THE WAY OF EXPLOITATION ASSESSMENT IN THE CONDITIONS OF OBJECT-ORIENTED SERVICING OF THE SELECTED PRODUCTION MACHINES AND EQUIPMENT

Sposób oceny eksploatacyjnej w warunkach obiektowego serwisowania wybranych maszyn i urządzeń produkcyjnych

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Abstract: The article discusses issues related to the ways of maintenance management of selected groups of production machines and devices. The first part identifies and characterizes two organizational models of machine servicing, i.e. the process model and the object model. It was justified that the object-oriented approach to machine servicing is an unusual concept, and it can be the basis for developing the models for the exploitation assessment of machines being the products of manufacturing processes, that require servicing tasks. As a result, it was proposed to use taxonomic methods for the purposes of developing a model, the analysis of which will allow the interpretation of the exploitation policy realized in the conditions of object-oriented servicing of machines and devices. The case study presented in the article confirms the possibility of building such models, and also justifies such analyzes for the purposes of shaping the exploitation decision-making process.
Keyword: maintenance, exploitation process, service of machines, taxonomy methods

Streszczenie: Artykuł omawia problemy zarządzania eksploatacją i utrzymaniem ruchu wybranych grup maszyn i urządzeń produkcyjnych. W pierwszej części zidentyfikowano i scharakteryzowano dwa organizacyjne modele serwisowania maszyn, to znaczy model procesowy i model obiektowy. Uzasadniono, że obiektowe podejście do serwisowania maszyn jest koncepcją nietypową i może być podstawą budowy modeli oceny eksploatacyjnej maszyn będących produktami procesów produkcyjnych i wymagającymi serwisowania. W efekcie zaproponowano wykorzystanie metod taksonomicznych dla potrzeb budowy modeli, których analiza pozwoli na interpretację polityki eksploatacyjnej prowadzonej w warunkach obiektowego serwisowania maszyn i urządzeń. Zaprezentowane w artykule studium przypadku potwierdza możliwość budowy takich modeli, a także uzasadnia prowadzenie tego typu analiz na potrzeby kształtowania eksploatacyjnego procesu decyzyjnego.
Słowa kluczowe: utrzymanie ruchu, procesy eksploatacyjne, serwisowanie maszyn, metody taksonomiczne

Introduction

In industrial practice, the need to achieve and maintain high operational efficiency applies not only to individual machines and devices, but primarily to complex technical systems (e.g. industrial installations, technological lines, network technical systems). Different durability and diagnostic and repair susceptibility of components of complex technical systems often impede rational exploitation. However, the total value (e.g. replacement cost) often exceeds the amounts that are currently available to maintain their efficiency. These factors cause, that in the aspect of the exploitation decision-making process of complex technical systems, it is necessary to jointly consider their constituents and together operating machines and devices. In the aspect of rapid development of operational methods as well as IT tools, it becomes justified to conduct the research related to the development of rational decision-making process concerning, among others, long-term operational processes as a part of the appropriate models of technical management.

Two separate processes are considered in the exploitation of machines and devices [8]:

a. exploitation process, which is an ordered collection of intentional and unintentional events occurring in the operation phase, as well as during the realization of maintenance tasks and procedures,
b. decision-making process, which is a sequence of decisions, whose effects relate to the way and scope of operate and/or maintenance proceedings, in relation to the exploited machines and devices, and also significantly affect the participants and the resources of the realized exploitation processes.

There is a clear and significant relationship between the operational process and the decision-making process. The specific steps in the decision-making process result not only from decision theory, but also from the specifics of the human-technical object relationship. This is reflected in the methods and conditions of operate, as well as conducting maintenance work.

Review of organizational models of machine servicing

The set of factors/criteria, necessary to be taken into account in the exploitation decision-making process, is multi-faceted in nature, related itself to the exploited technical object, as well as related to its broadly understood environment.

Long-term research of various authors [1, 4, 10] showed that the way of maintenance management, in particular, the realization of tasks defined by the pair: exploitation process - decision-making process, depends primarily on the selected method of organization of operating activities and maintenance works, as well as the technical and organizational context. Therefore, two main ways of servicing machines can be specified:

- process-oriented machine servicing,
- object-oriented machine servicing.

♦ Service and assessment of machines in the process-oriented system

The process-oriented way of machine service is strictly determined by the characteristics of the production process. The implementation of operational and decision-making processes results from the systemic ordering of machinery and devices. Such a system is located in the specific stationary organizational and technical conditions and is operated by the maintenance staff of the given (production) enterprise [2, 6]. This method is time-oriented, which means that the most important decision criterion is the time of realization of particular activities, which is a domain in the exploitation process (Fig. 1).

The process-oriented way of servicing machines is susceptible to apply most exploitation strategies, and hence, measures oriented on the identification, assessment and optimization of the time of the participation of exploitation processes in the production process. It can be mentioned here strategies, that are different forms of PM (preventive maintenance), based on the so-called service life [5].

The data resulting from the realization of exploitation processes, in the context of the process way of servicing are usually continuous in time and oriented to a specific technical system. This means that it is possible and susceptible to the use of CMMs/EAM tools for the purpose of data collection and processing. In this approach, the basis for the operation of such tools os constituted by individually built hierarchical models of the exploited technical systems, based on individual structural connections of components [4]. Exploitation measures are characterized by detailed identification and analysis of individual stages of the realization of exploitation processes. As a result, the use of statistical models is to allow optimization (minimization) of the share of time spent on maintenance works in the production process [2]. The hierarchical arrangement of the components of the technical system allows you to conduct analyzes at particular levels in the complex structure.

♦ Service and assessment of machines in the object-oriented system

The object-oriented way of servicing is determined by the specificity and exploitation characteristics of machines and devices. The implementation of exploitation processes and decision-making processes results from a separate discrete consideration of each of the serviced technical objects. Such facilities are located in various organizational and technical conditions (in various enterprises) and therefore they are treated discreetly by external entities carrying out the maintenance work. This method is object-oriented, which means that the most important decision criterion is the condition of the object in the context of the exploitation process and in the aspect of organizational and technical circumstances in which it operates. An important aspect that distinguishes object-oriented way from process-oriented way of machines servicing is the point of view of service personnel. In the object-oriented way, service covers many technical systems of the same or similar classes operated in different locations. In this context, the use of strategies typical of a process-oriented approach seems unpractical and sometimes even impossible. Each location of machines and devices work must be treated individually and separately, so it is necessary to adapt to the requirements and capabilities of maintenance services by users of technical systems.

Data resulting from the implementation of such processes are usually discrete in time, so they are dispersed and oriented on objects in specific locations,

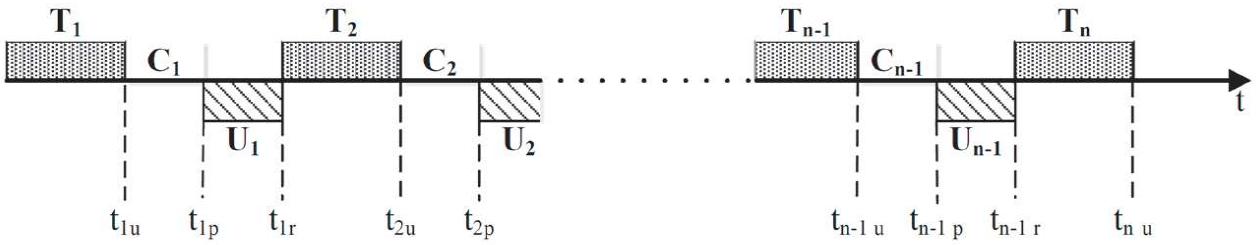

Fig. 1. The scheme of exploitation of the technical object in the conditions of process servicing of machines [5, 12]

as well as on specific classes of technical systems. In addition, industrial practice shows that the scope and the quality of data obtained from particular places of functioning of technical objects are much more limited than in the process-oriented way. It is caused by the lack of possibility of continuous supervision by service staffs over the implemented exploitation process, as well as a significant limitation of the scope of the acquired data on the context of implemented operational processes [11]. It allows carrying out analyzes based on registered values of machine work conditions, as well as exploitation history. Location dispersal of the data also determines a different approach to the use of common tools (CMMS/EAM systems) to support maintenance management tasks. In particular, there are required object-oriented models of technical system components (instead of the hierarchical ones), as well as the as-built way of proceeding maintenance works.

Taxonomic way of assessing machines service in the object-oriented system

On the basis of the specificity of machine servicing presented in the previous point, it can be said that in the object-oriented system, there are limitations on the use of exploitation assessment models typical in industrial practice, such as OEE, KPI or reliability indicators. The problem is mainly the dispersion and diversity of data acquisition sites (data sources), and the consequence is the potential incompleteness of information resources, as well as limited confidence in their credibility. Due to this reason, the assessment of the functioning of the machines may be subject to a significant error, and thus its value for the decision-making process can be reduced.

Therefore, for the purposes of the assessment of the machines exploitation in the object-oriented system, the author proposes the assumption, that the result of the realization of exploitation processes (the exploitation policy) is a function of three characteristics:

$$Y = f(k, c, l) \tag{1}$$

where: k - the cost of the service works, c - the time of the service works, l – the quantity of the service works

The above-mentioned characteristics are identified in the specific periods of time of production processes/exploitation processes (so-called macro times). In this way, it is possible to build models and determined measurement values related to defined groups (types) of machines or entire machine parks, with the simultaneous identification of the value and specificity of the exploitation policy. The use of feature aggregation methods allows to track changes in the exploitation policy in macro time (e.g. in subsequent years), analyze and evaluate its current level, as well as simulate and forecast the changes that may occur in the future [7].

The key aspect to implement the above assumptions is the selection of the method of aggregation of features. The author proposes the use of numerical taxonomy methods, which are traditionally used for linear ordering tasks [3, 9].

In this regard, it is proposed to develop synthetic measures using the features of the exploitation policy, and then using the obtained results in the analysis in a specific exploitation context. In particular, the construction of a synthetic measure using the Hellwig method is carried out according to the following procedure [3]:

A. Identification and ordering the input data, in the form of: the matrix of the features of the exploitation policy, the weight vector of the features of the exploitation policy, the weight vector of categories of the service and repair works:

$$x_{ij} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \cdots & \vdots \\ x_{p1} & \cdots & x_{pn} \end{bmatrix}, \quad WW = \begin{bmatrix} ww_1 \\ \vdots \\ ww_n \end{bmatrix}, \quad WK = \begin{bmatrix} wk_1 \\ \vdots \\ wk_p \end{bmatrix} \tag{2}$$

where: x_{ij} - values of features for particular categories of maintenance works, identified over a period of time limited by the number of completed maintenance cycles, $i=(1,...,p)$ - the number of key features included in the model of the assessment of the exploitation policy, $j=(1,...,n)$ - the number of maintenance work categories included in the model of the assessment of the exploitation policy, ww_j - the value that multiplies the importance of individual features in the assessment of exploitation policy, wk_i - the value differentiating the importance of individual categories of maintenance works in the assessment of the exploitation policy.

B. Determination of the matrix of normalized features

$$z_{ij} = \frac{x_{ij} - \overline{x}_j}{S(x_j)} \cdot ww_j \cdot wk_i \tag{3}$$

where: Z_{ij} - normalized feature, $\overline{x}_j$ - mean value of the feature class (column), $S(x_j)$ - standard deviation of the feature class (column).

C. Determination of synthetic measure, as a distance from the reference vector:

$$s_i = 1 - \frac{d_{i0}}{d_0}$$

where: $$d_{i0} = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_{0j})^2}, \qquad z_{0j} = \frac{\overline{z_j}}{s_j} \tag{4}$$

D. Determination of the coordinates of the geometric location of the synthetic measures:

$$x_i = \sqrt{\frac{\sum_{j=1}^{m} w_j \cdot (z_{ij} - \varphi_j)^2}{m \cdot (\overline{d} + 2 \cdot S_d)^2}} \quad ,$$

$$y_i = \sqrt{\frac{\sum_{j=1}^{m} [\![1 - w]\!]_j \cdot (z_{ij} - \varphi_j)^2}{m \cdot (\overline{d} + 2 \cdot S_d)^2}} \qquad (5)$$

where: $w_j = \frac{\omega_j}{\sum_{k=1}^{m} \omega_k}$, $\omega_j = \frac{S_j}{\overline{Z}_j}$

Based on the above procedure (1) – (5), there were determined taxonomic measures describing the exploitation policy.

Taxonomic assessment of machines service in a selected manufacturing company

The proposed way of building a machine service assessment model has been verified based on data from the realization of exploitation processes in a selected manufacturing company in the machines industry. For the purposes of verification, there was selected such an company, whose functioning corresponds to the conditions of object-oriented machine servicing. This company specializes in the production of machines and equipment that are part of automated production lines. In particular, this activity consists of unit and low volume production, sale and subsequent service of robotic palletizing lines, adapted to process almost any type of product and type of packaging, regardless of the weight, shape or material from which these elements were made. Therefore, the exploitation specificity of the discussed company applies simultaneously to two areas:

- servicing production machines and equipment, which are the components of the own machine park,
- servicing production machines and equipment, which are the effects (products) of the company production activity.

The exploitation problems of the first group of machines concern a typical process approach to servicing and will not be the subject of the solution proposed in this article. However, the second group of machines is characterized by object-specific servicing, because it is a set of discrete and locally dispersed technical systems. The exploitation assessment of such machines is less typical but susceptible to the proposed solution. That is why this group of machines of the examined enterprise will be the subject of the proposed taxonomic method of operational assessment.

The identification and analysis of the obtained historical service data allowed to specify the following input conditions:

- data came from the realization of maintenance works for production machines serviced at customer enterprises within one year (2017),
- diagnostic variables were determined based on three features of the exploitation policy: costs, time, quantity of maintenance work,
- diagnostic objects were created based on four categories of maintenance work: inspections, regulations/corrections, repairs, modernizations.

An ordered set of input data is presented in tab. 1.

Based on the data in tab. 1, and also in accordance with the formulas (1) – (5), there were carried out calculations, whose results are summarized in tab 2.

Tab. 1. Input data to the taxonomic method of the exploitation assessment

Diagnostic objects	Weights	Diagnostic features		
		Cost [PLN]	Time [hours]	Quantity of works
	wkj/wwi	1	1	1
Inspections	0,25	151 819,73	38 642	6 328
Regulations/Corrections	0,25	146 773,18	22 965	1 544
Repairs	0,25	192 134,67	8 741	530
Modernizations	0,25	561 928,82	10 908	1 296
Sum		1 052 656,40	81256	9698

Tab. 2. Values of taxonomic measures of the exploitation assessment

Diagnostic objects	Synthetic measure	Taxonomic geometric coordinates		
		x coordinate	y coordinate	Resultant coordinate
Inspections	0,2838	1,4502	2,1088	2,5593
Regulations/Corrections	0,6849	0,2143	0,2996	0,3683
Repairs	0,9742	0,4504	0,6476	0,7888
Modernizations	0,4525	0,6756	0,9372	1,1554

A graphical interpretation of the input data as well as the calculated taxonomic measures is shown in Fig. 2.

Interpretation of the obtained results

As a result of the proposed method, as well as on the basis of calculations, there were obtained values, which may constitute the basis for assessing the way and scope of the exploitation of machines and devices considered in the object service system. However, the method of analysis and interpretation of the results goes beyond the traditional way of using linear ordering methods. In the classic approach, the values of taxonomic measures have a direct impact on the value (position) of each of the assessed objects. In the approach proposed in the article, the complete taxonomic model is analyzed, taking into account the arrangement of all objects, as well as the relative differences in the values of the calculated measures.

The analysis of obtained and graphically summarized results of the development of the taxonomic assessment model consists in isolating the dominant categories of service works for the analyzed machines and devices, and then attempting to interpret the exploitation specificity of servicing procedures and machines. The domination of individual categories of maintenance work should be interpreted as one of two forms [7]:

- the absolute dominance of selected maintenance categories (taxonomic diagnostic objects), expressed in the form of maximizing the value of an appropriate taxonomic synthetic measure, while minimizing the resultant value of the taxonomic geometric distance (distance from the point of origin of the coordinate system),
- the relative dominance of selected categories of maintenance categories (taxonomic diagnostic objects), expressed by minimizing taxonomic geometric distances between particular categories within their clusters.

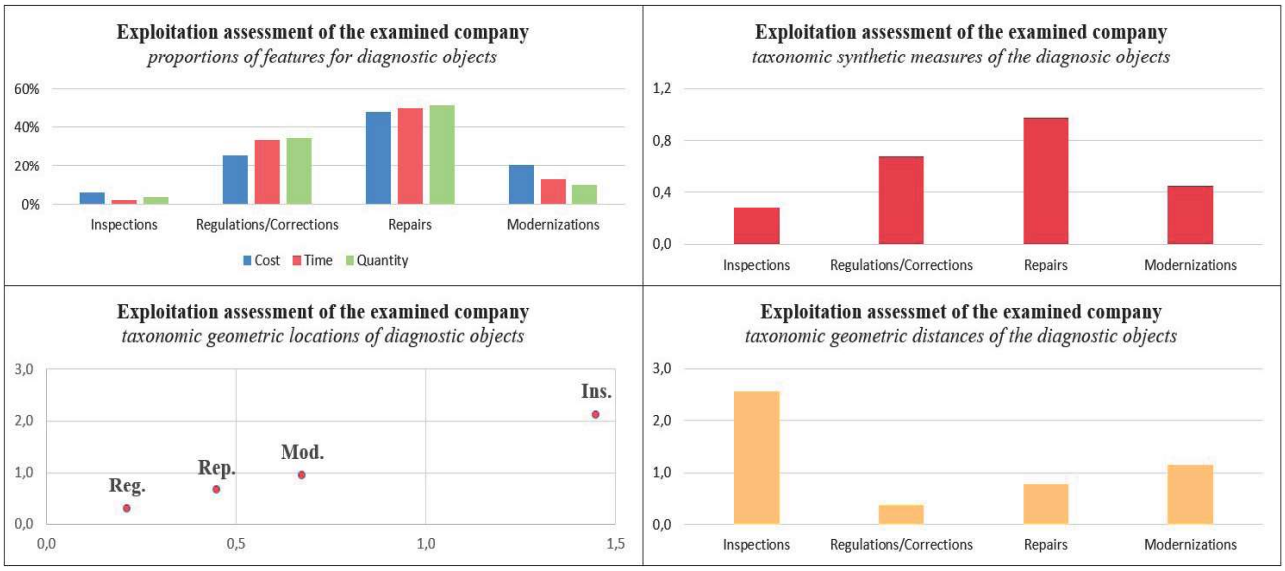

Fig. 2. Graphical interpretation of the results of the exploitation assessment of the examined production company

The exploitation policy realized in relation to the serviced machines and equipment by the analyzed company is characterized by:

- a distinct absolute taxonomic domination of repairs, with the addition of a fairly clear impact on the examined model of regulation/correction works,
- small (smallest in the analyzed case) taxonomic significance of inspections,
- medium mutual taxonomic dispersion of three categories of maintenance work (regulations, repairs, modernizations), with a small distance of the entire cluster from the beginning of the coordinate system, and at the same time a significant distance of the inspections both from the cluster and from the beginning of the coordinate system,
- the lack of distinct dominance of the values of particular features for individual diagnostic objects (categories of maintenance work).

According to the above interpretation, it should be stated that in taxonomic terms, the exploitation policy applied to the serviced machines is the nature of the intervention - of a normative type. This is indicated by the dominant taxonomic impact of repairs, but also a taxonomically balanced and significant system of regulation/corrections and modernization. The frequency and scope of work of these types is mainly based on the results of reliability tests, which corresponds to defining and fulfilling the predetermined norms.

Summary

The development of taxonomic models for the assessment of the exploitation policy allows for conducting the exploitation analyzes in atypical organizational and technical conditions, such as object-oriented machine servicing. In addition to classic analyses and interpretations related to the current time moment, there can be important indications, which are ahead of the current moment. Four concepts are possible and practically justified, in particular:

- linear analysis of the exploitation policy based on developed patterns,
- mutual comparative analysis of the exploitation policy of two or more maintenance organizations with similar business specificity,
- comparative analysis of the exploitation policy of the maintenance organization, carried out in relation to different time periods,
- simulation analysis of the exploitation policy, based on the controlled change in the value of selected features and weights.

From the concepts mentioned above, the first two are static in nature, referring to a specific moment of time, and in this approach they are the subject of interest in the current assessment of the exploitation policy. However, the other two concepts, due to the large time variability, can be used to assess the way and scope of functioning of the maintenance organization in dynamic changes in the environment, both in relation past features - current features, and in relation to the planned, considered or simulated conditions and specificity of the exploitation policy.

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