SmartMaintenance - The Concept of Supporting the Exploitation Decision-Making Process in the Selected Technical Network System

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Abstract. The article presents the SmartMaintenance concept, as a basis for the development of intelligent solutions that support exploitation activities. On the background of the main guidelines of the SmartMaintenance concept, as well as taking the principle of an open architecture, there was described the main components of a computer system supporting exploitation decision-making process. The last part of the article is the SMOPE module, which has been developed by the author. SMOPE complying with the requirements of the SmartMaintenance concept, supports the realization of the exploitation decision-making process of the selected technical network system.

Keywords: SmartMaintenance · Exploitation decision-making process · Technical network system

1 Introduction

Enterprises that manage network technical systems, distribute media from the source to the recipients ensuring the required quantitative parameters (diverse needs of the recipients, in space and in time, for assumed perspective period of predicted operation of the network), as well as the required qualitative parameters (a need to adapt and maintain qualities of supplied media at a level exceeding the criterial) [5, 19].

Due to the specificity of the activity, network companies are often natural monopolists on the local markets, that might suggest that they are not interested in making changes and increasing their competitiveness [9]. The companies are subject of public control, and the price of supplied media is regulated. In order to satisfy the expectations of the recipients, network companies are obliged to activities aimed at ensuring a reliable supply of media, with high quality and at an acceptable. With a limited income, these companies manage huge resources, which include networks, buildings and engineering equipment. In conjunction with the limited funds, it causes a need for rationalization exploitation activities.

Therefore, core activities of network companies should be rationalization of the exploitation, which is considered in the sense of operate and maintenance. The operate

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activity is intended to ensure the organizational and economic possibilities of effective use of all components of the technical network system, for the delivery of media to end users with the assumed parameters of quantitative and qualitative. The maintenance activity is intended to ensure technical possibilities for an efficient functioning and an effective use of all components of the technical network system.

Network enterprises often take advantage of modern IT systems, which allow for gathering the data about objects, events, and exploitation processes. The main objective of the use of IT systems in the exploitation activities of the network companies should be supporting the exploitation decision-making process. It requires a look at the needs of the maintenance organization and possibilities of a computer software (including intelligent solutions), not only in terms of the procedural realization of typical routine work orders, but especially in the context of the analytical and decision-making requirements, in the short and long term.

Therefore, later in the article, results of the research on the development of the SmartMaintenance concept are presented. They are considered in the context of the specificity of enterprises managing technical network systems.

2 The Assumptions of the SmartMaintenance Concept

Technical network systems are the subject of dynamic development and implementation of innovative solutions, that also generate problems resulting from aging and the wear processes of components of the technical network systems, and hence, there appear exploitation events. Therefore, developed and implemented innovative and technologically advanced solutions must take into account the exploitation activities.

The proposed concept, named by the author SmartMaintenance, includes the development of models, methods and tools adapted to requirements of exploiting of technical network systems and supporting the maintenance activities. In particular, SmartMaintenance is going to shape and support the realization of technical, organizational and economic tasks, to ensure rationality of the exploitation policy, and to achieve the intended functionality of smart technical solutions at the assumed level.

The developed concept represents a model consisting of the three task modules, differing in the scope of the collected data and the role and share of the particular components in the overall project. Schematic diagram of the SmartMaintenance concept is illustrated in Fig. 1. In this regard, it should be distinguished:

1. The module of identification and description of exploitation events, which is implemented in the operate field, and includes collecting and processing data and information about functional features of various parts of the technical network system, for the purpose of forming model sets of exploitation events.
2. The module of realization of maintenance tasks, which includes collecting and processing data and information about features of maintenance works, for the purpose of forming model sets of factors for assessment of the exploitation policy.
3. The module of realization of exploitation decision-making process, which includes collecting and processing data and information about factors of the exploitation

policy in the context of the defined environment features, for the purpose of selection and assessment of the decision path.

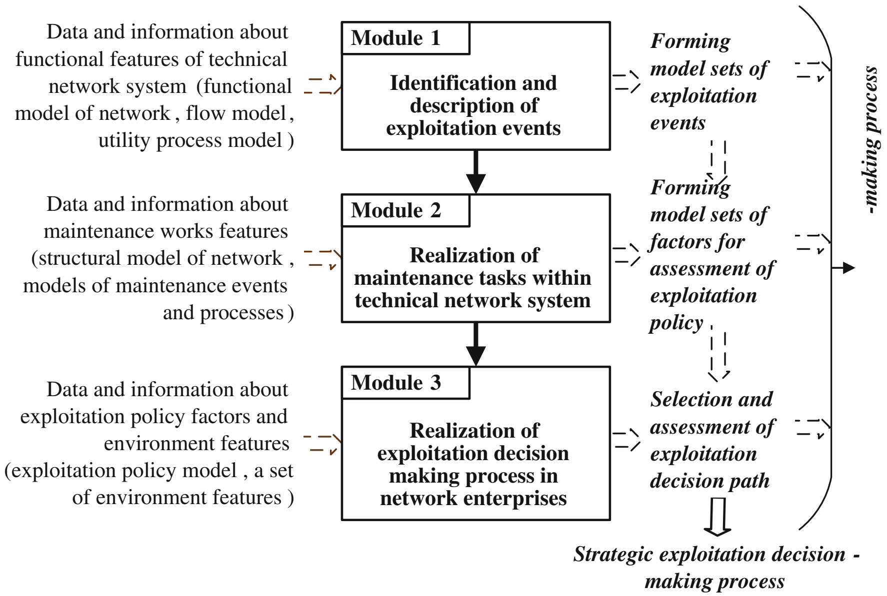


Fig. 1. The scheme of the developed SmartMaintenance concept

In this approach, each of the modules is a separate solution, represented in Fig. 1 by horizontal paths. These solutions are based on the individual arrangements of models and data structures, as well as on the ways of using them. Thus, the horizontal paths reflect supporting selected (individual) aspects of the exploitation processes, e.g. failure identification, workload analysis of maintenance works, assessment of the results of enhance preventive maintenance works. The comprehensive implementation of the exploitation decision-making process is represented, in Fig. 1, by the vertical path. This is result of cumulative use of all modules, e.g. the assessment of the exploitation policy, the scenario shaping the exploitation decision-making process [12].

3 Computer-Aided Under the SmartMaintenance Concept

Development of a computer supporting system, according to the proposed SmartMaintenance concept, involves the use of partial solutions and their adaptation to the requirements of exploitation decision-making process. This allows for carrying out tasks under horizontal linkages (partial exploitation procedures of the decision-making process) and the tasks carried out in a vertical linkages (procedures of the strategic exploitation decision-making process).

The supporting way, shown schematically in Fig. 2, is logically divided into three layers, with proposed models, methods and tools, in an orderly manner. It includes:

1. The data layer, in this case being the data warehouse, based on the assumption of deliberate use of existing data resources of the enterprise without any interference and modification of IT solutions applied in the enterprise. This layer, in addition to the functions of defining and storing structure models, makes it possible disposal of space or data and information, to perform calculations, to store intermediate and final results, and visualizing the effects of the analyzes and interpretations.
2. The analytical layer, including a set of algorithms for determining exploitation measures, in order to assess the exploitation policy by the assumed model.
3. The interpretation layer, which allows for expert processing the measures, identified in the analytics layer, with the use of environmental exploitation factors. The effect of these is interpretation of the functioning of the technical network system in the context of the exploitation decision-making process.

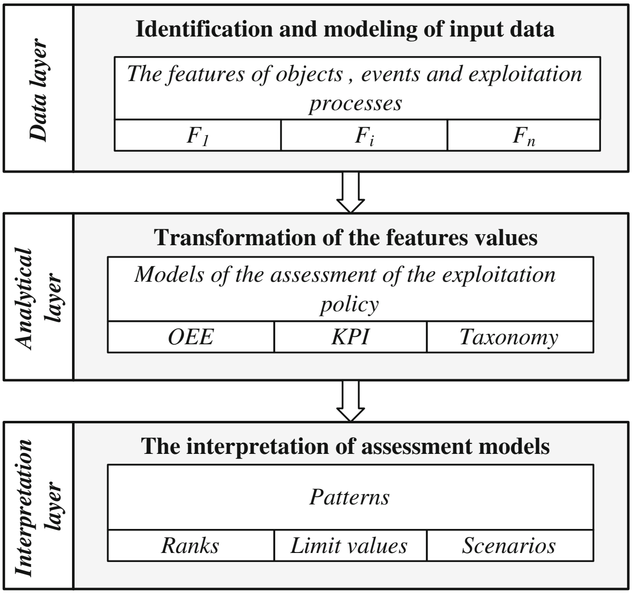


Fig. 2. The scheme of a computer system supporting the SmartMaintenance concept

The developed way of computer-aided of the SmartMaintenance concept is conceived as an universal platform for the realization of the exploitation decision-making process in a flexible manner - adapted to the opportunities and requirements of the maintenance organizations managing technical networked systems. This platform has an open character, what is meant by:

- the lack of restrictions on the implementation of the model of data collection,
- the lack of restrictions on the implementation of analytical methods for assessing the exploitation policy (e.g. OEE, KPI, taxonomic methods) [1, 3, 7],

- the lack of restrictions on the implementation of intelligent interpretation solutions (rank methods, reference methods, variants methods, scenario methods, expert systems, neural networks) [4, 8, 18].

4 Computer-Aided Under the SmartMaintenance Concept - Case Study

Research on the SmartMaintenance concept led to the development of computer module named SMOPE. In the structural context, SMOPE was built in web technology, with the use of relational database management system MySQL, PHP, as well as jQuery and CSS libraries. In the functional context, SMOPE, launched within a web browser. It allows for the assessment of procedural support of the exploitation decision-making process in the scenario technique.

SMOPE is based on the assumptions of the SmartMaintenance concept (Fig. 1), including the guidelines of the proposed computer-aided way (Fig. 2). Within the particulars layers, there have been prepared partial solutions, which on the one hand, allow for supporting the exploitation decision-making process, and on the other, constitute its dedication. The further points belong to these solutions:

- the data layer: the multi-model of the technical network system,
- the analytical layer: the taxonomic model of the assessment of the exploitation policy [11, 15, 16],
- the interpretation layer: the scenario model of the exploitation decision-making process [12, 13].

4.1 The Multi-model of the Technical Network System

Application of the multi-model within the SMOPE module, is intended to unambiguous identification and location of the components of the network technical system. For this purpose, there was developed the structure of the multi-model system, based on the concept of three subsystems, formally described by graph theory and matrix algebra.

The functional subsystem, reflects the time and spatial conditions (or their lack) of the possibilities of achieving the final parameters (output) at known and preset input values. This subsystem is formally represented by a set of relationships between engineering objects ob_j, including the linear objects ol_i, and it can therefore be described by the incidence matrix:

$$SY = \left[sy_{ij}\right] \tag{1}$$

where: sy_{ij} is 1, if j-th ob_j edge is incident with the i-th ol_i node, is 0, otherwise.

The structural subsystem, reflects the relationship type of parent–child, in relation to a particular section of the system or within a specific class of similar objects - groups of objects. This subsystem can be described by the neighborhood matrix:

$$ST = \left[st_{ij}\right] \tag{2}$$

where: stij is 1, if there is an edge between i-th node $ob_i(ol_i)$, and j-th node $ob_j(ol_j)$, is 0 otherwise.

The topological subsystem reflects the arrangement of the components (technical objects) integrated with places their physical occurrence in the area. This subsystem can be described by the arrays of the point and linear coordinates representing the engineering and line objects:

$$TP = \left[ol_i(ob_i), xp_i, yp_i, xk_i, yk_i, w_j\right] \quad (3)$$

where: ol_i (ob_i) - identifier of a linear or engineering object, xp_i, yp_i - initial coordinates of a linear or engineering object, xk_i, yk_i - end coordinates of a linear or engineering object (for engineering objects $xk_i = yk_i = 0$), w_j - identifier of map layer, to which is assigned an object.

Developed multi-model allows for the fragmentation of the technical network system within the analysis and interpretation implemented in the SMOPE. Figure 3 shows an excerpt of the analyzed technical network system, while Table 1 summarizes features of the topological subsystem.

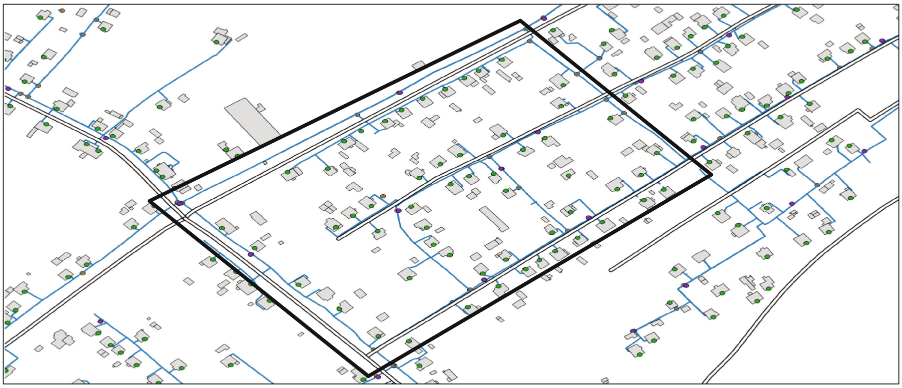


Fig. 3. An excerpt of the analyzed technical network system

Table 1. The arrays of the coordinates representing the engineering and line objects of the exemplary technical network system

Object ident.	Initial xp_i coordinate	Initial yp_i coordinate	End xk_i coordinate	End yk_i coordinate	Layer	Description
02	212576,49	857153,83	0,0000	0,0000	01	Node
03	212726,78	857258,05	0,0000	0,0000	01	Node
721	212615,54	857179,66	0,0000	0,0000	02	Water hose
43157	212727,38	857257,19	0,0000	0,0000	03	Valve
43051	212576,94	857153,36	0,0000	0,0000	03	Valve
45024	212576,49	857153,83	212587,71	857142,11	05	Pipe
41322	212576,49	857153,83	212726,78	857258,05	05	Pipe

4.2 The Taxonomic Model of the Assessment of the Exploitation Policy

The taxonomic model applied within the analytical layer of the SMOPE module includes determination of synthetic measures and geometric distances from the pattern (the Euclidean measure), based on a set of key features of the exploitation policy (cost, time, quantity of maintenance works) for selected categories of the maintenance works (inspections, maintenances, repairs, overhauls). The taxonomic model can be described using the formulas [15, 16]:

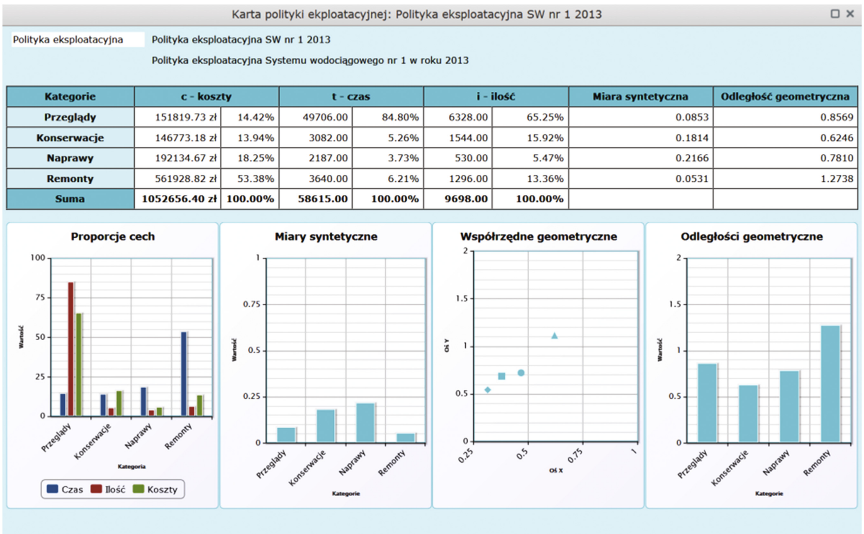
$$d_{i0} = \sqrt{\sum\nolimits_{j=1}^{m} \left(z_{ij} - z_{0j}\right)^2} \tag{4}$$

$$s_i = 1 - \frac{d_{i0}}{\sqrt{\frac{1}{n} \cdot \sum\nolimits_{i=1}^{n} \left(d_{i0} - \overline{d_0}\right)^2}} \tag{5}$$

where: d_{i0} - the measure of the geometric distances from the pattern, s_i - the synthetic measure, z_{ij} - the normalized feature.

The taxonomic way of modeling has been described in detail [13]. It constitutes the subject of assessing the contribution of the works of specified categories within the exploitation policy, and it is the basis for the interpretation of the exploitation decision-making process.

Figure 4 shows the screen of the SMOPE module with numerical and graphical visualization of the calculation results of the taxonomic measures for the exploitation policy of the analyzed network technical system, realized in 2013.



Kategorie	c - koszty		t - czas		i - ilość		Miara syntetyczna	Odległość geometryczna
Przeglądy	151819.73 zł	14.42%	49706.00	84.80%	6328.00	65.25%	0.0853	0.8569
Konserwacje	146773.18 zł	13.94%	3082.00	5.26%	1544.00	15.92%	0.1814	0.6246
Naprawy	192134.67 zł	18.25%	2187.00	3.73%	530.00	5.47%	0.2166	0.7810
Remonty	561928.82 zł	53.38%	3640.00	6.21%	1296.00	13.36%	0.0531	1.2738
Suma	**1052656.40 zł**	**100.00%**	**58615.00**	**100.00%**	**9698.00**	**100.00%**		

Fig. 4. Sample screen of the SMOPE module with visualization of the taxonomic assessment of the exploitation policy of the analyzed technical network system

4.3 The Scenario Model of the Exploitation Decision-Making Process

Interpretation of the exploitation policy should be carried out into consideration of the environment circumstances of the exploited technical network system [2, 17]. Therefore, a key aspect of the SmartMaintenance concept is a collection of pattern models, which can represent a specific reference level. For this purpose, within the SMOPE module, there are applied scenario models, according to the La Prospective methodology [6]. This allows for the interpretation of the exploitation decision-making process, in the environment of future variants, represented by different scenarios.

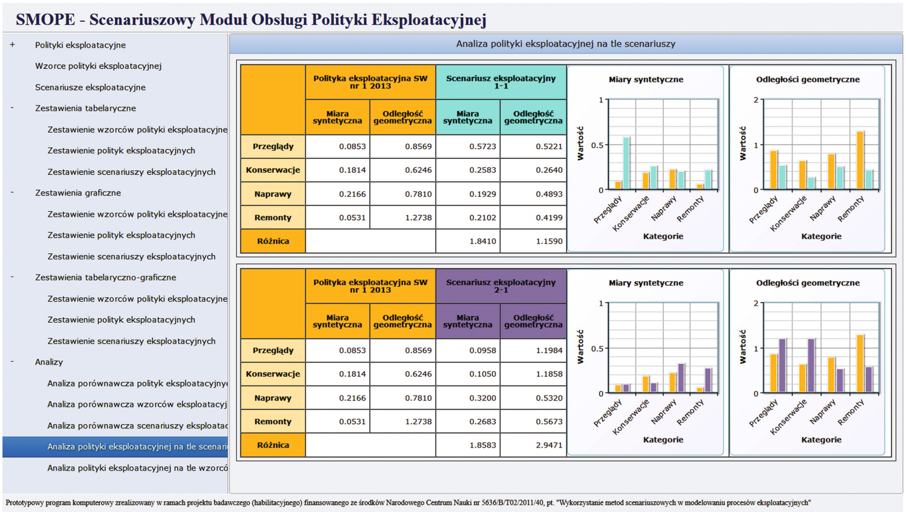


Fig. 5. Sample screen of the SMOPE module with scenario interpretation of the exploitation policy of the analyzed technical network system

Figure 5 shows the screen of the SMOPE module with numerical and graphical visualization of the comparison of the exploitation policy and the scenarios for the development of the exploitation policy of the analyzed technical network system. The exploitation policy as well as the scenarios are described by the taxonomic measures. Scenario shaping the exploitation decision-making process, with the use of the SMOPE module, enables:

1. The analytical taxonomic comparative procedure of the exploitation policy with the scenario models.
2. The assessment of the similarity (convergence) of the exploitation policy with the particular scenarios,
3. The assessment of the implementation of the exploitation decision-making process, in the context of potential different future variants, represented by the scenarios.
4. Monitoring of the exploitation policy, consisting of cyclic assessment of the exploitation policy based on the developed taxonomic models, and then interpreting the statement in successive, predefined, time points [10] (this allows for continuous

assessment of the direction and level of changes in the degree of similarity (convergence) exploitation policies to individual scenarios. This, in turn, can correct the assumptions and guidelines for exploitation decision-making process.

5. Simulation assessment of changes in the exploitation decision-making process, consisting in the analysis and interpretation of the impact of the modification of the features in change of the level of similarity (convergence) of the exploitation policy with individual scenarios.

5 Conclusions

Presented in this paper, key aspects of exploitation of technical network systems, justify the need to optimize exploitation processes in the context of rational decisions. The solution proposed by the author, methodologically housed within the SmartMaintenance concept. This enabled the development of computer system, supporting rational exploitation decisions. The methodology of scenario development of the exploitation decision-making process, as the basis for the implementation of the SmartMaintenance and supporting with the SMOPE was presented in detail in [14].

The test results of the SMOPE module, based on exploitation data of the analyzed technical network systems, confirmed the possibility, desirability and reasonableness of applying the tools of the analytical and expert class, for the needs of supporting exploitation decision-making process in the long term, according to the developed methodology. The SmartMaintenance concept, having an open specificity, can form the basis for the development and implementation of innovative and intelligent support solutions. Further author's research focus on the development and adaptation solutions, in the SMOPE environment, based on knowledge engineering, including:

- rule-based expert systems, for the needs of interpretation of exploitation decision-making in the short term,
- artificial neural networks, for the needs of quantitative interpretation of development scenarios for exploitation decision-making process in the long term.

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References

1. Antosz, K., Stadnicka, D.: Evaluation measures of machine operation effectiveness in large enterprises: study results. Eksploatacja i Niezawodnosc Maint. Reliab. **17**(1), 107–117 (2015)
2. Baran, J., Janik, A., Ryszko, A., Szafraniec, M.: Selected environmental methods and tools supporting eco-innovation implementation within national smart specialisations in Poland. In: 3rd International Multidisciplinary Scientific Conference on Social Sciences and Arts SGEM 2016, Conference Proceedings. Book 2, vol. 3, pp. 1029–1036, Albena (2016)

3. Brodny, J., Stecuła, K., Tutak, M.: Application of the TPM strategy to analyze the effectiveness of using a set of mining machines. In: 16th International Multidisciplinary Scientific GeoConference SGEM 2016, Albena. Book 1: Science and Technologies in Geology, Exploration and Mining, pp. 65–72 (2016)
4. Burduk, A.: Assessment of risk in a production system with the use of the FMEA analysis and linguistic variables. In: 7th International Conference on Hybrid Artificial Intelligent Systems (HAIS), Salamanca, Hybrid Artificial Intelligent Systems, PT II. Lecture Notes in Computer Science, vol. 7209, pp. 250–258 (2012)
5. Denczew, S.: Organizacja i zarządzanie infrastrukturą komunalną w ujęciu systemowym. Szkoła Główna Służby Pożarniczej, Warszawa (2006)
6. Godet, M., Roubelat, M.: Creating the future: The use and misuse of scenarios. Long Range Plan. **42**(2), 164–171 (1996)
7. Jasiulewicz-Kaczmarek, M., Drożyner, P.: Maintenance management initiatives towards achieving sustainable development. In: Golinska, P., et al. (eds.) Information Technologies in Environmental Engineering Environmental Science and Engineering, pp. 707–721. Springer, Berlin (2011)
8. Kalisch, M., Przystalka, P., Timofiejczuk, A.: Actuator fault diagnosis using single and meta-classification strategies. Artificial Intelligence for Knowledge Management, AI4KM 2014. IFIP Advances in Information and Communication Technology, vol. 469, pp. 132–149 (2014)
9. Karwot, J., Kaźmierczak, J., Wyczółkowski, R., Paszkowski, W., Przystałka, W.: Smart water in smart city: a case study. In: 16th International Multidisciplinary Scientific GeoConference SGEM 2016, Albena. Book 3: Hydrology and water resources, pp. 851–858 (2016)
10. Kosicka, E., Kozłowski, E., Mazurkiewicz, D.: The use of stationary tests for analysis of monitored residual processes. Eksploatacja i Niezawodnosc Maint. Reliab. **17**(4), 604–609 (2015)
11. Loska, A.: Exploitation assessment of selected technical objects using taxonomic methods. Eksploatacja i Niezawodnosc Maint. Reliab. **15**(1), 1–8 (2013)
12. Loska, A.: Remarks about modelling of maintenance processes with the use of scenario techniques. Eksploatacja i Niezawodnosc Maint. Reliab. **14**(2), 92–98 (2012)
13. Loska, A.: Scenario modeling exploitation decision-making process in technical network systems. Eksploatacja i Niezawodnosc Maint. Reliab. **19**(2), 268–278 (2017)
14. Loska, A.: Metodyka modelowania eksploatacyjnego procesu decyzyjnego z wykorzystaniem metod scenariuszowych. Wydawnictwo Politechniki Śląskiej, Gliwice (2016)
15. Młodak, A.: Analiza taksonomiczna w statystyce regionalnej. Wydawnictwo Difin, Warszawa (2006)
16. Panek, T.: Statystyczne metody wielowymiarowej analizy porównawczej. Szkoła Główna Handlowa, Warszawa (2009)
17. Ryszko, A.: Interorganizational cooperation, knowledge sharing, and technological eco-innovation: the role of proactive environmental strategy - empirical evidence from Poland. Pol. J. Environ. Stud. **25**(2), 753–763 (2016)
18. Stecuła, K., Brodny, J.: Application of the OEE model to analyze the availability of the mining armored face conveyor. In: 16th International Multidisciplinary Scientific GeoConference SGEM 2016, Albena. Book 1: Science and Technologies in Geology, Exploration and Mining, pp. 57–64 (2016)
19. Wyczółkowski, R.: Inteligentny system monitorowania sieci wodociągowych. Eksploatacja i Niezawodnosc Maint. Reliab. **37**(1), 33–36 (2008)