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Patterning as a way to identify and assessment of the exploitation policy of selected technical systems

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INTRODUCTION

The exploitation decision-making process represents subject and the effect of direct, indirect or mutual influence on the technical system, including two groups of factors:

- factors of the external environment, being a set of the features of the company's policy, realized with regard to the service effects of exploitation of technical system,
- factors of the internal environment, being a set of features of the exploitation policy, enabling and/or facilitating the realization of operation and maintenance works in relation to technical systems.

In the context of maintenance management tasks, the exploitation decision-making process focuses the effects of shaping the exploitation policy, being the subject of its assessment, in the context of the functioning of the technical system, as well as in terms of requirements and conditions of the maintenance organization environment (Antosz, 2018, Palka at al., 2018, Biały & Ruzbarsky, 2018, Timofiejczuk at al., 2018). The exploitation policy should be interpreted here as a set of possible events, process and decisions, which are closely related to the structure, resources and environment of the exploited technical system (Loska & Paszkowski, 2017).

The assessment of the exploitation policy allows for analyzing functioning of the maintenance organization. Four concepts are possible and practically justified in this respect, in particular:

- linear analysis of the exploitation policy,
- mutual comparative analysis of the exploitation policy of two maintenance organizations with similar specificity of activity,
- temporary comparative analysis of the exploitation policy of the maintenance organization, carried out in relation to different periods,
- simulation analysis of the exploitation policy, of the maintenance organization, based on a controlled change in the value of selected features and weights.

Of the above mentioned concepts, the first two are static, referring to a specific point in time, and in this approach they are of interest in the current assessment of the exploitation policy. However, the other two concepts, due to the high variability of time, can be used to assess the functioning of the maintenance organization in the conditions of dynamic changes in the environment. All concepts assume the need to develop:

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- models of exploitation policy assessment, based on selected measurable features,
- pattern models, as reference and interpretations points of the assessment of the exploitation policy.

This approach is justified by the multifaceted nature of exploitation features. This causes the complexity of the problem of interpretation, which requires defining reference patterns, that are structurally similar to models of the assessment of the exploitation policy. Therefore, the subject of the next part of the article will be the concept of pattern models for the assessment of the exploitation policy. These models will be adapted to the taxonomic method (Hellwig 1968, Młodak, 2006, Panek, 2009), of evaluating the exploitation policy, developed by the author and described in (Loska, 2015).

DEVELOPMENT OF PATTERN MODELS OF THE ASSESSMENT OF THE EXPLOITATION POLICY

For the purpose of developing pattern models for the assessment of the exploitation policy, it was assumed that the pattern is a measure of the distance of the analyzed real exploitation policy from the possible or intended situation. This solution assumes the necessity to develop a model structure of maintenance works, based on a set of definable features, whose values are the result of direct experiences and intentions of the maintenance organization decision makers. In this regard, the following was identified:

- the structure of maintenance works based on four types of tasks: inspections, maintenance, repairs, overhauls,
- a set of three features describing the maintenance activity: costs, time and the quantity of maintenance works.

The development of pattern models for the assessment of the exploitation policy was based on the realization of the four main steps, which are presented in Fig 1.

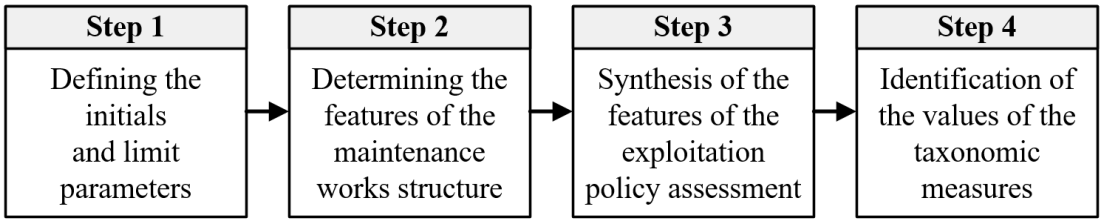

Fig. 1 The procedure for elaborating a pattern model of exploitation policy assessment

Defining the initials and range parameters

This step consists in determining the value of the basic parameters defining the structure of maintenance works, in particular.

- initial parameters of the structure of maintenance works, including:
  m – total quantity of maintenance works in the pattern,
  p – quantity of the categories of the maintenance works,
  z – quantity of the complexity levels of the maintenance works.
- a set of initial and range parameters of the features describing the exploitation policy:

$$Cg_{ij} =< c_{min_{ij}}; c_{max_{ij}} >$$
$$Tg_{ij} =< t_{min_{ij}}; t_{max_{ij}} > \quad (1)$$

where:
$i = \langle 1, \dots, z \rangle$ - the number of complexity levels of maintenance works,
$j = \langle 1, \dots, p \rangle$ - the number of categories of maintenance works,
Cg_{ij} – a set of range values, describing the range of costs, within the i-th complexity level of maintenance works, in the j-th category,
Tg_{ij} – a set of range values, describing the range of time, within the i-th complexity level of maintenance works, in the j-th category,
c_{minij}, c_{maxij} – cost range values, within the i-th complexity level of maintenance works, in the j-th category,
t_{minij}, t_{maxij} – time range values, within the i-th complexity level of maintenance works, in the j-th category.
Defining the quantitative structure of maintenance works, by arranging the initial and range features, including:
lz_{ij} – the relative (percentage) quantity of maintenance works, per i-th level of complexity of maintenance works,
lp_j – the relative (percentage) quantity of maintenance works, per j-th category of maintenance works.
Identified range and initial parameters, are presented in an orderly form in the Table 1.

Table 1
Arrangement of range and initial parameters of the maintenance works structure, for the purpose of developing the pattern model of the assessment of the exploitation policy

Category of works/level of complexity	Costs		Time		Quantity
	$cmin_{ij}$	$cmax_{ij}$	$tmin_{ij}$	$tmax_{ij}$	lp_j
Category 1					lp_1
Level of complexity 1	$cmin_{11}$	$cmax_{11}$	$tmin_{11}$	$tmax_{11}$	lz_{11}
...	...	...	...	...	...
Level of complexity z	$cmin_{z1}$	$cmax_{z1}$	$tmin_{z1}$	$tmax_{z1}$	lz_{z1}
...	...	...	...	...	...
Category p					lp_p
Level of complexity 1	$cmin_{1p}$	$cmax_{1p}$	$tmin_{1p}$	$tmax_{1p}$	lz_{1p}
...	...	...	...	...	...
Level of complexity z	$cmin_{zp}$	$cmax_{zp}$	$tmin_{zp}$	$tmax_{zp}$	lz_{zp}

Determining the features of the maintenance works structure
This step consists of using the parameter values, defined in step 1, to develop a quantitative model, describing the structure of maintenance works. Such a structure is based on the values of costs, time and the quantity of maintenance works, ordered within particular levels of complexity and categories.

$$Ck_{ij} = \frac{cmax_{ij} \cdot cmin_{ij}}{2} \cdot Lk_{ij}$$
$$Tk_{ij} = \frac{tmax_{ij} \cdot tmin_{ij}}{2} \cdot Lk_{ij} \quad (2)$$

where:

$$Lk_{ij} = lp_j \cdot lz_{ij} \cdot m$$
$$lz_i \in < 0,1 >;\ lp_j \in < 0,1 > \quad (3)$$
$$\sum_{i=1}^{p} lz_i = 1;\ \sum_{j=1}^{k} lp_j = 1$$

$i = \langle 1, \dots, z \rangle$ - the number of complexity levels of maintenance works,
$j = \langle 1, \dots, p \rangle$ - the number of categories of maintenance works,
Ck_{ij} – the cost value of maintenance works, per i-th level of complexity of maintenance work, in the j-th category,
Tk_{ij} – the time value of maintenance works, per i-th level of complexity of maintenance work, in the j-th category,
Lk_{ij} – quantity of maintenance works, per i-th level of complexity of maintenance work, in the j-th category.
The way of arranging the values of the features describing the structure of maintenance works, for the development of a pattern model of exploitation policy assessment, is included in the Table 2.

Table 2
Arrangement of the features of the maintenance works structure, for the purpose of developing the pattern model of the assessment of the exploitation policy

Category of works/level of complexity	Costs	Time	Quantity
	Ck_{ij}	Tk_{ij}	Lk_{ij}
Category 1			
Level of complexity 1	Ck_{11}	Tk_{11}	Lk_{11}
...	...	...	...
Level of complexity z	Ck_{z1}	Tk_{z1}	Lk_{z1}
...	...	...	...
Category p			
Level of complexity 1	Ck_{1p}	Tk_{1p}	Lk_{1p}
...	...	...	...
Level of complexity z	Ck_{zp}	Tk_{zp}	Lk_{zp}

Synthesis of the features of the exploitation policy assessment

This step consists in determining the total values of the features (costs, time and quantity), within particular categories of maintenance and repair works, according to the following dependencies:

$$C_j = \sum_{i=1}^{z} Ck_{ij};\ T_j = \sum_{i=1}^{z} Tk_{ij};\ L_j = \sum_{i=1}^{z} Lk_{ij} \quad (4)$$

where:
$i = \langle 1, \dots, z \rangle$ - the number of complexity levels of maintenance works,
$j = \langle 1, \dots, p \rangle$ - the number of categories of maintenance works,
C_j – the total value of costs of maintenance works, in the j-th category,
T_j – the total value of time of maintenance works, in the j-th category,
L_j – the total quantity of maintenance works, in the j-th category.
As a result of this step, the structure of maintenance works is organized within a single pattern.

Table 3
Arrangement of the maintenance works structure, of the pattern model of the assessment of the exploitation policy

Category of works	Cost	Time	Quantity
Category 1	C_1	T_1	L_1
...	...	...	...
Category p	C_p	T_p	L_p
Sum	$CC = \sum_{j=1}^{k} C_j$	$TC = \sum_{j=1}^{k} T_j$	$LC = \sum_{j=1}^{k} L_j$

Identification of the values of the taxonomic measures

The developed and arranged structure of maintenance works is the basis for determining the taxonomic measures of the assessment of the exploitation policy. Due to the comparative purpose of the developed model models, calculations will be based on the Hellwig's taxonomy guidelines in the form of a set of formulas ((Hellwig 1968, Młodak, 2006, Panek, 2009) prepared by the author and described in (Loska, 2015, Loska, 2017). In this case, a synthetic measure was selected as way of the assessment of the exploitation policy, based on the identified three features of the exploitation policy (costs, time, the number of maintenance works), determined within the structure of the maintenance works (inspections, maintenance, repairs, overhauls). In addition, it was determined the measure of geometric distances identified in the Euclidean plane.

PATTERN MODELS FOR THE ASSESSMENT OF THE EXPLOITATION POLICY SELECTED TECHNICAL SYSTEMS – CASE STUDY

In order to verify the developed way of building pattern models for the assessment of the exploitation policy, it was prepared an ordered package of three separate pattern procedures of exploitation of technical network systems.

Technical network systems are included in the technical infrastructure, which is the basis of operation of municipal engineering sectors (Kaźmierczak at al. 2018, Wyczółkowski & Matysiak, 2009). Through the technical network systems, there are supplied various types of media complying with the required specifications to multiply groups of customers, territorially dispersed and belonging to different categories, such as households, industrial plants, utilities, service facilities and other (Jasiulewicz-Kaczmarek at al., 2017, Karwot at al., 2017, Kozłowski at al. 2018). The most common technical network systems include the:

- water supply system – which functions is water supply to customers in an organized and constant manner, with the required level of pressure and of appropriate quality,
- sewer system – allowing the discharge of domestic, industrial, rain and snowmelt sewage to the wastewater treatment plants, and then to the final receiver after appropriate cleaning,
- heat supply system – main task is to transfer heat from the heat source (power plant, heating plant, boiler) to heat consumers, which are residential buildings, public buildings, industrial sites.

The technical network systems consist of devices, which concern typical exploitation events, what a consequence it is the necessity of carrying out regular maintenance and works. For this reason, network technical systems are susceptible to the way of the assessment of the exploitation policy, presented in this article.

In this case, it have been determined the following initial parameters:

- development of three patterns of the assessment of the exploitation policy,
- ordering the features values (costs, time and quantity) for 1000 maintenance works,
- five classes of organizational, technical and economic complexity of maintenance works,
- four categories of maintenance works (inspections, maintenance, repairs, repairs).

Two assumptions were also formulated regarding the internal construction of the models being built:

- dominant influence of those categories of works, which are the most important in a given exploitation policy model (eg repairs in the exploitation model of emergency policy or maintenance under the exploitation model of a preventive policy),
- a less significant or insignificant influence of those categories of works, which in a given exploitation policy model, by definition, are present in a small number and to a small extent (eg inspections as part of the emergency policy exploitation model or repairs under the diagnostic policy exploitation model).

Taking into account the above assumptions, three separate models of patterns were defined:

1. A pattern model of emergency exploitation policy, whose idea is to wait for an event without taking any previous preventive or anticipatory actions. In this approach, interventional works, which is a direct result or effect of damages or breakdowns, become dominant, while preventive works are significantly limited to those, that result from direct and absolute normative and legal requirements(eg inspections or repairs, the frequency and scope of which are conditioned by the provisions of the regulation or guarantee agreements).
2. A pattern model of preventive exploitation policy, whose idea is based on preventing and/or anticipating the occurrence of unintended events, taking into account statistical reliability criteria. In this perspective, the dominating ones are those categories of works which, as a rule, lead to the extension of the period of operation of technical facilities, but without the need for conditional decision-making.
3. A pattern model of diagnostic exploitation policy, whose idea assumes a conditional realization of the necessary maintenance and repair work, based on the results of the current assessment of the technical condition of the facilities.

Based on the prepared assumptions, the values of limit and initial parameters as well as based on the calculations carried out in accordance with the formulas (1) - (4), it has been developed the structure of maintenance works, for pattern exploitation policy assessment models, which is summarized in the Table 4.

Based on the prepared pattern structures of maintenance works, there was made the calculations, using a taxonomic model. As a result, collections of values of synthetic measures and geometric distances for individual patterns were obtained (Table 5).

Table 4
The structure of maintenance works of pattern exploitation policy assessment models

Pattern model of emergency policy	Inspections		weight:	0,05	Maintenances		weight:	0,15	Repairs		weight:	0,7	Overhauls		weight:	0,1
	Quantity	50	Costs (PLN)	Time (hours)	Quantity	150	Costs (PLN)	Time (hours)	Quantity	700	Costs (PLN)	Time (hours)	Quantity	100	Costs (PLN)	Time (hours)
Level of complexity: 1	0,5	25	500	6,25	0,5	75	1500	18,75	0,05	35	700	8,75	0,5	50	2500	75,00
Level of complexity: 2	0,2	10	250	5,00	0,2	30	750	15,00	0,1	70	1750	35,00	0,2	20	3000	40,00
Level of complexity: 3	0,15	8	375	7,50	0,15	23	1125	22,50	0,15	105	21000	105,00	0,15	15	3750	60,00
Level of complexity: 4	0,1	5	250	5,00	0,1	15	750	15,00	0,2	140	35000	140,00	0,1	10	5000	40,00
Level of complexity: 5	0,05	3	250	2,50	0,05	8	750	7,50	0,5	350	175000	350,00	0,05	5	7500	20,00
Sum:	**1**	**50**	**1625**	**26,00**	**1**	**150**	**4875**	**79,00**	**1**	**700**	**233450**	**639,00**	**1**	**100**	**21750**	**235,00**
Pattern model of preventive policy	**Inspections**		*weight:*	*0,1*	**Maintenances**		*weight:*	*0,55*	**Repairs**		*weight:*	*0,05*	**Overhauls**		*weight:*	*0,3*
	Quantity	*100*	*Costs (PLN)*	*Time (hours)*	*Quantity*	*550*	*Costs (PLN)*	*Time (hours)*	*Quantity*	*50*	*Costs (PLN)*	*Time (hours)*	*Quantity*	*300*	*Costs (PLN)*	*Time (hours)*
Level of complexity: 1	0,5	50	1000	12,50	0,05	28	550	6,88	0,5	25	500	6,25	0,05	15	750	22,50
Level of complexity: 2	0,2	20	500	10,00	0,1	55	1375	27,50	0,2	10	250	5,00	0,1	30	4500	60,00
Level of complexity: 3	0,15	15	750	15,00	0,15	83	4125	82,50	0,15	8	1500	7,50	0,15	45	11250	180,00
Level of complexity: 4	0,1	10	500	10,00	0,2	110	5500	110,00	0,1	5	1250	5,00	0,2	60	30000	240,00
Level of complexity: 5	0,05	5	500	5,00	0,5	275	27500	275,00	0,05	3	1250	2,50	0,5	150	225000	600,00
Sum:	**1**	**100**	**3250**	**53,00**	**1**	**550**	**39050**	**502,00**	**1**	**50**	**4750**	**26,00**	**1**	**300**	**271500**	**1103,00**
Pattern model of diagnostic policy	**Inspections**		*weight:*	*0,6*	**Maintenances**		*weight:*	*0,2*	**Repairs**		*weight:*	*0,05*	**Overhauls**		*weight:*	*0,15*
	Quantity	*600*	*Costs (PLN)*	*Time (hours)*	*Quantity*	*200*	*Costs (PLN)*	*Time (hours)*	*Quantity*	*50*	*Costs (PLN)*	*Time (hours)*	*Quantity*	*150*	*Costs (PLN)*	*Time (hours)*
Level of complexity: 1	0,05	30	600	7,50	0,05	10	200	2,50	0,5	25	500	6,25	0,5	75	3750	112,50
Level of complexity: 2	0,1	60	1500	30,00	0,1	20	500	10,00	0,2	10	250	5,00	0,2	30	4500	60,00
Level of complexity: 3	0,15	90	4500	90,00	0,15	30	1500	30,00	0,15	8	1500	7,50	0,15	23	5625	90,00
Level of complexity: 4	0,2	120	6000	120,00	0,2	40	2000	40,00	0,1	5	1250	5,00	0,1	15	7500	60,00
Level of complexity: 5	0,5	300	30000	300,00	0,5	100	10000	100,00	0,05	3	1250	2,50	0,05	8	11250	30,00
Sum:	**1**	**600**	**42600**	**548,00**	**1**	**200**	**14200**	**183,00**	**1**	**50**	**4750**	**26,00**	**1**	**150**	**32625**	**353,00**

Table 5
Arrangement of range and initial parameters of the maintenance works structure, for the purpose of developing the pattern model of the assessment of the exploitation policy

Category of works	Pattern model of emergency policy		Pattern model of preventive policy		Pattern model of diagnostic policy	
	Synthetic measure	*Geometric distance*	*Synthetic measure*	*Geometric distance*	*Synthetic measure*	*Geometric distance*
Inspections	0,5423	0,3769	0,3820	0,2560	0,1840	0,4466
Maintenances	0,2641	0,3303	0,1512	0,5370	0,2589	0,2430
Repairs	0,1431	0,6032	0,4864	0,3756	0,5855	0,4581
Overhauls	0,2389	0,2550	0,1509	0,5239	0,2354	0,2831

The developed taxonomic pattern models for the evaluation of the exploitation policy are presented graphically on Fig. 2.

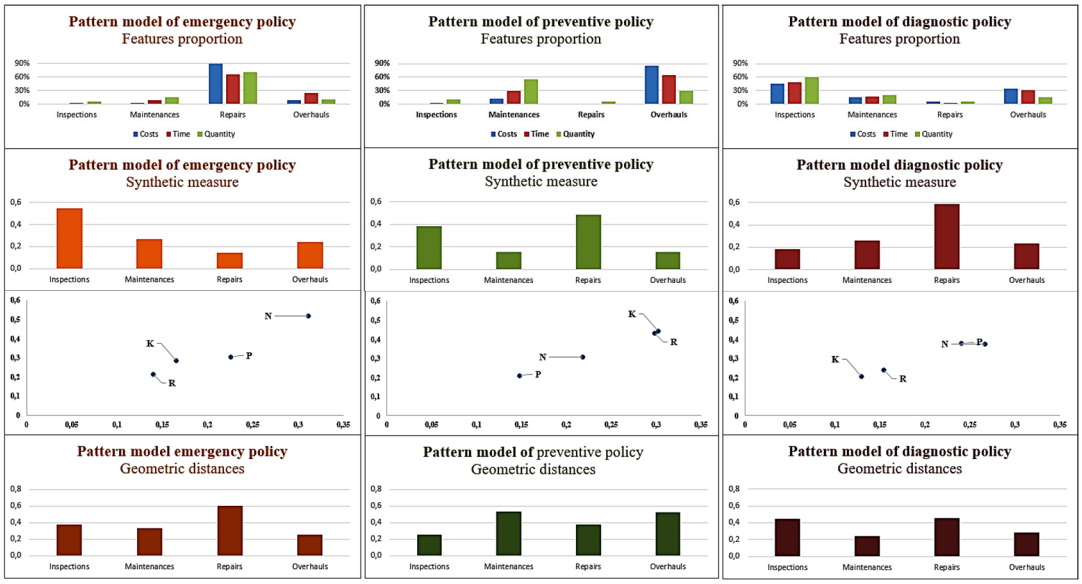

Fig. 2. Graphical presentation of taxonomic measures of pattern models of exploitation policy assessment

ANALYSIS OF THE STRUCTURE OF MAINTENANCE WORK OF THE TECHNICAL NETWORK SYSTEMS, AGAINST THE TAXONOMIC PATTERN MODELS OF THE EXPLOITATION POLICY ASSESSMENT

The development of taxonomic models for the evaluation of the exploitation policy (both pattern and those, that describe the exploitation policy of the technical network systems), allows to analyze the functioning of their maintenance organizations. Therefore, it is necessary to compare the values of the features of the exploitation policy of the analyzed technical network systems with the corresponding features of the pattern models. Such comparison proceeds according to the following relationships:

$$Ps_{min} = \min_{1 \geq j \geq 3} \left| \sum_{i=1}^{4} \left(Ss_i - Sw_{ij} \right) \right|$$
$$Pd_{min} = \min_{1 \geq j \geq 3} \left| \sum_{i=1}^{4} \left(Ds_i - Dw_{ij} \right) \right| \quad (5)$$

where:

i – the number of the maintenance work categories,

j – the number of the pattern model of the exploitation policy assessment, Ps_{min}, Pd_{min} - the result of the comparison of the assessment of the exploitation policy of the technical network system and the pattern model of the exploitation policy assessment, for particular categories of maintenance works, accordingly – in the field of synthetic measures and in the field of geometric distances,

Ss_i, Sw_{ij} – the value of a synthetic measure for particular categories of maintenance works, accordingly – assessment of the exploitation policy of the technical network system and the pattern model of the exploitation policy assessment,

Ds_i, Dw_{ij} – the value of a geometric distances for particular categories of maintenance works, accordingly – assessment of the exploitation policy of the technical network system and the pattern model of the exploitation policy assessment.

The results of taxonomic calculations are presented in Table 6 and on Fig. 3.

The analyzed exploitation policies assume the specificity of these pattern models, whose values of synthetic measures and geometric distances, for the corresponding categories of maintenance works, at least deviate from the reference values.

The comparative analysis showed:

- taxonomic similarity of the exploitation policy model of the analyzed water supply system to the preventive policy pattern,
- taxonomic similarity of the exploitation policy model of the analyzed sewage system to the emergency policy pattern,
- taxonomic similarity of the exploitation policy model of the analyzed heat supply system to the preventive policy pattern.

It should be noted, that despite the selection of the smallest values, the analyzed technical network systems differ taxonomically (in some situations in a significant way) from the pattern models. This indicates a large potential space for possible modification. According to the author, this modification should take place both inside and between different categories of maintenance works, and its effect should be to minimize particular differences.

Table 6
A list of the taxonomic features of the exploitation policy assessment of the analyzed technical network systems against the pattern models

	Water supply system		**Pattern model of emergency policy**		**Pattern model of preventive policy**		**Pattern model of diagnostic policy**	
	Synthetic measure	*Geometric distance*	*Synthetic measure*	*Geometric distance*	*Synthetic measure*	*Geometric distance*	*Synthetic measure*	*Geometric distance*
Inspections	0,0740	0,8929	0,5423	0,3769	0,3820	0,2560	0,1840	0,4466
Maintenances	0,1196	0,7729	0,2641	0,3303	0,1512	0,5370	0,2589	0,2430
Repairs	0,1994	0,7776	0,1431	0,6032	0,4864	0,3756	0,5855	0,4581
Overhauls	0,0541	1,2544	0,2389	0,2550	0,1509	0,5239	0,2354	0,2831
Comparison			0,8539	2,1324	**0,7235**	**2,0054**	2,4340	0,8080
Median			1,4931		**1,3645**		1,6210	

	Sewer system		**Pattern model of emergency policy**		**Pattern model of preventive policy**		**Pattern model of diagnostic policy**	
Inspections	0,0866	0,9988	0,5423	0,3769	0,3820	0,2560	0,1840	0,4466
Maintenances	0,3340	0,3298	0,2641	0,3303	0,1512	0,5370	0,2589	0,2430
Repairs	0,1224	0,8207	0,1431	0,6032	0,4864	0,3756	0,5855	0,4581
Overhauls	0,2472	0,5803	0,2389	0,2550	0,1509	0,5239	0,2354	0,2831
Comparison			**0,5545**	**1,1652**	0,9385	1,4516	0,6473	1,2987
Median			**0,8599**		1,1950		0,9730	

	Heat supply system		**Pattern model of emergency policy**		**Pattern model of preventive policy**		**Pattern model of diagnostic policy**	
Inspections	0,0962	1,5849	0,5423	0,3769	0,3820	0,2560	0,1840	0,4466
Maintenances	0,0222	1,8227	0,2641	0,3303	0,1512	0,5370	0,2589	0,2430
Repairs	0,0903	1,4773	0,1431	0,6032	0,4864	0,3756	0,5855	0,4581
Overhauls	0,0423	1,7000	0,2389	0,2550	0,1509	0,5239	0,2354	0,2831
Comparison			0,9374	5,0194	**0,9194**	**4,8924**	1,0128	5,1540
Median			2,9784		**2,9059**		3,0834	

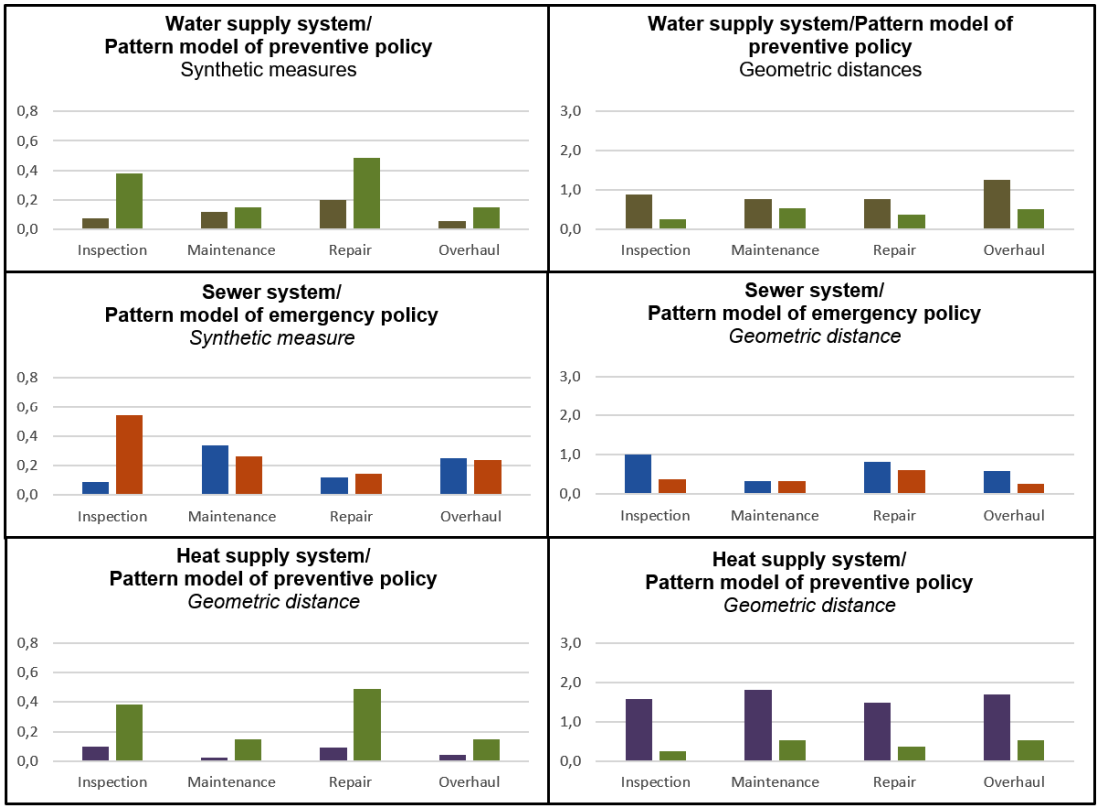

Fig. 3 Graphical comparison of taxonomic models of exploitation policy assessment of the analyzed technical network systems against the pattern models

CONCLUSIONS

The research results presented in this article, realized on the basis of data from activity of the maintenance organization of the selected enterprises managing technical network systems, confirmed the ability to identify quantitative and qualitative features of the exploitation policy, as a starting point for defining the needs and requirements of the exploitation decision-making process. Thus, it should be noted, that the developed method of assessment of the exploitation policy can be an important part of the shaping the exploitation decision-making process formulated over a longer time horizon.

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Abstract. The article presents a method of solving the problem of the assessment of the exploitation policy. It was assumed that the evaluation of the exploitation policy can and should be carried out with reference to defined universal patterns. This allows comparability of such a policy, as well as making decisions regarding necessary changes. Therefore, there was proposed a way of building pattern models of the exploitation policy and there was carried out the assessment of the exploitation policies of the selected technical network systems, based on the selected taxonomic model.

Keywords: exploitation policy, technical network system, taxonomy, exploitation decision-making process