Technique for Improving the Organization of Maintenance of Transport and Technological Vehicles

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Abstract. In this work the technique of improvement of transport and technological vehicles maintenance is presented. A high-quality organization of technical service is impossible without determining the characteristics of the intensity of requests for a certain type of repair work. The failure flow as a set of successive failures of parts and assembly units is considered as a stationary Poisson process. The check of the stationarity of the failure flow was carried out using the Pearson criterion. The presented technique for researching the failure flow can be extended to any structural elements of technological machines. The results of calculations using this technique can be used, for example, to organize a rational supply of spare parts in order to reduce downtime and material losses during the technical operation of equipment.

1. Introduction
The problems of organizing a rational supply of spare parts in order to reduce downtime and material losses during technical operation of equipment are discussed in [1-5]. At the same time, despite a lot of work on justifying the supply of spare parts [6-10], the issue of organizing the optimal operational supply of spare parts remains relevant. To resolve this issue, you need information about the characteristics of hardware failure processes. Thus, when determining the necessary amount of equipment for technical service enterprises, as objects of an open-type Queuing system, it is necessary to know the characteristics of the request and failure flows for performing certain works [11-16].

Justification of the required amount of equipment at open-type queuing facilities, when the number of serviced equipment is not limited to any specific values of a particular enterprise, can be considered by the example of justifying the number of washing units (washing stations) of vehicles (cars). The car wash receives the simplest request flow with a density of \( \lambda = 3 \) objects per hour. The washing periods are distributed according to the exponential law with the average washing time \( T_{\text{mean}} = 20 \) minutes or one third of an hour per object. Thus, the service flow density is \( \mu = 3 \), i.e. it is three objects per hour. You need to determine the number of washing stations \( k \), at which the probability of failure to the client \( P_f \) is not higher than 0.12.

For the given parameters, the value of the reduced density of requests, calculated by the formula

\[
U = \frac{\lambda}{\mu}
\]

is equal to one \( (U = 1) \).

The probability \( P_f \) that the request will be rejected is determined by the expression

\[
P_f(k) = \frac{U^k}{k!} \cdot \frac{1}{\sum_{i=0}^{k} \frac{U^i}{i!}}
\]
We will take $k = 2, 3, \ldots$ and determine the corresponding values of the probability of denial of service:

$$P_F(k = 2) = \frac{1}{2 \cdot \left( \frac{1^0}{0!} + \frac{1^1}{1!} + \frac{1^2}{2!} \right)} = 0.2;$$

$$P_F(k = 3) = \frac{1}{6 \cdot \left( \frac{1^0}{0!} + \frac{1^1}{1!} + \frac{1^2}{2!} + \frac{1^3}{3!} \right)} = 0.0625.$$

Thus, if there are three car wash stations, the probability of failure in service will be less than the specified one (0.12). Further calculations to increase the number of washing stations are not required in this case.

2. Materials and methods

For effective organization of repair work, it is necessary to know the characteristics of the intensity of requests for a certain type of work: diagnostics, restoration or replacement of elements or machine parts [17-21].

The number of necessary, for example, tire repair or tire repair equipment is determined by the number of requests for repair of elements that work independently of each other, namely, the wheels of vehicles whose technical condition is diagnosed independently of each other.

At the same time, diagnostic stands for checking the operation, for example, the ignition system or power supply, are used to diagnose the entire system. There is a simultaneous comprehensive check and diagnostics of all elements included in the system, which does not work without the participation of any of them. In this case, you should justify the number of necessary diagnostic equipment, such as motor testers. This requires a study and determination of the intensity of requests for diagnostics of complete vehicles, taking into account the total flow of dependent, connected in one functional chain of individual elements of various systems. For example, such as ignition and power systems.

A sequence of successive failures of parts and assembly units (systems) in time forms a failure flow as a flow of random events. Random flows are characterized by properties, the most important of which are aftereffect, ordinariness, stationarity. If the failure flow events has no aftereffect, is ordinary and stationary, it is called the simplest or stationary Poisson process. The absence of aftereffect is determined by the condition under which the failures are random, independent events, and if the object has worked until the moment $\tau$ and the time interval for failure is distributed according to the exponential law, then the probabilistic characteristics of the failure-free operation of the object are preserved in the future, regardless of the time of this interval.

The ordinary condition means that the probability of the appearance of two or more events in a small interval $\Delta \tau$ is a value of a higher order of smallness compared to the probability of the appearance of one event in this interval.

A failure flow belongs to the class of stationary flows if the probability of a fixed number of failures in a given time interval depends only on the length of the interval, and not on where this interval is located on the time axis. Under these conditions, the probability of occurrence $R$ of object failures for the operating time from zero to $t$ is

$$F(R, t) = \frac{[\lambda(t) \cdot t]^R}{R!} \cdot e^{-\lambda(t) \cdot t},$$

where $\lambda(t)$ is the failure rate. The failure rate $\lambda(t)$ is related to the failure probability $F(t)$ on the interval $(t, t + dt)$ by the dependence $F(t) = \lambda(t) dt$ [15].

We can assume that the failure rate in Poisson’s law is nothing more than the probability of failure per unit of operating time. Testing the hypothesis of stationarity is identical to testing the hypothesis of a uniform distribution law.

In queuing theory, it is proved that each ordinary flow without consequence and with limited aftereffect after some time becomes close to stationary [15].
The hypothesis on the stationarity of the machine failure flow was tested under two possible conditions:

1) when the deviation of the failure flow parameter does not have a pronounced multiplication (or increase) over time;
2) when the failure flow parameter tends to decrease (or increase) over time.

In the first case, if there are sufficient statistical data and in each interval $\Delta t$ there are at least $5\text{–}8$ observations, then testing the hypothesis of stationarity is identical to testing the hypothesis of a uniform distribution law using the usual tests used to test the hypothesis of convergence of theoretical and statistical distributions. For example, you can use the Pearson test

$$\chi^2 = \frac{\sum_{j=1}^{C} (m_j - m_j^T)^2}{m_j^T},$$

where $m_j^T$ is the theoretical number of failures in the $j$-th interval; $m_j$ is the number of failures in the $j$-th interval; $C$ is the number of intervals into which the MTBF is divided.

If the statistical (observed) value of the criterion found by the formula is less than the tabular (critical) value, then the hypothesis of the flow stationarity is not rejected, and vice versa. The critical value of the Pearson criterion $\chi^2(\alpha, k)$ is determined at the significance level $\alpha$ and the number of degrees of freedom $k$.

3. Results and discussion

Using the example of a contactless ignition system for internal combustion engines, let us consider a list of elements, the failure rate of which will determine the amount of equipment required for maintenance and repair.

Structurally, a contactless ignition system combines a number of elements, including: a power source, an ignition switch, a pulse sensor, a transistor switch(s), an ignition coil(s), a distributor, spark plugs, low and high voltage wires with tips, sensors or a control unit in electronic systems.

If the ignition system uses several coils, then there may be several switches. The main failures and malfunctions of the system: carbon deposits, wear of electrodes, destruction of plugs insulation; damage of wires; failures of the switch, ignition coil, pulse sensor and other elements.

Failures of all of these elements form the failure flow of the ignition system, the characteristics of which determine the intensity of requests for service and repair of the system, the number of diagnostic equipment, for example, motor testers.

Let us check the hypothesis about the stationarity of the failure flow according to the observation data for nine objects using the example of a working body of a technological machine. The initial data are shown in Table 1.

| Failure number | Machine’s number |
|----------------|-----------------|
|                | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1              | 1439 | 212 | 331 | 226 | 863 | 1500 | 248 | 250 | 700 |
| 2              | - | - | 1110 | 1632 | - | - | 1036 | 352 | 334 |
| 3              | - | - | 1362 | 713 | - | - | 234 | 1312 | 314 |
| 4              | - | - | 403 | - | - | - | - | - | 286 |
| 5              | - | - | - | - | - | - | - | - | 283 |
| 6              | - | - | - | - | - | - | - | - | 324 |

Let $L_j$ denote the number of failures when the earlier operating time of the $j$-th object is the smaller of the later ones. This number is a random variable with an estimate of the mean $M[L_j]$, the variance
The value $L_j$ should be centered and normalized, i.e. introduce into consideration the value $Z_j$, which is calculated by the formula

$$Z_j = \frac{L_j + 0.5 - M[L_j]}{\sigma[L_j]}.$$ 

### Table 2. Estimation of the mean, variance and standard deviation of the value $L_j$.  

| Machine's number | $m_j$ | $L_j$ | $M[L_j]$ | $D[L_j]$ | $\sigma[L_j]$ | $Z_j$ |
|------------------|-------|-------|----------|----------|---------------|------|
| 1                | 1     | 0     | 0.25     | 0        | 0             | 0    |
| 2                | 1     | 0     | 0.25     | 0        | 0             | 0    |
| 3                | 4     | 4     | 3.0      | 2.17     | 1.47          | 1.019|
| 4                | 3     | 2     | 1.5      | 0.92     | 0.96          | 1.044|
| 5                | 1     | 0     | 0.25     | 0        | 0             | 0    |
| 6                | 1     | 0     | 0.25     | 0        | 0             | 0    |
| 7                | 3     | 1     | 1.5      | 0.96     | 0.96          | 0    |
| 8                | 3     | 3     | 1.5      | 0.96     | 0.96          | 9.088|
| 9                | 6     | 3     | 7.5      | 2.66     | 2.66          | -1.503|
| Total            |       |       |          |          |               | 2.648|

To calculate the statistical value of the criterion for a set of observations of $N$ objects, the following expression is used

$$Z_{mon} = \frac{\sum_{j=1}^{N} Z_j}{\sqrt{N}},$$

where $N$ is the number of objects monitored.  
This value can vary depending on the duration of observations for each object.  
The hypothesis test condition is

$$Z_{mon} < Z_\alpha$$

where $Z_\alpha$ is the quantile of the normal distribution at a given significance level $\alpha$.  
According to Table 1, we count the number of cases $L_j$, when the earlier operating time is less than one of the block of late operating times, then we determine the value of $Z_{mon}$ (according to Table 2)

$$Z_{mon} = \frac{1}{\sqrt{9}} \cdot 2.648 = 0.882.$$  

At the significance level $\alpha = 0.1$ the quantile of the normal distribution is $Z_{0.1} = 1.282$ [15].  
The hypothesis about the stationarity of the flow of failures of the considered element is not rejected, since the condition $Z_{mon} < Z_\alpha$ is satisfied at a given significance level $\alpha$.  Thus, the investigated flow of failures can be further considered as a stationary Poisson process.  
Using the calculation results based on the given method, you can get information about the characteristics of failure flows.  The hypothesis of compliance with the simplest type of superposition of failure flows of parts of the machines fleet can be evaluated by statistical modeling.  

### 4. Conclusion  
The article describes a method for researching the failure flow, which makes it possible to determine the intensity and volume of requests for repair work and, thus, to plan their implementation at special-
ized areas of technical service enterprises. The presented technique can be extended to any structural elements of any machine.

The results of calculations using this technique can be used, for example, to organize a rational supply of spare parts in order to reduce downtime and material losses during the technical operation of equipment.

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