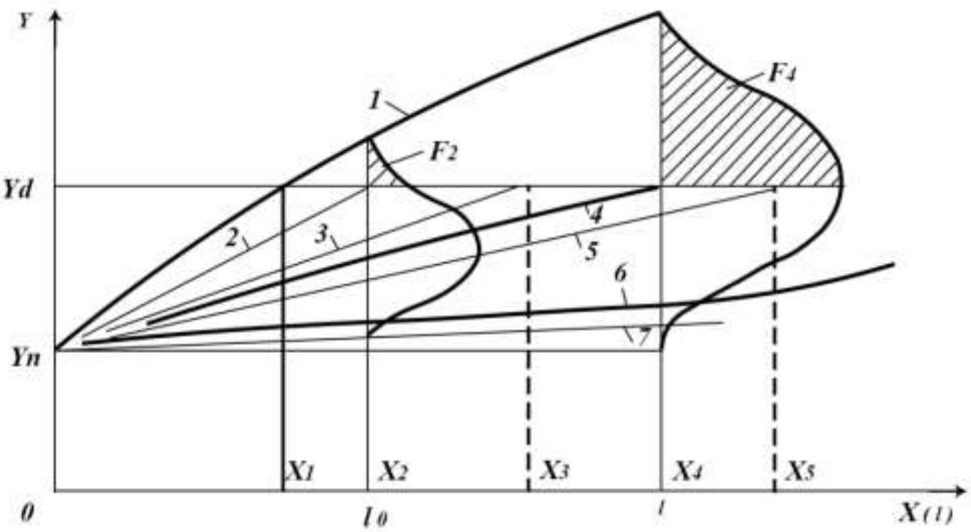

Figure 2. Method for determining the frequency of maintenance by the permissible value and regularity of changes in the technical condition parameter

Knowing the coefficient of variation and given a confidence level of probability, determine, and then the maximum intensity of the parameter change. Therefore, taking into account the clarifications, this method allows you to determine the frequency of maintenance at which the probability of exceeding the permissible value of the technical condition parameter is less than the permissible one. Naturally, the confidence level of probability cannot be constant for all nodes, aggregates and mechanisms or decisions made: for the more responsible, it increases, and for the less responsible, it decreases (Table 2.).

Table 2. Generalization of values of confidence probability levels

The consequences of choosing the wrong confidence level	R_D
Failures or incorrectly made decisions that lead to economic losses (increased labor intensity, cost, downtime, schedule disruption, fines, the need for redundancy, etc.) when:	
- rationing the durability of bevel gears of aircraft gearboxes;	0,95
- rationing the durability of bearings, gears, hubs, valves, crankshafts, springs, wheels and other car parts;	0,90-0,95
- rationing the durability of traction engines of electric locomotives;	0,94
- determining the frequency of maintenance operations for tractors;	0,85
- development of technological processes in mechanical engineering;	0,80-0,90
- calculations of the reliability of automation tools in the chemical industry.	0,90
Refusals and incorrectly made decisions that threaten people's health and life, when:	
- rationing the durability of parts that affect the safety of movement or flight;	0,95-0,99
- calculations on the safety and organization of the movement of cars;	0,90-0,95
- evaluation of new drugs, methods of treatment, including surgical ones.	0,95-0,99

Taking into account the conducted research, as well as the experience of other industries and transport, when assigning the frequency of car maintenance, the following approximate values of confidence probability levels can be taken: for aggregates, mechanisms, assemblies, parts and connections affecting traffic safety, R_D = 0.9-0.95, for other R_D= 0.85-0.90.

The scope of application of the considered method is service objects with a clearly fixed change in the parameters of the technical condition, which include most of the components, aggregates, mechanisms subjected to adjustment (brakes, clutch, front wheel mounting angles, relay regulator, tension belts, valve mechanism, etc.), cleaning, (filter cleaning, sludge drain) and some lubricating (level check) work.

It should be emphasized that this method determines the rational frequency of the control part of the operation, and the executive part is performed according to need with a certain repeatability coefficient [14].

When applying this method, it should be borne in mind that it does not directly consider the economic side of a certain periodicity of maintenance.

Determination of the frequency of maintenance by unit costs for maintenance and repair (technical and economic method)

The considered methods for determining the frequency of maintenance are valid, provided that during some mileage or operating time of the car, changes in the parameters of the technical condition, although they occur, are not taken into account, and after passing this mileage, maintenance is carried out, which fully or partially restores the lost properties of the connection, mechanism or unit. For example, as the car is running, the average gap between the brake pads and the drums gradually increases to an acceptable value. At the same time, the braking distance also increases, remaining, however, within the established norms corresponding to the permissible clearance value. However, in some cases, any change in the frequency of maintenance has an impact on the cost of maintenance and repair.

The technical and economic method for determining the rational maintenance regime takes into account the impact of the frequency of maintenance on the wear of parts (inter-repair mileage L), the cost of materials consumed, as well as labor costs for maintenance and repair. At the same time, the unit costs of maintenance and repair are determined as follows:

$$C_\Sigma = C_I + C_{II} \text{ , (4)}$$

$C_\Sigma -$ where is the total specific (i.e., attributed to the unit of mileage) cost of maintenance and repair;

$C_I = \dfrac{A}{l} -$ the unit cost of maintenance (A – the cost of maintenance operations; l-the frequency of maintenance);

$C_{II} = \dfrac{B}{L} -$ the unit cost of repairs (B – repair costs; L – mileage between repairs).

The dependences of the unit costs of maintenance and repair in general are hyperbolic or close to them functions, and with an increase in the frequency of maintenance, maintenance costs decrease, but at the same time repair costs increase. Therefore, the total unit cost of maintenance and repair has an extreme point corresponding to the optimal frequency of maintenance with a minimum of costs [16].

Minimum maintenance and repair costs are only one economic characteristic or criterion for optimal frequency and maintenance regime in general.

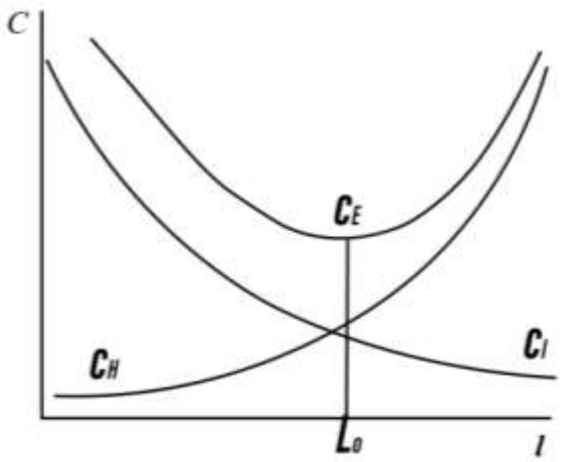

Figure 3. Determination of the frequency of maintenance according to the unit costs of maintenance and repair (technical and economic method)

Technical criteria, traffic safety, losses associated with the termination of the transport process, downtime, the cost of the base for maintenance and repair, etc. can also be taken into account. In this case, the optimal periodicity is determined from the minimization condition of the function:

$$C_{\Sigma} = \sum_{j=1}^{n} C_j, \quad (5)$$

$C_j -$ where are the factors affecting the total costs.

Thus, in accordance with the technical and economic method, the optimal maintenance regime is understood to be such a regime that ensures reliable and safe operation of rolling stock with minimal costs of materials, funds and labor for maintenance and repair attributed to a unit of mileage or transport work.

A rational maintenance regime should be considered such a regime that, in these operating conditions, provides, in comparison with the previously adopted regime, an increase in the reliability and safety of rolling stock and a reduction in the cost of materials, funds and labor for maintenance and repair, as well as a reduction in downtime of rolling stock in maintenance and repair. The technical and economic method, following its development, has found wide application in justifying optimal maintenance modes for various machines and mechanisms. At the same time, it is used both to determine optimal or rational modes for certain types of work (for example, lubricating), and for a comparative assessment of the effectiveness of the mode as a whole.

Determination of the frequency of maintenance by the economic-probabilistic method

This method generalizes the previous ones and takes into account economic and probabilistic factors, as well as allows you to compare different strategies for maintaining and restoring the performance of the car.

As already noted, one of the strategies is to eliminate product malfunctions as they occur (Figure 4. a), i.e. according to need. Unit costs are defined as the ratio of one-time repair costs to the average operating time for failure.

The advantage of this strategy is simplicity, the main disadvantage is the uncertainty of the condition of the product, which can fail at any time. In addition, planning and organization of maintenance and repair are difficult.

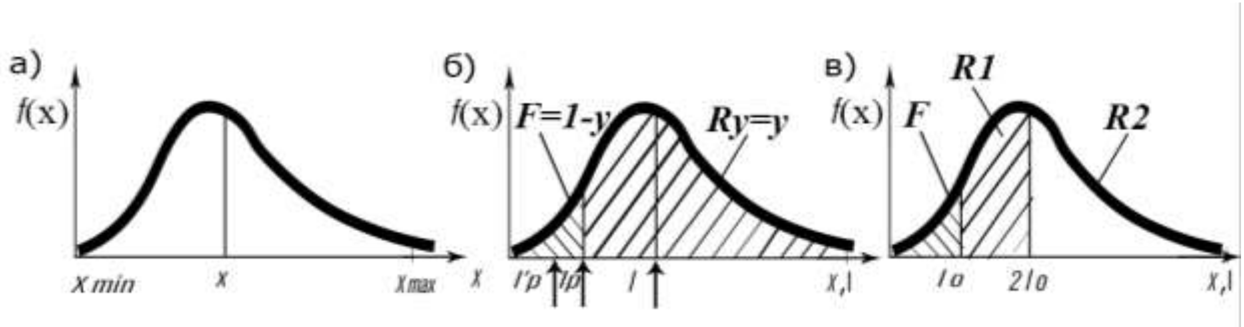

Figure 4. Economic-probabilistic method for determining the periodicity of the

An alternative strategy (Figure 4. b) provides for the prevention of failures and damage, restoration of the original or close to it state of the product before the limit state is reached. This strategy is implemented with preventive maintenance, preventive replacement of parts, assemblies, mechanisms, etc.

Let's consider the method of implementing this strategy. Since, theoretically, failure can occur at any arbitrarily small frequency, the strategy is implemented not in pure, but in a mixed form: a certain, as a rule, low probability of failure is allowed, and the frequency of preventive maintenance or repair is less than the average operating time for failure. At the same time, those failures that occurred before the specified maintenance periodicity are eliminated as they occur. Usually, the acceptable probability of failure or the required probability of uptime is set.

The rest of the work will be carried out with a frequency of cost d and a given probability of this event.

The advantages of this strategy are as follows. Firstly, a certain level of reliability of the product can be guaranteed. Secondly, maintenance costs are significantly lower than repair costs in case of failure, which may also be accompanied by additional losses associated with assistance due to disruption of the transport process. Thirdly, the preventive nature of this strategy creates conditions for the planned organization of maintenance and repair. These advantages compensate for a certain disadvantage of this strategy, which consists in underutilization of the product's resource, since the frequency of preventive work is less than the average operating time to failure [18].

With this strategy, unit costs are defined as the ratio of the weighted average cost of one operation to the weighted average operating time, taking into account the failure of a part of the products:

$$C = \frac{cF + dR}{l}, \quad (6)$$

where c - is the unit cost of repairs;

d - is the unit cost of maintenance;

l - is the weighted average operating time.

In the economic-probabilistic method, as well as in determining the optimal periodicity by reliability, the concept of the rational periodicity coefficient is used.

$$l_0 = \beta_0 \overline{L}, \quad (7)$$

$$\beta_0 = \left[\frac{2(d/c)v}{(1+v^2)(1-v)} \right], \quad (8)$$

where $\beta_0 -$ is the coefficient of rational periodicity;

v - is the coefficient of variation.

The economic-probabilistic method makes it possible to calculate the rational frequency of maintenance based on a given reduction in the flow of failures in the inter-control periods, i.e. between two consecutive maintenances.

The economic-probabilistic method also determines rational ways to improve the organization of maintenance.

Indeed, with a periodicity of l_o, those products (the first group) actually require preventive action, the potential failure of which may occur with some probability R_1 (Figure 3.), with an operating time of $l_o \leq l \leq 2l_o$ (without taking into account the variation of the most optimal periodicity). Products with a potential time to failure $l_o > 2l_o$ (the second group) can be serviced not at this, but at subsequent services. The probability of this event is $R_2 = R\text{-}R_1$, therefore, with the second method of implementing a preventive strategy, it is necessary to separate the products of the first and second groups, which is carried out with the help of monitoring (diagnostics), which requires additional costs.

Thus, with an optimal periodicity l_o, all products that have not failed up to this point are monitored. The cost of this control is d_k, and work to bring the technical condition to the norm, having a cost of d, with a probability of R_1, is carried out only for the first group of products. Obviously, such a development of a preventive strategy using diagnostics will be advisable if the additional cost of control (special equipment, skilled labor) is compensated by a reduction in the cost of preventive surgery and damage from failures. Consequently, the preventive operation in its control part will be performed for all products according to the need, taking into account the results of the control.

The second condition for the application of preliminary control is to ensure reliable separation (prediction) by diagnosing products that require maintenance during the next or subsequent preventive actions.

Obviously, preliminary control is advisable when reducing the total costs of the second method. At the same time, the optimal periodicities for the first and second methods may not coincide. One of the methods of control work is diagnostics, which serves to determine the technical condition of the car, its units and assemblies without disassembly and is a technological element of maintenance and repair.

Determination of the frequency of maintenance by statistical testing

This method is based on imitation (modeling) of real random processes, which makes it possible to speed up tests, eliminate the influence of side factors, drastically reduce the cost of experiments, conduct research, if necessary, in order to select the most suitable option. The source material for modeling is both the actual data obtained during observation and the distribution laws.

Methods of grouping operations

Maintenance includes 8-10 types of work (lubrication, fixing, adjustment, diagnostic, etc.) more than 200 maintenance facilities that require preventive actions. Each object, in turn, has its own optimal frequency of maintenance, determined by the methods described above. If you follow these intervals, then the car as a whole should be almost continuously servicing individual connections, aggregates, systems, which causes great difficulties with the organization of work and additional time losses, especially on preparatory and final operations.

Therefore, after determining the optimal frequency of each operation, operations are grouped into types of maintenance. There are two approaches to grouping operations into steps:

- the frequency of maintenance is considered to be set;

- the frequency of maintenance is not set in advance.

Currently, a large number of methods for grouping operations have been developed.

The classification of methods for grouping operations into lists of work steps is shown in Figure 5. Let's consider just some of the methods.

Grouping by core operations is based on the fact that the execution of a group of operations is timed to the optimal frequency of l_{CT} so-called core operations, which have the following characteristics:

a) affect traffic safety;

b) failure to comply with them reduces reliability, efficiency and affects performance;

c) are characterized by great labor intensity, require special equipment and arrangement of the post;

d) are regularly repeated.

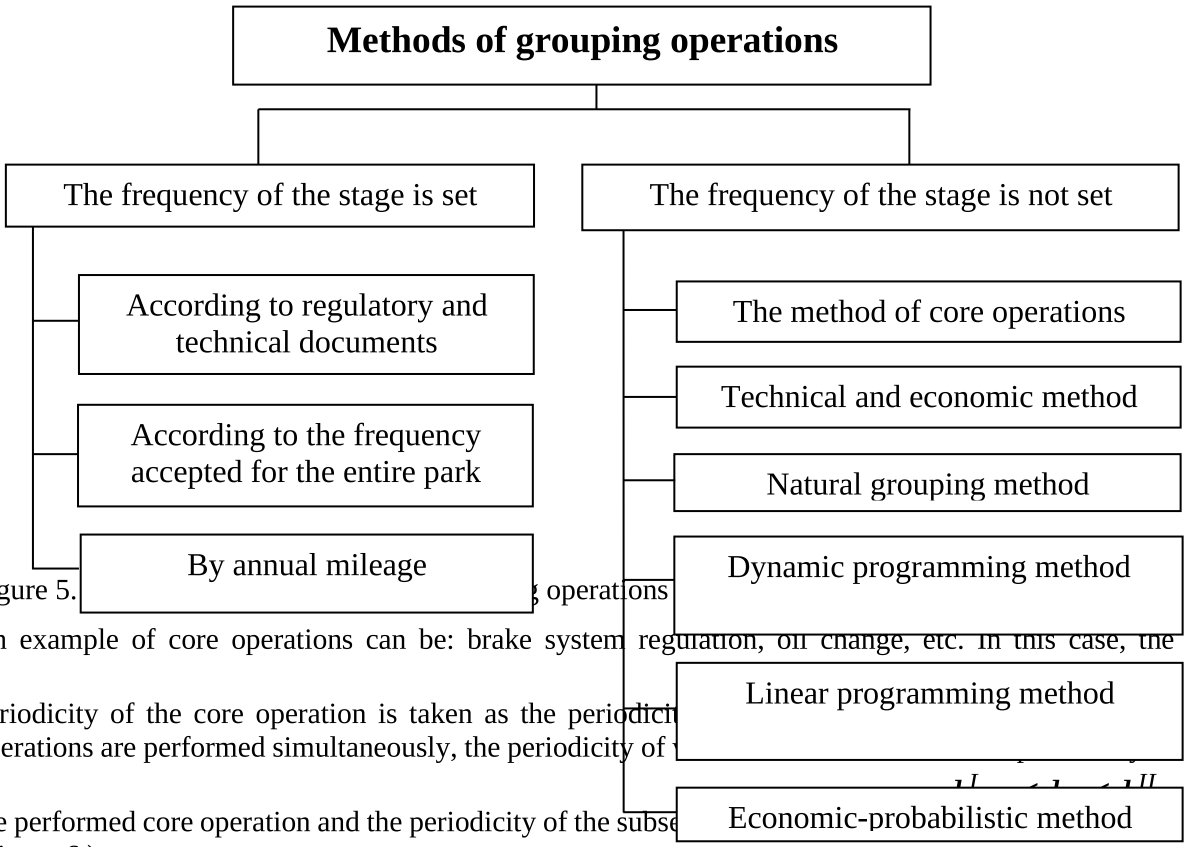

Figure 5. … operations

An example of core operations can be: brake system regulation, oil change, etc. In this case, the

periodicity of the core operation is taken as the periodici…
operations are performed simultaneously, the periodicity of …

the performed core operation and the periodicity of the subse…
(Figure 6.).

Operations whose optimal periodicity is higher than the periodicity of the core operation are performed with a repeatability coefficient that is equal to:

$$k_i = \frac{l_{CT}^I}{l_{0i}} = \frac{(l_{TO})_1}{l_{0i}}, \quad 0 \leq k \leq 1 \quad (9)$$

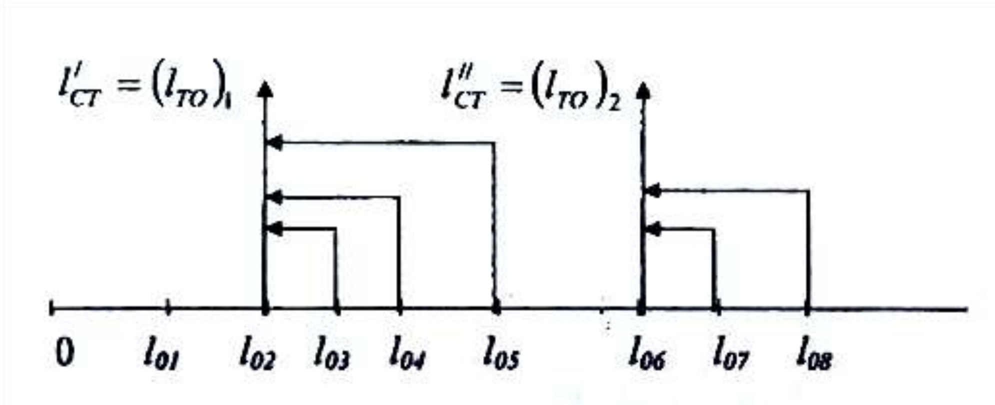

Figure 6. The scheme of grouping by core operations

The technical and economic method determines such a group periodicity of maintenance, which corresponds to the minimum maintenance and repair costs for all the objects under consideration.

$$C_{\Sigma\Sigma} = \sum_{i=1}^{S} C_{Ii} + \sum_{i=1}^{S} C_{IIi}, \quad (10)$$

where $C_{\Sigma\Sigma}$ – are the total unit costs for maintenance and TR of objects;

C_{Ii} - unit costs of the i – th object;

C_{IIi} - unit costs for the TR of the i – th object;

S - is the number of operations in the group.

Thus, the optimal frequency of maintenance for a group of objects is selected from the condition $C_{\Sigma\Sigma} = C_{мин.}$

The method of natural grouping is used in cases where a number of service objects have very close optimal maintenance periodicities. For example, the whole set of non-self-locking fasteners have two peaks of the need to resume pre-tightening in the intervals of 2-5 and 10-14 thousand km. Braking mechanisms (10-12 thousand km), valve mechanisms (9-14 thousand km.), installation angles of controlled wheels (7-12 thousand km.) [18-20].

Determination of the complexity of maintenance and repair

Labor intensity refers to the labor costs of performing the work of an operation or a group of maintenance or repair operations in person-hours.

The rate of labor intensity of performing operations consists of:

- preparatory and final works (3.5%);

- operational work (88%);

- workplace maintenance (2.5%);

- rest breaks and so on (6%).

1. The preparatory and final time is necessary to familiarize the performer with the assigned work, prepare the workplace, receive and deliver the outfit, tools, materials, etc.

2. The operational time required to perform a production operation is divided into main and auxiliary.

The main (technological) – the actual operation is carried out.

Auxiliary is necessary to ensure the possibility of performing the operation (installation time at the post, providing access to the maintenance or repair facility, etc.).

3. The maintenance time of the workplace is necessary for the maintenance of the workplace and the tools or equipment used.

The time or labor intensity of performing maintenance and repair operations is a random variable with significant variation, therefore, the norm of operational time is defined as the average value of a number of time–lapse observations of a given operation in specific conditions - the qualifications of personnel, equipment, technology of maintenance and repair.

The method of microelement standards is the use of time standards for the simplest movements of the performer, for example: the body, legs, hands, fingers, which are necessary to perform this operation, etc.

Determination of resources and consumption rates of spare parts

When rationing resources, the following indicators are used:

- medium resource;

- gamma-percent (at 85-90%) resource.

Norms for these indicators are usually set for the following cases:

- resource up to the 1st major repair under certain operating conditions;

- the average service life (in years) or the resource of the car before the write-off.

The consumption rates of spare parts are necessary for planning their production and determining the required volume of spare parts for this ATP.

The current regulations set the average consumption of spare parts (for each part) in pieces per 100 cars per year.

In general, the flow rate (H) is determined using the leading function of the flow of failures (replacements) specific details:

$$H = \frac{\Omega(t)}{t}, \quad (11)$$

where t-is the duration of the period (in years) for which the corresponding norm is obtained $\Omega(t)$ and determined.

For parts whose resource is comparable to the average annual mileage of the L_G car, the consumption rate is determined for the full service life according to the formula:

$$H \approx \left[\frac{L_r t_a - L_1}{\eta L_1} + 0,5\left(\frac{v^2}{\eta} + 1 \right) \right] \frac{100}{t_a}, \quad (12)$$

where t_a - is the service life of the car;

L_1 - resource before the first replacement;

v - is the coefficient of variation of the part resource;

η - is the coefficient of recovery of the part's resource during subsequent replacements.

The consumption of spare parts increases with a reduction in the service life of parts during subsequent replacements, i.e. a decrease in η. If there are several identical parts or assemblies on the vehicle, then the norm increases accordingly.

Thus, in order to determine the consumption rates of spare parts, information is needed on the reliability of parts, the intensity of operation and the service life of the vehicle before decommissioning.

4. Conclusion

In addition to the nomenclature, the cost norms for the consumption of spare parts are established: total – for operation and repair in rubles for the year of operation and for maintenance and repair (rubles /

1000 km of mileage). They serve to control and plan the costs of spare parts when operating cars on the ATP.

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