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LOGISTICS OF MACHINERY AND EQUIPMENT REPAIR PROCESSES IN THE MANUFACTURING INDUSTRY

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Abstract: Maintaining continuity of production is an extremely important factor in the functioning of entities in the manufacturing industry. The importance of machinery and equipment maintenance is growing in the area of carrying out planned and emergency repairs to ensure the availability of spare parts or implementation of systematic maintenance. The article includes a logistic model of the process of repair and includes indicators of inventory management of spare parts. Simultaneous necessity to reduce production costs and efficient management of replacement parts logistics requires further actions and the use of new tools. The aim of the paper has been to present the selected indicators of the repair process and the availability of facilities, taking into account their critical features affecting the organization of this process. There have also been presented the main components of the process of eliminating damage based on the model of logistics repair. As a result of the conducted analyses, there have been identified the most important aspects of management of the repair process in the production company.
Keywords: *production logistics, repair process, inventory management, logistic model of machine maintenance, repair rate*

1. Introduction

Ensuring the availability of technological equipment is the basic condition for the accomplishment of production tasks. The area of upkeep of machinery and equipment is an important element of production logistics, whose task is to carry out repairs, provide the availability of spare parts or the implementation of systematic maintenance activities. Therefore, the effective use of the maximum production capacity requires both regular maintenance, efficient repairs and the availability of spare parts. The significance of the issue has determined the main objective of the paper which is the identification of the most important indicators of the repair process and the availability of facilities, taking into account their critical features, affecting the organization of the repair process.

2. Inventory management of spare parts

The pressure exerted by competition on an enterprise frequently constitutes one of the multiple factors defining the need for adjustment to the market requirements [1, 2]. At the same time, the awareness of entrepreneurs and manufacturers about the need to take account of the need for planning and executing manufacturing operations consistent with the principles of minimizing costs and maximizing productivity is increasing [3].

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During the operation of machines and devices, components are damaged, or their functional characteristics are lost as a result of gradual wear. An element after taking damage, can be restored (regenerated), restored to its original state in which it will again be able to carry out its tasks, a repaired element is also defined as an element restored to its original state of functionality [4].

Inventory management of serviceable parts is more complex than managing traditional supplies [5, 6]. The process of repair usually includes those parts that had already been previously repaired and returned for reuse. Inventories consist of items for which repair is usually less expensive than replacement [7]. "Developing a comprehensive support system for materials is not an easy task." [8]

The basic indicators used to evaluate the proper operation of serviceable parts include: the probability of correct operation and probability of damage occurrence [9].

The probability of correct operation of R(t) is the ratio of the number of undamaged parts until the time t and the number of all registered parts at the beginning of the period:

$$R(t) = \frac{I(t)}{k} \tag{1}$$

where:

I(t) – number of parts that have been damaged to the time *t,*

k – number of elements welded at the beginning of period *t,*

The probability of *damage* **occurrence** *q(t)* expresses the ratio of the number of damaged parts until the time t and the number of all parts:

$$q(t) = 1 - \frac{I(t)}{k} \tag{2}$$

In the case of irreparable parts, the main task seems to be the determination of the inventory level of parts so as to, in the absence of the parts, a supplementary order could be realized [10]. Optimization of the level of these components will be based on the analysis of the criterion of long-term reliability, the range of which depends on the time of execution or delivery conditions.

3. Selected indicators of equipment effectiveness

There are many indicators for assessing the performance of maintenance operations, only some of them are presented below, those related to the optimization of repair times of machinery and equipment included in the logistic model of device operation.

The **Mean Time Between Failures (MTBF)** is one of the key indicators to measure the reliability of system maintenance which assumes the average value of the total time between successive object dysfunctions [11]:

$$MTBF = MTTR + MTTF \tag{3}$$

where, calculation of the average time between failures requires technical knowledge on the **mean time to repair** (MTTR):

$$MTTR = \frac{T_n}{n} \tag{4}$$

and **the mean time to failure** (MTTF):

$$MTTF = \frac{(t_{db} - t_n)}{n} \tag{5}$$

where:

t – time elapsed since the occurrence of an unplanned failure to its repair,
t_{db} – time of complete planned availability of a technical facility designed to implement production, calculated without the planned downtime,
n – number of executed repairs.

In order to estimate the average time between failures, consider the identical time range in which maintenance of machines and equipment is carried out.

The **OEE** (**Overall Equipment Effectiveness**) indicator is a commonly used one, which is the main tool for measuring the performance evaluation of equipment in the TPM approach. The OEE is calculated as the product of the availability of *D*, the utilization factor *G* and the quality factor *H:*

$$OEE = D*G*H \tag{6}$$

This indicator is estimated on the basis of the operational availability of a machine, its load and the quality of manufactured products. The level of machine availability is significant in the logistic process of equipment maintenance. Based on the OEE, the equipment availability indicator can be determined, comprising the following component [12]:

- operational time, being the difference between the shift fund of operation and the time of planned downtime,
- unplanned equipment downtime which is the sum of failure, exchange time or other events that resulted in downtime,
- net operation time constituting the difference between the machine operation time and, sometimes, the unplanned downtime,
- availability indicator, calculated as the ratio of net operation time to operation time.

The OEE should be calculated for each of the machines that are used in the production process of the company. Their comparison will make it possible to determine the best and worst use of machines, pointing the direction and the area of improving the use of equipment operation time, which will increase its effectiveness in the long term.

4. Assessment of the availability of machines

Maintaining the established degree of production continuity requires a percentage estimate for the current level of trouble-free operation of all machines. For the purposes of the study elaborated, the availability indicator, which was adapted to the availability time of all machines *(Table 1).*

Table 1
Structure of the availability indicator of machines and devices, based on the OEE

Indicator components	**Indicator structure**
Shift fund operation time	T_S
Planned machine downtime	T_P
Operation time	$T_W = T_S - T_P$
Unplanned machine downtime	$T_{UnP} = \sum n_i$
n_1. Failures	
n_2. waiting for spare parts	
n_i. other causes	
Net Operating Time	$T_{En} = T_W - T_{UnP}$
Availability indicator	$I_a = \frac{T_{En}}{T_w} * 100\%$

Based on the equipment availability indicators and the assessment of its criticality based on the categorization of machinery, the logistic model of repair processes is subject to optimization with a focus on production continuity.

5. Logistic model of the repair process

In the production process, one of the key logistic activities aimed at ensuring production continuity is the proper care of the technical-technological equipment.

NATO military structures perceive the maintenance of equipment as one of the logistic functions implemented in the defense system, and it is one of the elements of logistics planning. The process of repairing machinery and equipment takes the form of a typical logistic process, which takes into account "means of all actions, including repair, to retain the material in or restore it to a specified condition" [13].

Considering the machinery and equipment repair process model, where the number of independent objects is K and the indicators of failure and repair are known, individual variables supporting the maintenance of technical equipment in a condition capable of efficient functionality can be specified (Figure 1).

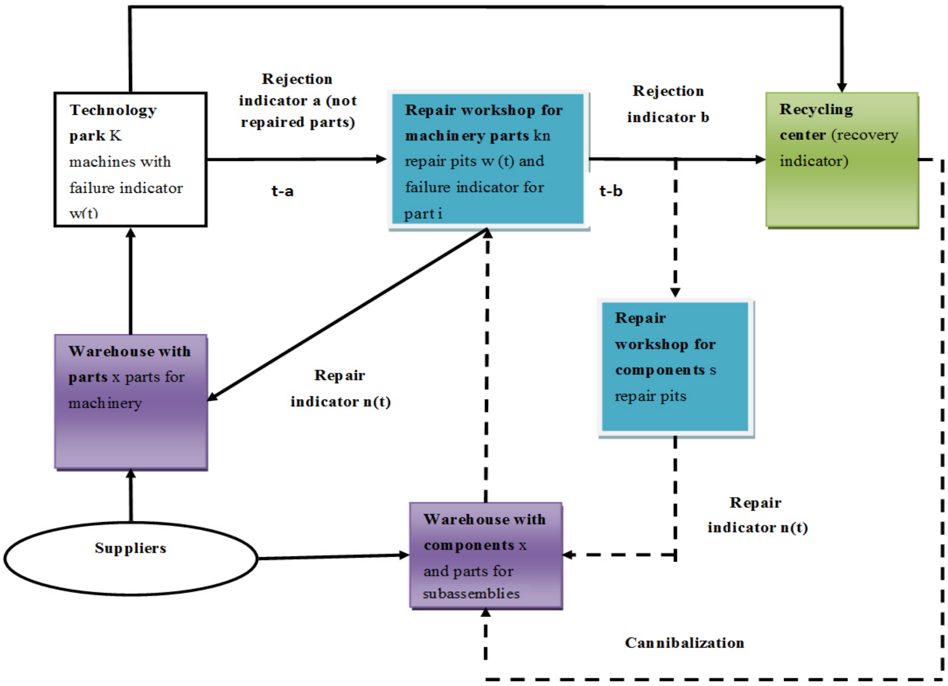

Figure 1. The main variables of the logistic model of machine maintenance [14]

Spare parts for machines are designated as a set X. When one of the machines from the set K is damaged, in order to re-start it, the defective part is exchanged from the set X. The broken part is delivered to a workshop equipped with parallel repair pits k_n. The defective part is repaired and returned to the warehouse with parts [15]. The repair process is completed when both the machine from the set K and the parts from the set X ceased to function at the same time. Observing the repair process of an object, consider the following assumptions [16]:

- object X is composed of X units each of which is under repair when it is damaged,
- damage and repair of each of the units included in the object occur independently of each other,
- damage to each unit generates a separate process of restoration,
- the structure of the object is known.

Given the assumptions of the model, assessment of reliability in the case of a reparable item will take into consideration both the operational time and the downtime when repair is performed. In the case of an irreparable item, equipment reliability assessment would only require the operational time of a technical facility and its components [17]. A universal repair cycle can be saved as consecutive states of an item during a failure [18]:

- s_1 – waiting for restoration. This condition is due to the technical and organizational requirements, during which human and equipment resources are mobilized to conduct the repair. Sometimes this condition is omitted in a situation when an item is removed during the preventive inspection and automatically directed for repair s_5.
- s_2 – diagnostics. A state of an item when the cause of damage is unknown and the dysfunction was detected during operation. In the case of noting a damage of a component during an inspection, this state may not take place.
- s_3 – waiting for parts. This state occurs when regeneration covers a subassembly of components.
- s_4 – a state in which a subassembly is subject to dismantling in order to repair individual parts.
- s_5 – repair – a state when regeneration of an item is conducted.
- s_6 – control of an item's capability of re-operation in the operational process. An item unfit for work is directed back to recovery.
- s_7 – completion of the recovery. When an item is suitable for operation, it is prepared for a restart.

The basic repair process can be observed during preventive maintenance or a failure when the defective element is removed from the system and replaced with another replacement part. At that time, the damaged component is sent to a workshop, where it is regenerated with the aim of restoring its original functionality [19, 13]. The logistic model of repair should take into account the processes of unification of repair management solutions based on the values of failure indicators and the availability of equipment, taking into account resource allocation and optimization of problems [20].

6. Summary

The main criterion of the operation of production logistics in the activity of industrial companies is efficient management of the possessed resources. This requires not only the concentration on the flow of materials and information but also is associated with providing the access to efficient technological equipment.

The size of the maintenance parts' inventory is largely due to the usage and maintenance of production equipment, thus effective management of the flow of spare parts, it is important to identify strategies for machinery and equipment repairs. Typically, the maximum downtime in the continuation of production processes is the result of the limited functionality of a system. Observing the failure indicator and the availability of machines can increase the predictability of demand for repair and the maintenance required, thereby increasing the efficiency of the system maintenance.

Systematic observation of the condition and availability of equipment is to increase the efficiency of the maintenance system and simultaneously facilitate the production process. The level and direction of the impact of the presented indicators on production logistics is the basis for further research.

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