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METHODOLOGY OF VARIANT ASSESSMENT OF EXPLOITATION POLICY USING NUMERICAL TAXONOMY TOOLS

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Abstract:
The article shall discuss the possibility of exploitation policy assessment of companies managing complex technical systems. The analysis of the opportunities and needs of quantitative assessment of exploitation policy showed, that such assessment may be conducted on the basis of multidimensional set of values resulting from the synthesis of the key features associated with the performing maintenance works. Based on the results of previous studies, it was built taxonomic model for assessing exploitation policy, supplemented by an identification procedure of reference (positioning) taxonomic variants. The developed way of assessing exploitation policy will be subject of verification in terms of functioning of selected technical network systems.

***Key words**: exploitation policy, numerical taxonomy, exploitation decision-making process, efficiency assessment, maintenance management*

INTRODUCTION

The efficiency of exploitation of technical systems is defined inconsistently, due to the ongoing scientific discussions about the "effect" of work of object. In the classical approach, it's said about technical and/or economic efficiency [2, 6, 17]. More sophisticated interpretations assuming the possibility of shaping efficiency as the resultant of characteristics with different meanings [5, 10, 24, 28, 29]. Thus, efficiency issue is reflected in a wide range of research activities, that focus mostly on trying to determining mathematical models of measurements, as well as assessing the implementation of organizational procedures, allowing to obtain this efficiency. Contemporary publications describing the results of the research of exploitation/maintenance efficiency include attempts to build and industrial verification computational models, based on measurement under OEE indicator (Overall Equipment Effectiveness) [19, 26, 27], or more popular maintenance measures contained within the KPI indicators (ang. Key Performance Indicators) [1, 12, 23, 25], often associated with benchmarking issue [5, 22, 28].

Under the conditions of maintenance management of complex technical systems, exploitation efficiency is associated more with the results of maintenance department activity, rather than with the functioning individual technical object. Therefore, a quantitative measure of the efficiency can and should be formed within the exploitation policy evaluation. It is assumed that the exploitation policy, with a multi-faced character, includes a set of all possible realizations of exploitation decision-making situations, within defined structural and resource considerations, enable and/or facilitate the realization of operate and maintenance works [6, 8, 9]. Exploitation policy, realized with regard to the technical system can be described by the following general relation [9, 16]:

$$PE = \langle ESD_1, ESD_2, ..., ESD_n \rangle \quad (1)$$

where:
ESD_i - a set of attributes and mapping of this set for a single decision situation.

Defined in this way multi-faced exploitation policy, on the one hand, includes a set of exploitation processes, carried out in the internal environment (closer), and on the other hand, is a major component of exploitation decision-making process, realized by maintenance organization for the benefit of company in the external environment (further). It constitutes key component of maintenance management of technical systems (Fig. 1).

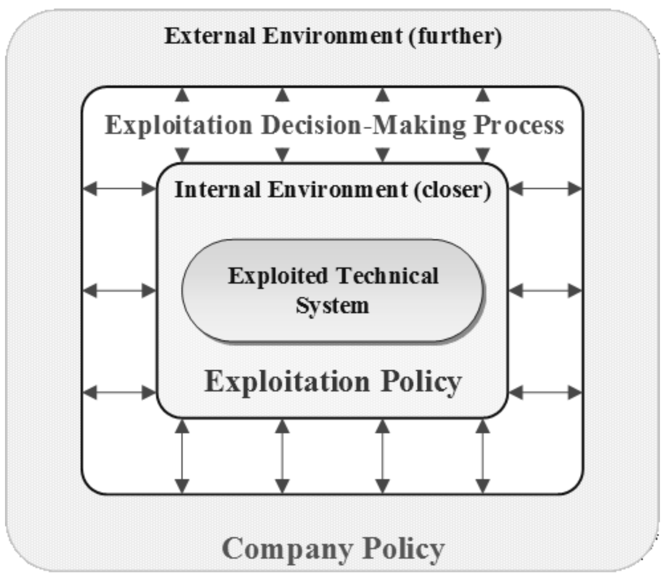

Fig. 1 Location of exploitation policy in the industrial company

Such an interpretation (both symbolic that descriptive), extends the scope of the term "exploitation policy" in relation to the terms used in the existing literature (including [9]). Listed extension refers to the personal role of the maintenance organization and objective place of exploited technical system, into exploitation decision-making process.

To describe exploitation policy can be used models such, as: model of areas and tasks of realization of management functions [6, 15], BCM model (Business Centered Maintenance) [8, 13], TPM model (Total Productive Maintenance) [19, 26], or graph model [9, 30]. They allow you to organize information about the "content of" exploitation policy realized for exploited technical systems.

In response to the above considerations, the author has developed consistent multi-faced method of assessing exploitation policy, which is one of the key components of research on methodology for exploitation process modelling with using scenario methods [14, 16].

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REVIEW OF NEEDS AND POSSIBILITIES OF BUILDING ASSESSMENT MODEL OF EXPLOITATION POLICY IN COMPLEX TECHNICAL SYSTEMS

The arguments formulated in the Introduction (section 1) allowed to clarify the assumptions about the possibility of building such a model for assessing, which should represent, in a quantitative manner, level and course (magnitude and direction) of changes of exploitation policy, expressed by the features, which are crucial but different in interpretation importance for examined object – maintenance organization. In particular, it is a possibility of comparing the features that are inherently incomparable.

It should be noted that the functioning of objects under consideration of the organizational and technical conditions, makes it necessary to identify data and information about the various stages of exploitation processes. Therefore, the assessment of exploitation policy may be carried out on the basis of set of values, describing completed maintenance works of specified categories, taking into account key features that describe the maintenance organization activities.

In view of these assumptions, and based on the results of previous work carried out in relation to exploited complex technical systems [7, 11, 16], the author has developed a method to assess the exploitation policy, including:

- taxonomic model of exploitation policy assessment,
- procedure of generating positioning pattern,
- variant assessment of exploitation policy based on the prepared data sets.

The proposed method takes into account solutions of taxonomic methods [3, 4, 18, 20, 21], known and used in the socio-economic area. Used in this regard mathematical models can perform a statistical comparison of the various interrelated categories.

The concept of using of taxonomic methods for the development of exploitation policy assessment model is based on the transformation of key features (cost, time and number of maintenance works), describing in a dispersed manner different parts of the analyzed exploitation processes, in the synthetic variable, which is the specific resultant of exploitation policy assessment in terms of considered events and processes. In turn, it allows to carry out a variant comparative analysis, and consequently – assessment of exploitation policy.

TAXONOMIC MODEL OF ASSESSMENT OF EXPLOITATION POLICY

Taxonomic methods in theoretical assumption, are a set of heterogeneous and highly dispersed mathematical models, selection and use of which depends on described phenomenon and accepted analysis purposes. Therefore, preliminary study relied on choosing, testing, and ultimately selecting these taxonomic methods and componential models, that are susceptible to the specificity specifics of realization and opportunity to describe exploitation processes. Released in this way taxonomic procedure for constructing exploitation policy assessment model includes four stages, which is schematically shown in Fig. 2.

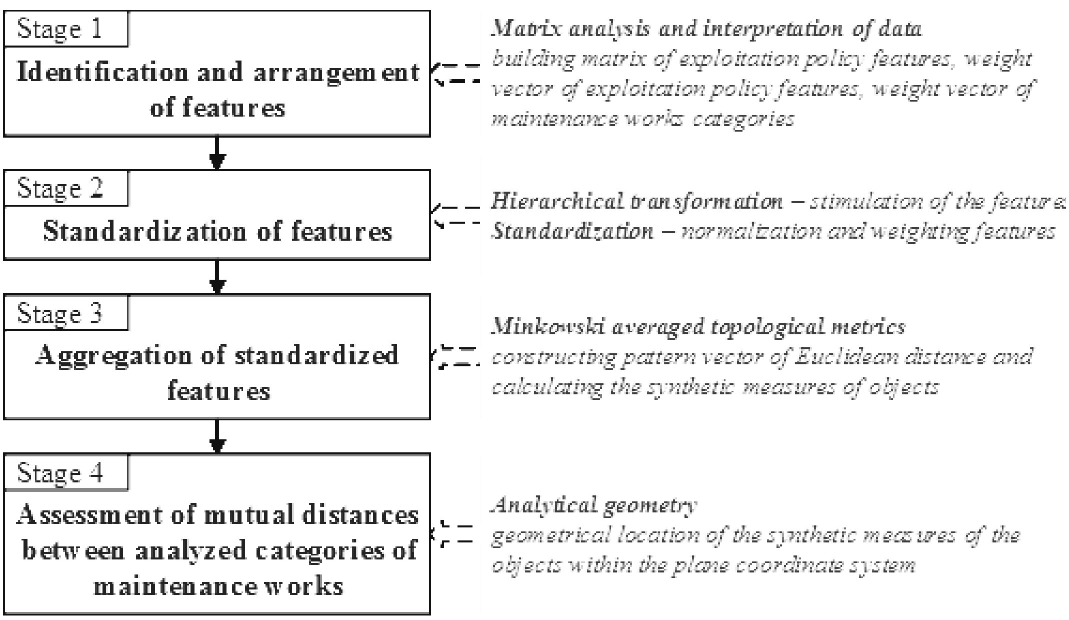

Fig. 2 The procedure for the construction of exploitation policy assessment model
Source: based on [18, 20].

The procedure, shown in Fig. 2, forms:

Stage 1: Identification and arrangement of features, consisting of choosing the key features of exploitation policy and their organization into the categories of maintenance works, typical for technical systems within the considered class (Table 1).

Table 1
Layout of input variables of exploitation policy assessment model

		Key feature n	...	Key feature n
	W/B	w_1	...	w_n
Category 1	b_1	ch_{11}	...	ch_{11}
...	...	...	...	...
Category p	b_n	ch_{p1}	...	ch_{pn}

The result of stage 1 is the set of matrices including: the matrix of exploitation policy features – A, the weight vector of exploitation policy features – W, the weight vector of maintenance works categories - B:

$$A = \begin{bmatrix} ch_{11} & \cdots & ch_{1n} \\ \vdots & \cdots & \vdots \\ ch_{p1} & \cdots & ch_{pn} \end{bmatrix} \quad W = \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} \quad B = \begin{bmatrix} b_1 \\ \vdots \\ b_p \end{bmatrix} \tag{2}$$

where:
n - the number of key features, taken into account in exploitation policy assessment,
p - the number of maintenance works categories, taken into account in exploitation policy assessment,
ch_{ij} - values of features for particular categories of maintenance works, identified in the time interval, which is limited by multiple of maintenance cycles,
w_j - the weight values multiplexing the importance of particular features in the assessment of exploitation policy,
b_j - the weight values differentiating the importance of particular categories of maintenance works within the exploitation policy.

Stage 2: Standardization of features that proceeding in two steps [18, 20]:

- stimulation of features, ie the hierarchical transformation, which results in the growing trend of all the features:

$$x_{ij} = \frac{1}{ch_{ij}} (i = 1,..., p, j = 1,..., n) \tag{3}$$

- normalization and weighting features based on the standardization procedure:

$$z_{ij} = \frac{x_{ij} - \overline{x_J}}{S(x_j)} w_j b_i \tag{4}$$

where:
z_{ij} – normalized feature,
x_J – the average value of feature class (column),
$S(x_j)$ – standard deviation of features class (columns).
The results of calculations, according to the formulas (3) – (4), form the matrices of standardized features Z.

$$W = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \cdots & \vdots \\ z_{p1} & \cdots & z_{pn} \end{bmatrix} \tag{5}$$

Stage 3: Aggregation of standardized features, which runs within three steps [18]:

- defining the pattern vector (with using Minkowski averaged topological metrics):

$$O_0 = [z_{0j}] \tag{6}$$

where:

$$z_{0j} = \frac{\overline{z_J}}{S_j} \tag{7}$$

- determining the geometric distance from maintenance works categories to pattern object, based on Euclidean measure:

$$d_{i0} = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_{0j})^2} \tag{8}$$

- determining synthetic measures for particular categories of maintenance works:

$$s_i = 1 - \frac{d_{i0}}{d_0} \tag{9}$$

where:

$$d_0 = \overline{d_0} + 2S(d_0), \quad \overline{d_0} = \frac{1}{n}\sum_{i=1}^{n} d_{i0},$$

$$S(d_0) = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (d_{i0} - d_0)^2} \tag{10}$$

Stage 4: Assessment of mutual distances (dependiences) between analyzed categories of maintenance works. Using the properties of planar analytical geometry [20], there is determinated:

- coordinate values representing flat location points of particular categories of maintenance works:

$$x_i \sqrt{\frac{\sum_{j=1}^{m} w_j (z_{ij} - \varphi_j)^2}{m(\overline{d} + 2Sd)^2}}, \; y_i \sqrt{\frac{\sum_{j=1}^{m} (1 - w_j)(z_{ij} - \varphi_j)^2}{m(\overline{d} + 2Sd)^2}} \tag{11}$$

where:
w_j – importance coefficient,
ω_j – variation coefficient:

$$w_j = \frac{\omega_j}{\sum_{k=1}^{m} \omega_k}, \omega_j = \frac{s_j}{\overline{x_j}} \tag{12}$$

- geometric distances of locations of particular maintenance works categories from the origin:

$$D_i = \sqrt{x_i^2 + y_i^2}, (i = 1,..., p) \tag{13}$$

Determined characteristics specify the taxonomic level of distance of each of the maintenance works categories from the pattern. This is the basis of assessment of their contribution within the exploitation policy.

PROCEDURE OF GENERATING POSITIONING PATTERN OF EXPLOITATION POLICY ASSESSMENT

Determined values of taxonomic measures express the impact of selected features on the functioning maintenance organization, pointing to quantify the relative proportions between particular categories of maintenance works. However, multi-faced nature of proposed assessment method, expressed in the form of calculated resultant values of taxonomic measures, reflects in the complexity of the problem interpretation, which should be carried out in comparative view. It requires defining reference patterns (positioning), structurally similar to exploitation policy assessment models and representing measure of taxonomi distance of analyzed realizations of exploitation processess from possible or desired situation. It was not until, on a background of thus prepared patterns, exploitation policy assessment of analyzed technical systems may be carried out.

The procedure for generating positioning patterns was based on the implementation of the four major stage, which are schematically shown in Fig. 3.

Proposed procedure, susceptible to observation and mapping past and present "exploitation reality", assumes the need to develop a pattern structure of maintenance works, based on a set of defined parameters (which are the result of direct experiences and objectives of decision makers of maintenance organizations), then its quantitative description with the use the taxonomic model, shown in section 3.

Step 1: Defining the initial and the boundary parameters

This step consists in determining the values of the basic parameters defining the pattern structure of maintenance works, particularly:

- defining a set of initial parameters of pattern structure of maintenance works (Table 2)
- defining a set of boundary parameters of features, which describe pattern exploitation policy:

$$Cg_{ij}=<cmin_{ij}: cmax_{ij}>, Tg_{ij}=<tmin_{ij}: tmax_{ij}> \quad (14)$$

where:

$$i=1,\ldots,z, j=1,\ldots,p \quad (15)$$

i – established number of levels of maintenance works complexity,

j – established number of maintenance works categories,

Cg_{ij} – a set of boundary values, describing the range of the cost, as part of the i-th level of complexity of the maintenance works in the j-th category,

Tg_{ij} – a set of boundary values, describing time period, within i-th level of complexity of the maintenance works in j-th category,

mini, $cmax_{ij}$ – established boundary cost values, within i-th level of complexity of the maintenance works,

$tmin_{ij}$, $tmax_{ij}$ – established boundary time values, within i-th level of complexity of the maintenance works.

- defining quantitative structure of the maintenance works, in particular:

lz_{ij} – established relative (percentage) number of maintenance works of j-th category per i-th level of their complexity,

lp_j – established relative (percentage) number of maintenance works of j-th category.

Listed boundary and initial parameters are shown in Table 3.

Step 2: Identyfying features values of maintenance works structure

This step consists in using initial and boundary values, established and/or calculated in step 1, to build a quantitative model describing the pattern structure of maintenance works.

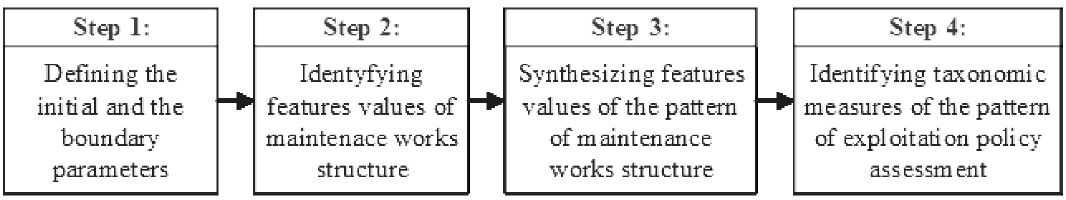

Fig. 2 The procedure for the construction of positioning patterns of exploitation policy assessment

Table 2
Summary of initial parameters of pattern structure of maintenance works

Parameter	Description
m	assumed total of maintenance works
P	assumed number of categories of maintenance works
z	assumed number of complexity levels of maintenance works

Table 3
A way of organizing limit and initial features of maintenance works structure for the construction of exploitation policy assessment patterns

Works category/Complexity level	Cost		Time		Number
	$cmin_{ij}$	$cmax_{ij}$	$tmin_{ij}$	$tmax_{ij}$	lp_j
Category 1					lp_1
Works complexity level 1	$cmin_{11}$	$cmax_{11}$	$tmin_{11}$	$tmax_{11}$	lz_{11}
...	...	...	...	...	...
Works complexity level z	$cmin_{z1}$	$cmax_{z1}$	$tmin_{z1}$	$tmax_{z1}$	lz_{z1}
...	...	...	...	...	...
Category p					lp_p
Works complexity level 1	$cmin_{1p}$	$cmax_{1p}$	$tmin_{1p}$	$tmax_{1p}$	lz_{1p}
...	...	...	...	...	...
Works complexity level z	$cmin_{zp}$	$cmax_{zp}$	$tmin_{zp}$	$tmax_{zp}$	lz_{zp}

$$Ck_{ij} = \frac{c\max_i c\min_i}{2} Lk_{ij}, \quad Tk_{ij} = \frac{t\max_i t\min_i}{2} Lk_{ij},$$

$$Lk_{ij} = lp_j lz_{ij} m \tag{16}$$

where:

$$i = 1,...,z, \quad j = 1,..., p, \quad lz_i \in < 0,1 >, \quad lp_j \in < 0,1 >,$$

$$\sum_{i=1}^{p} lz_i = 1 \quad \sum_{j=1}^{k} lp_j = 1 \tag{17}$$

Ck_{ij} – the cost of maintenance works, within i-th level of complexity of the maintenance works in j-th category,
Tk_{ij} – the time value of maintenance works, within i-th level of complexity of the maintenance works in j-th category,
Lk_{ij} – the number of maintenance works, within i-th level of complexity of the maintenance works in j-th category.

In the typical approach (intended by the author), the structure has to be based on the following values: cost, time and number of maintenance works, ordered within each category of work and levels of their complexity.

The way of organizing features values of maintenance works structure description, for the needs of building patterns of exploitation policy assessment, are listed in the Table 4.

Table 4
A way of organizing maintenance works structure features for the construction of exploitation policy assessment patterns

Works category/ Complexity level	Cost	Time	Number
	Ck_{ij}	Tk_{ij}	Lk_{ij}
Category 1			
Works complexity level 1	Ck_{11}	Tk_{11}	Lk_{11}
...	...	...	...
Works complexity level z	Ck_{z1}	Tk_{z1}	Lk_{z1}
...	...	...	...
Category p			
Works complexity level 1	Ck_{1p}	Tk_{1p}	Lk_{1p}
...			
Works complexity level z	Ck_{zp}	Tk_{zp}	Lk_{zp}

Step 3: Synthesizing features values of the pattern of maintenance works structure

This step consists in calculating aggregated data of the features (cost, time and number of works), within particular categories of maintenance works, according to the following formulas:

$$C_j = \sum_{i=1}^{z} Ck_{ij}, \quad T_j = \sum_{i=1}^{z} Tk_{ij}, \quad L_j = \sum_{i=1}^{z} Lk_{ij} \tag{18}$$

where:
L_{ij} – the total number of maintenance works, in the j-th category,
C_{ij} – the total value of costs of maintenance works, in the j-th category,
T_{ij} – the total of time value of maintenance works, in the j-th category.

The result of the calculation is ordering the structure of the maintenance works within a single pattern (Table 5).

Step 4: Identifying taxonomic measures of the pattern of exploitation policy assessment

Prepared and organized structure of maintenance works is now ready to determine the taxonomic measures of exploitation policy assessment. Because of comparative aim of patterns of exploitation policy assessment, taxonomic calculations have to be performed on the basis of a set of equations (2) – (13), contained in section 3 of the article.

Table 5
A way of organizing maintenance works structure for the construction of exploitation policy assessment patterns

Works category	Cost	Time	Number
Works category 1	C_1	T_1	L_1
...	...	...	...
Works category p	C_p	T_p	L_p
Amount	$CC = \sum_{j=1}^{k} C_j$	$TC = \sum_{j=1}^{k} T_j$	$LC = \sum_{j=1}^{k} L_j$

DISCUSSION ON THE POSSIBILITY OF USING DEVELOPED METHODOLOGY FOR ASSESSING EXPLOITATION POLICY OF COMPLEX TECHNICAL SYSTEMS

Building of taxonomic models of exploitation policy assessment (both pattern - positioning, as well as those that describe the exploitation policies of complex technical systems) allows to carry out an analysis of the maintenance organizations. There are possible and reasonably practicable four concepts, in particular:

- linear analysis of exploitation policy based on the developed positioning patterns,
- mutual comparative analysis of exploitation policy for the maintenance organization with similar specificity of activity (eg. a comparison of the two maintenance organizations managing separate technical systems),
- time comparative analysis of exploitation policy, carried out within the various maintenance cycles,
- simulation analysis of exploitation policy, based on controlled changing the value of selected features and weights, within the future (planned or projected) maintenance cycles.

Within those concepts, the first two have a static nature, relating to a predetermined point in time, and in this perspective they are of interest in the present assessment of exploitation policy. Third and fourth concepts, due to the high variability of the time, can be used to assess the manner and scope of functioning of the maintenance organization in under conditions of dynamic changes of environment, both in the relationship: the features of the past – the features of the present, as well as in relation to the planned or simulated condition and specifics of exploitation policy.

The present assessment of exploitation policy may proceed in two steps:

1. Extract the dominant category of maintenance works of the analyzed technical system, and then attempt the initial (linear) interpretation of the nature and specificity of exploitation policy. The dominance of particular categories of maintenance works should be interpreted as one of two forms:
   - the absolute domination of selected categories of maintenance works, expressed as a minimization of synthetic measure, whilst maximization of the resultant of geometric distance, which may constitute nature of exploitation policy,
   - the relative dominance of selected categories of maintenance works, expressed as a maximization of the geometric distances between individual catego-

ries, in the context of forming agglomerates (larger mutual distance between categories/clusters, means the larger relative dominance of the analyzed categories/clusters).

2. Carrying out comparative procedures, on the background of patterns or taxonomic model of exploitation policy of another technical system with similar specificity. Then to attempt interpretation of exploitation conditions of maintenance organization, in terms of both taxonomic similarities, as well as the level of alignment of the individual features describing the structure of maintenance works.

The described comparative procedure should include a reference of key features values of analyzed technical systems to the corresponding analogous features of the patterns. Such a comparison, carried out for each category of maintenance works should proceed according to the following relationships:

$$Ps_{min} = \min_{1 \geq j \geq 3} \left| \sum_{i=1}^{4} \left(Ss_i - Sw_{ij} \right) \right|$$
$$Pd_{min} = \min_{1 \geq j \geq 3} \left| \sum_{i=1}^{4} \left(Ds_i - Dw_{ij} \right) \right| \quad (19)$$

where:

Ps_{min} – the result of comparing assessment of exploitation policy of technical system with positioning pattern, in the field of synthetic measure, for particular categories of maintenance works,

Pd_{min} – the result of comparing assessment of exploitation policy of technical system with positioning pattern, in the field of geometric distance, for particular categories of maintenance works,

Ss_i – synthetic measure of assessment of exploitation policy of technical system, for particular categories of maintenance works,

Sw_i – synthetic measure of positioning pattern of assessment of exploitation policy, for particular categories of maintenance works,

Ds_i – geometric distance value of assessment of exploitation policy, for particular categories of maintenance works,

Dw_i – geometric distance value of positioning pattern of assessment of exploitation policy, for particular categories of maintenance works.

Models of exploitation policy of analyzed technical systems take the specificity and nature of the positioning patterns with the highest taxonomic similarity, ie in the case of the smallest resultant values absolute differences for the corresponding synthetic measures and geometric distance (19).

CONCLUSIONS

On the basis of the constructed taxonomic model, it has been shown the possibility, as well as the need for a comprehensive assessment of exploitation policy in multifaceted approach (taking into account the features of different types). Thus prepared methodology of modelling exploitation policy, based on resources of historical data about realization of exploitation processes, can be an important part of the assessment and shaping exploitation decision-making process formulated in the long term [14].

The developed method of assessing exploitation policy will be subject to verification under conditions of functioning operationally specific technical systems, which are technical network systems (including water supply system, sewer system, heating system). The research results of the verification will be published in the next article of the author (in the next issue of the Management Systems in Production Engineering), entitled: Variant assessment of exploitation policy of selected companies managing technical network systems.

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