Methodology to calculate the required number of spare parts in order to ensure the required operability of equipment parks

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Abstract. Comprehensive mechanization of work is accompanied by large expenditures for ensuring the serviceability and operability of the machines fleet. There is an almost constant need for spare elements (machines, units, parts) to maintain the required use level of machines and equipment, as well as to perform work on schedule. An algorithm of actions allowed finding a rational level of redundancy for machines and their parts under various operating conditions and constructive improvement of technology. The article showed that the rate of failure is influenced by the natural and climatic factor, the “age” of machines, and other conditions. Optimization of the companies’ repair policy in terms of ensuring the serviceability of equipment is a complex multi-vector problem. The described methodology makes it possible to determine the necessary range and volumes of spare elements for a known fleet of machines at a given load and under the conditions of ensuring the calculated level of reliability and serviceability of the equipment, maintenance, and repair. The application of the proposed method allows optimizing the cost of spare elements while ensuring the established level of reliable operation for machines and technological sets of equipment. Also, it becomes possible to obtain rational solutions for the formation of a warehouses network on different levels to meet the needs of firms with the dispersed operation of machines and mechanisms at a large number of objects.

1. Introduction

The intensification of machines parks usability is possible only under conditions of increasing the reliability of machines [1], reducing the time of repair and maintenance works [2]. One of the factors in achieving a new, increased level of equipment readiness is the presence of a sufficient number of reserve elements for vehicle fleets [3]. The reserve elements here mean spare parts, repair materials, reserve machines and units. The complexity of solving the problem is exacerbated by the following points: a sharp increase in the level of complex mechanization [4], the enlargement of machines parks, a large number of work objects [5], the desire to reduce the time of their construction. These factors have sharply raised the cost of a single machine downtime since the failure of one machine leads to a shutdown or a sharp decrease in the productivity of the entire technological set of machines at the facility [6]. On the other hand, with such a large amount of equipment, the warehouses of spare parts
increased sharply, the cost of temporarily dead capital rose. This, in turn, also leads to the increase in the cost of the work performed. The presence of extremely scarce parts further complicates this task [7]. The complexity of solving the problem of spare parts reserve is aggravated by the fact that some spare parts are suitable for several types of machines, and the other part is only suitable for one brand of machines [8]. At the same time, the nomenclature of the fleet is significant, the number of vehicles of the same type in each group varies [9] within wide limits. The problem of determining the rational volumes of redundancy for machines and their parts were solved earlier [10], but for construction machines in the developed methods, simplifications were adopted that did not provide the desired optimization [11].

2. Methodology

**Problem statement:** there is a fleet of machines with known characteristics of each unit. The operating time of each machine for the considered planned period is set. It is required to determine the need for spare elements to maintain the serviceability and operability of a machines fleet.

The task can be solved sequentially in the P stage:

Stage I. Determination of the number of machine elements failures;
Stage P. Solving the problem of determining the need for spare elements.

To obtain a specific numerical solution, it is necessary to collect the relevant statistics. For a number of construction equipment models, we collected such information, obtained regularities, which were then verified and showed the reliability of theoretical results.

3. Results

**Problem statement:** there is a fleet of machines with well-known characteristics of each unit. The operating time of each machine for the considered planned period is set. It is required to determine the need for spare parts in order to maintain the serviceability and operability of a machinery fleet.

The problem can be solved sequentially in II stages.

Stage I. Determining the number of failures for machine elements.

The pattern of machine failures during its operation is established.

\[
I_{1i} = (X_{1i}, X_{2i}, \ldots, X_{ni})
\]  

Where \((I_{1i})\) is the number of failures, \((i)\) is the machine, \((I) = \{1, 2, \ldots, I, \ldots, m\}\) is the set of indexes for a machine of the same kind, \(X_{1i}, X_{2i}, \ldots, X_{ni}\) is the factors affecting the flow of failures of the machine (the total operating time of the machine, the temperature of the environment, the qualification of the driver, soil conditions - for earthmoving machines, etc.).

The probability of a major repair in the period in question is determined. When capital repair is possible; the following condition must be met:

\[
\frac{T_{ik} + T_i}{T_k}
\]  

Where \((T_{ik})\) is the operating time of the \(i\)-machine from the last major repair, mach-hour; \((T_i)\) operating hours of the \(i\)-machine in the planned period, mach-hour; \((T_k)\) is the turnaround hours, mach-hour.

The probability of replacing a part during a major repair is revealed.

\[
P_{eni} = (1 - P_{ei})
\]

Where \((P_{eni})\) is the probability of replacing the \(e\)-part of the \(i\)-machine during a major repair; \((P_{ei})\) is the probability of the part being usable until the next repair.
If several identical elements are installed on the machine, then the probability of the number of replaced parts ($n_{eik}$) from the total number can be calculated by the (Equation 4).

$$n_{eik} = (1 - P_{eik})n_{ei} + a \quad (4)$$

Where (a) is the integer correction.

Similarly, the probability of replacing the part with a planned current repair is calculated.

Condition (2) is checked if there is no major repair, then the number of current repairs is determined by the dependence:

$$N_T = \frac{T_{ir} + T_i}{T_T} \quad (5)$$

If major repairs are made, then

$$NT = \frac{T_{ir} + T_i}{T_T} - a - 1 \quad (6)$$

Where ($T_{ir}$) is the operating time from the last scheduled repair, mach-hour; ($T_i$) is standard operating time between two current repairs.

The number of replaced parts $n'$ during current repairs of the $i$ machine

$$n'_{eir} = [(1 - P_{eir})n + a]N \quad (7)$$

Where ($P_{eir}$) is the probability that the part will not be replaced during the current repair.

A number of parts (for example, filters) are replaced during the maintenance of machines, after reaching the standard operating time.

The number of elements to be replaced in this case will be:

$$T'_{eiTo} = \frac{(T_{i3} + T_i - a)n_{eTo}}{T_T} \quad (8)$$

Where ($T_{i3}$) - time from the last part’s replacement, mach-hour; ($T_{3ei}$) is standard operating time between two replaced parts $i$ of the $i$ - machine.

Besides planned replacements, parts can be replaced as a result of an emergency failure. The probable need for these elements $n_{eia}$, for unplanned repairs will be equal to:

$$h'_{eia} = \frac{\lambda_{i}}{T_i} \sum P_{eia} + a \quad (9)$$

Where ($\lambda_{i}$) is the failure rate of the $i$ - machine in the considered period 1 / mach-hour, $x_i$ can vary for different periods of operation; ($P_{eia}$) is the likelihood that the $e$ -part of the $i$ - machine will be replaced during an unplanned repair.

If there are several such parts on the $i$ - machine, then

$$n'_{eia} = \frac{\lambda_{i}}{T_i} \sum P_{eia} + a \quad (10)$$

Where ($P_{eia}$) is the probability of failure of the $r$ unit

Thus, the total need for $e$ - parts for the $i$ - machine during its operation will be $e$ - part of the $i$-machine.

$$h_{ei} = h'_{eik} + h'_{eiT} + h'_{eiro} + h'_{eia} \quad (11)$$
Since the machines in the considered period $T$ can have different operating times, then for the cars the number of $e$-parts will be:

$$n_e = \sum_0^T \sum_{i=1}^M n_{ei}$$  \(12\)

Stage P. Solution of the problem of determining the need for spare parts.

The need for a fleet of machines in spare parts, meanwhile, depends on a number of reasons. These include seasonal uniformity of loading, changes in the intensity of parts replacements both during the year and throughout the entire service life.

We define the need in the $e$-parts at the $T$ planning period. Since during the planning period $T_i$ - machine can have an operating time $T$ equal to or less than this period (if they are given in the same units of measurement), then under the condition $T \geq T_i \geq 0$

There may be peaks of need in individual parts. Using statistical sampling, we can set the amplitude of the oscillations of the part output from the system as a whole for a machinery fleet.

The need for $e$-part in the most unfavorable way can be expressed through the (Eq.13):

$$n_e^n = k_{en} \frac{n_e^n}{T'}$$  \(13\)

Where ($T'$ ) is the planning calendar; ( $k_{en}$ ) is coefficient taking into account the maximum need for replacing the $e$-part; $n_e^n$ is the need for the $e$-part during the period of maximum exit from the structure of this part.

The total number of $e$-parts taking into account the unevenness of their deliveries to the organization’s warehouse is:

$$n_e^c = k_3 n_e$$  \(14\)

Where ($K_3$) is the reserve ratio taking into account the unevenness of supplies ($k_3 = 1.1 - 1.3$). For repairable revolving parts

$$n_e^c = k_3 (n_e + \frac{\sum_{Toei} n_e^c}{365})$$  \(15\)

Where ($Toei$) is the turnaround time of the $e$-repaired part on the $n$-machine; ($n_e$) is the number of replaced parts; ($n_e^c$) is the number of revolving parts.

### 4. Conclusion

This technique allows rationalizing the required amount of spare elements for the entire range of used units, parts, machines. The developed methodology allows solving the problem of the optimization of the formation of a warehouses network on various levels, both large and medium-sized enterprises, as well as factories - machine manufacturers, creating their own warehouses network and support points in the territory where their products are distributed.

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