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Solutions for supporting the management of network technical systems in the aspect of the Smart City concept

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INTRODUCTION

Network technical systems are part of the infrastructure, which is the basis for the functioning of the municipal engineering sectors. Through network technical systems there are provided services for supplying of media to different categories of customers, such as households, industrial plants, municipal companies, service companies and others (Loska et al., 2016). Typical examples of network technical systems are: water supply system, sewage system, heat supply system, gas supply system, energy transmission system, telecommunications system.

Companies managing network technical systems perform media distribution from the source to the recipients providing (Jasiulewicz-Kaczmarek et al., 2017, Biały & Ruzbarsky, 2018):

– required quantitative parameters – varied, in time and space, the needs of recipients, for the assumed perspective period of the foreseen network exploitation,
– required quality parameters – taking into account the need to adjust and maintain the features of the media supplied at a level exceeding the criterion values.

Network companies are a specific group operating on the market. Due to the specificity of your business, they are often natural monopolists on local markets. This could suggest that they are not interested in making changes and increasing their competitiveness. However, these companies are subject to social control, and the price of the media they sell is regulated. In order to meet the expectations of its customers – recipients, network companies are forced to take actions, which are aimed at ensuring reliable media supplies, of high quality and at an acceptable price. With limited revenues, these companies manage huge resources that include networks, buildings and engineering devices. This makes it necessary to rationalize exploitation. It should be noted that, these assets are most often extremely durable - there are functioning network systems that are 100 years old or older – but neglecting

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the rational recovery of exploitation potential in the long time leads to their degradation. This problem is particularly important in urban conditions, where high traffic, earthworks and the occurrence of mining damage, even at a considerable distance from the network, have a very negative impact on its durability.

Therefore, the key activities that are undertaken by network companies is the rationalization of operating activities, which is considered in terms of use, service and repair. In this approach, two forms of operating activity should be distinguished (Antosz, 2018, Kozlowski et al., 2018, Palka et al., 2018):

- usable activity, which consists in ensuring organizational and economic possibilities of effective use of all elements of the network technical system, for the purpose of selling produced media to end users (optionally, reception of media from users – sewage system), with assumed quantitative and qualitative parameters,
- maintenance activity, which aims to provide technical opportunities for effective operation and effective use of all elements of the network technical system, by controlling and maintaining the value of key features of individual facilities at the required level (eg pressure in the water supply network, voltage in the power grid), reduction of losses resulting from the so-called principles of finite durability of technical objects (eg removal of heating network cable failure), as well as intended and/or unintended human activity and environmental factors (eg inspections of pump units, removal of clogging of sewer network channels).

Challenges faced by network enterprises cause, that in their activities, they are increasingly using modern IT systems, that allow for the collection and processing of data on facilities, events and exploitation processes. However, the main purpose of using IT systems in the exploitation activities of network companies should be to support the exploitation decision-making process. This requires a look at the needs of maintenance organization and the possibilities of existing IT systems, not only through the prism of the procedural implementation of typical routine work orders, but above all in the context of analytical and decision-making needs in the short and long time horizon, including intelligent solutions (Kabiesz & Bartnicka, 2018). Therefore, as part of the developed and implemented innovative and technologically advanced solutions in the area of Smart City, it should be taken into account the aspects directly related to the maintenance management of technical systems. These aspects must concern both the use and the maintenance phase. For these reasons, there is a need for research and development of solutions supporting the exploitation management of technical infrastructure, which function within the framework of municipal engineering, driven by the idea of Smart City (Panori, 2017).

EXPLOITATION PROBLEMS OF NETWORK TECHNICAL SYSTEMS ON THE EXAMPLE OF WATER SUPPLY NETWORKS

Water supply companies face challenges resulting from two unfavourable phenomena (ICT, 2015):

1. Suburbanization of cities, which, in the context of water supply, is perceived primarily in the aspect of the need to provide additional outlays for the expansion of the water supply network. The problem of increasing the cost of providing water to very distant customers is rarely noticed. But extension of water supply networks

causes an increase in pressure losses in water transport, which entails a reduction in the transmission efficiency of networks.

2. Decreasing drinking water resources in many EU countries, including Poland. Poland occupies a distant position in the European Union in terms of water resources per capita (Fig. 1), and this situation will worsen due to the expected climate changes. It is predicted, that by the end of the XXI century, the average annual temperature will increase by 3-3.5℃, with different rainfall forecasts depending on greenhouse gas emission scenarios and climate prediction models (Kundzewicz, 2013). It undoubtedly will have a negative impact on water resources in Poland.

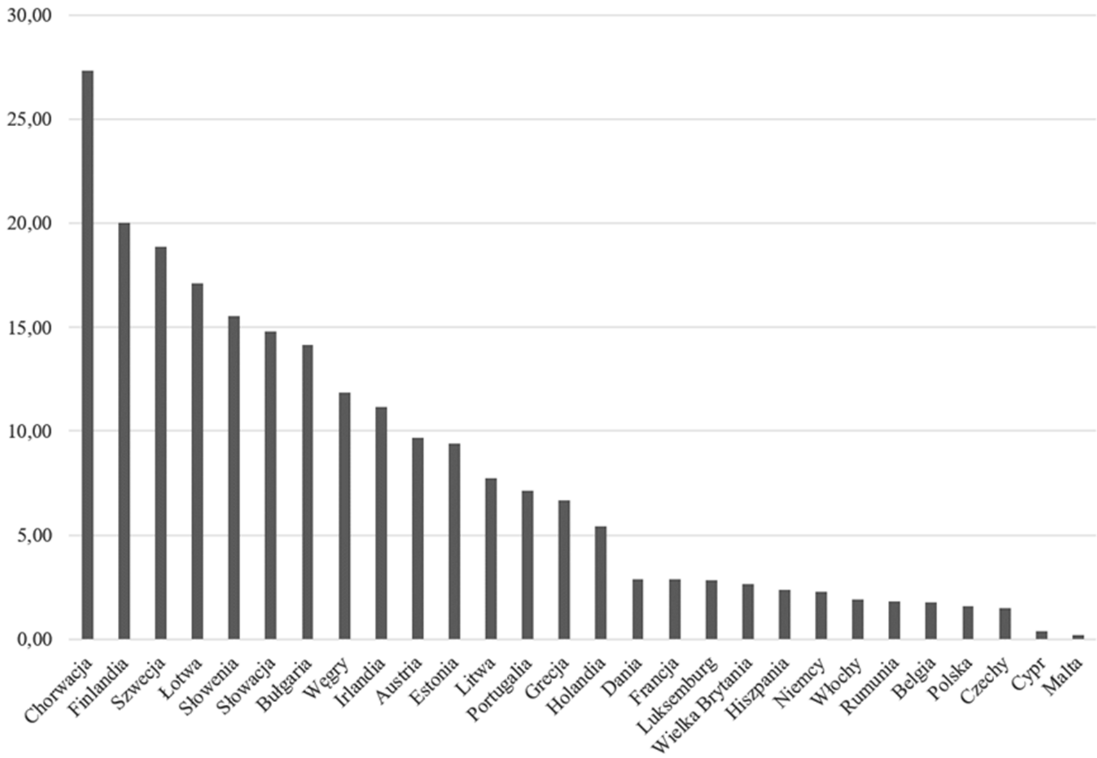

Fig. 1 Water resources in the European Union in 2017 (1000 m^3 per 1 inhabitant)
Source: (Eurostat, 2019).

This situation has been mitigated by the reduction of water absorption, by industry and households, but this decline has clearly slowed down in recent years (Fig. 2).
The problem of low water resources is aggravated by high failure rate of water supply networks resulting largely from the age of devices and components. The average annual water losses due to leaks in water supply networks in large cities in Poland amounted to an average of 19.9% of water injected into the network. Wherein the minimum loss was 5.5%, and the maximum was 25.5%, and the age of the network ranged from 50 to 100 years (Hotloś, 2007). According to the reports of the Polish Supreme Audit Office, published in the following years, concerning water supply companies of various sizes, this problem still exists, and "record holders" lose even more than 50% of the water produced.

a)

b)

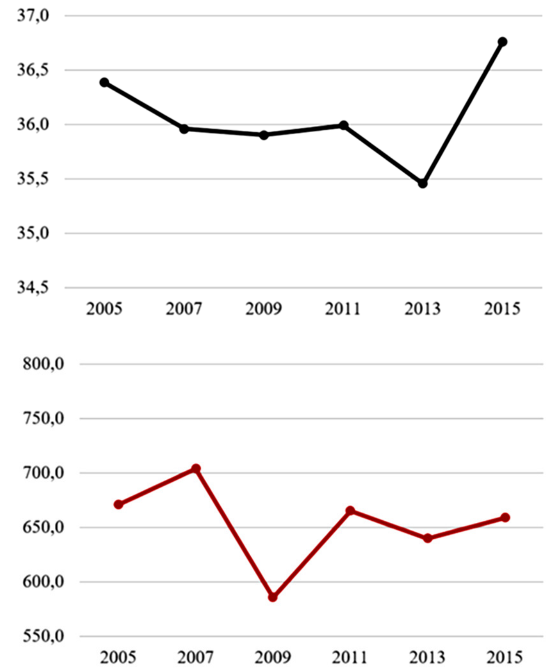

Fig. 2 Water use in Poland: a) by the domestic sector (m^3 per inhabitant), b) by industry (w milion m^3)

Source: (Eurostat, 2019).

Conducted maintenance works are related to both the modernization of water supply networks and preventive activities, such as condition monitoring of the network or effective maintenance They have the effect of reducing the level of water loss, but this does not solve the completely described problem. Water loss rates in Poland are determined to be comparable to the loss rates found in Slovakia, Romania, Hungary and the eastern German states, and higher than in the western states of Germany and other western countries (Eurostat, 2019). Additionally, it should be noticed, that on average only 0.9% of the networks in operation are renewed or replaced annually, which means that the problem will not disappear in the nearest future.

GAPS AND CHALLENGES IN THE AREA OF THE EXPLOITATION OF WATER SUPPLY SYSTEMS

Basic gaps in the effective management of network technical systems, including water supply systems, and challenges in the implementation of modern technologies are presented in the document (ICT, 2015). It has been developed based on the opinions of research centres, as well as the experience of leading companies in the industry.

This document can be a starting point for developing a road map, which should be a set of solutions at the interface between the identified shortcomings and anticipated challenges. These solutions form the directions of activities in the field of developing methods and tools that effectively support the management of the water supply system (Fig. 3).

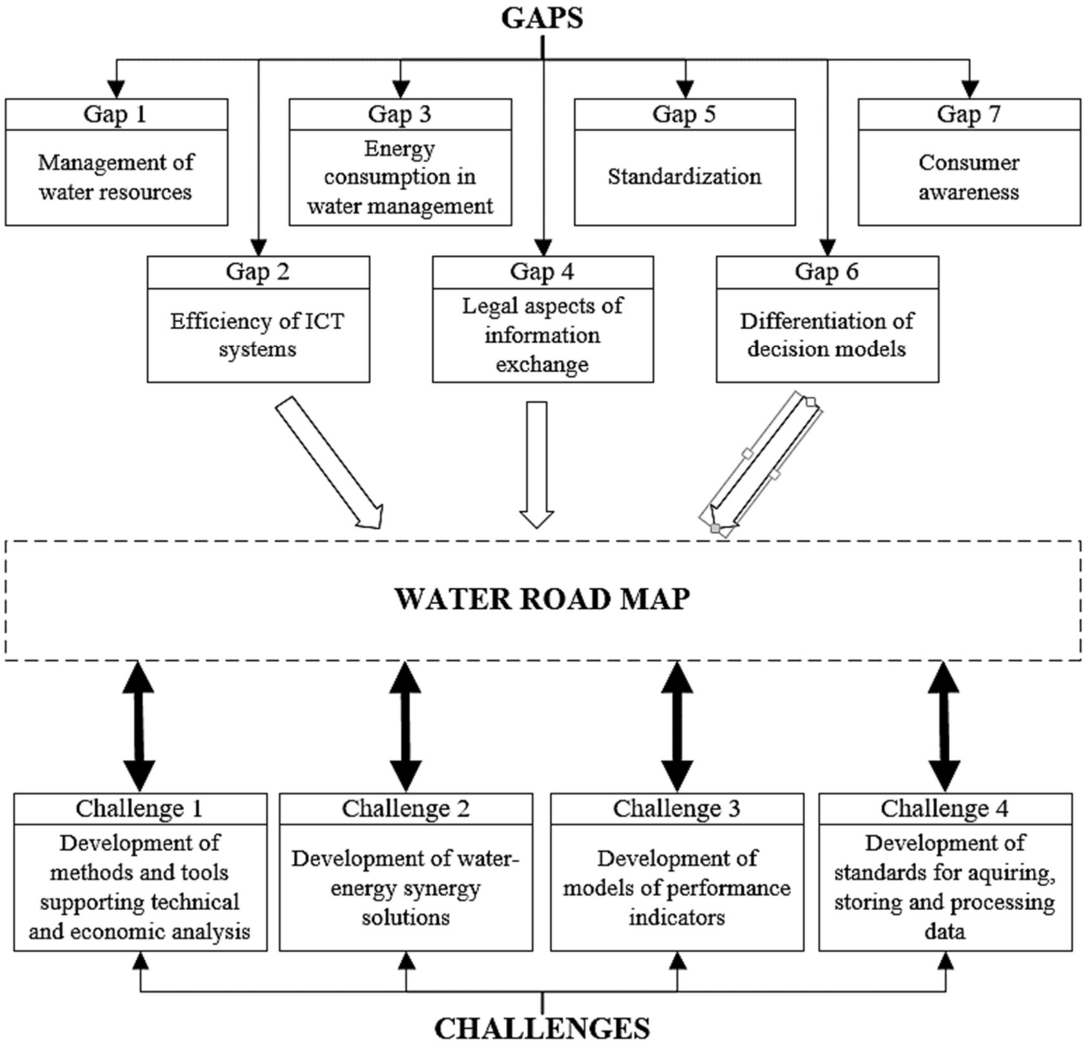

Fig. 3 The general scheme of the idea of an water road map

Source: own elaboration based on (ICT, 2015).

In the context of the roadmap being developed, basic gaps can be identified, that relate to the seven most important exploitation aspects:

a. effective use of water resources (gap 1), from detection of leaks, reduction of water consumption, reuse of water, to increased awareness of users of water resources,
b. analysis of the costs of implementing and maintaining of ICT systems (gap 2), which for the stakeholders of water supply companies and water recipients, They constitute a barrier to the effective monitoring and understanding of water use and demand for it,
c. water - energy cells (gap 3), an aspect that should not only be limited to the reduction of energy consumption necessary for water distribution and treatment (processing) of sewage, but first of all, it should aim to reduce the total cost of energy consumption including identification of the causes of energy consumption (when and why),
d. data sharing and the related problem of the lack of legislative solutions (gap 4), including aspects of security and protection of property (private, intellectual), as a basis for facilitating the exchange of data between stakeholders,

e. standardization (gap 5), ie lack of standards increasing interoperability between stakeholders at various levels (eg software, data exchange, vocabulary), taking into account the coherence of the requirements of the standardization committees,
f. diversification of Decision Support Systems – DSS (gap 6), the implementation of which depends on the individual needs of a specific water distribution company, ultimately resulting in the inability to compare such systems (structures, models, operating rules),
g. improve consumer awareness, to cause permanent changes in consumer habits and the improvement of "social aspect" of the perception of the water resource.

The proposal of challenges in the area of operation of water systems, which are the result of observation and analysis of gaps in the context of the water road map, can be classified in four groups below.

1. Development of methods and tools supporting technical and economic analysis (challenge 1), includes building methods and tools for the analysis of costs and benefits of using ICT solutions in water management. These solutions should be evaluated in the direction of implementing decision support systems that use more and more data types (eg, Real Time Data, geographic data) to improve the detection of leaks.
2. Development of water-energy synergy solutions (challenge 2), includes research in the identification of factors for the mutual reinforcement of activities (synergies) between the water and energy sectors.
3. Development of models of performance indicators (challenge 3), research in the scope of development and identification of new measures, allowing for the assessment of the level of operation of the water supply system and maintenance activity, as well as determining the direction and size of changes in this area.
4. Development of standards for acquiring (challenge 4), storing and processing data, includes research on the sharing and exchange of data on the operation and monitoring of the water supply system and their standardization.

OVERVIEW OF SOLUTIONS SUPPORTING THE IMPLEMENTATION OF IDENTIFIED CHALLENGES

Taking into account the gaps and challenges presented, the authors of the article have been undertaking research tasks for many years, the aim of which is to search for solutions in the discussed area. One of the key aspects to be taken into account is the monitoring of the operation of technical network systems, implemented both in the short and long term. The goal of such a targeted approach is to optimize operational processes both in terms of technical criteria and economic criteria. Special significance for action takes the challenge 3, which in this case is the subject of developing models, methods and tools, that can be used in practice to exploitation assessment of network technical systems. In the above approach, the authors pay attention to three proprietary solutions (Loska et al., 2016, Karwot et al., 2016, Timofiejczuk et al., 2018, Wyczółkowski & Matysiak, 2009).

The first tool solution – SysDetLoc – supports monitoring of the water supply system. It allows for detection, location and also signaling failure of the water supply network. Thus, it is a starting point for initiating the procedure of generating a set of exploitation events (Karwot et al., 2016). An exemplary screen of the SysDetLoc tool, containing an event notice board, is presented on Fig. 4.

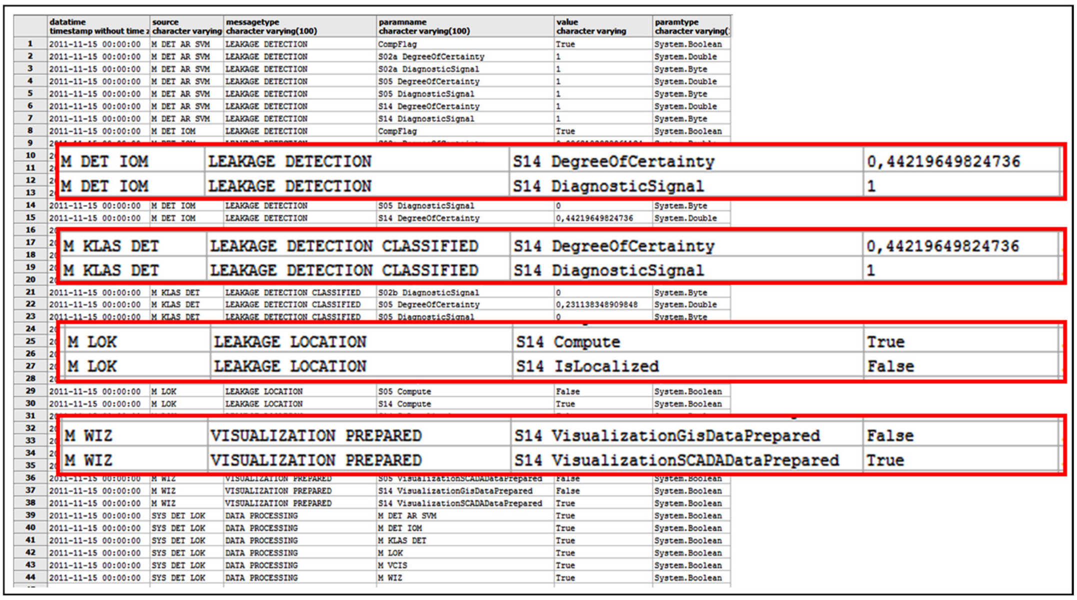

Fig. 4 An exemplary screen of the SysDetLoc tool

Source: (Loska et al., 2016, Karwot et al., 2016).

The second tool solution – ISOZE – supports maintenance management and exploitation analysis tasks. It allows for the analysis and assessment of the exploitation policy using a complex set of exploitation measures (30 indicators) whose values are calculated on the basis of data collected in the ERP module (Fig. 5) (Loska, 2015).

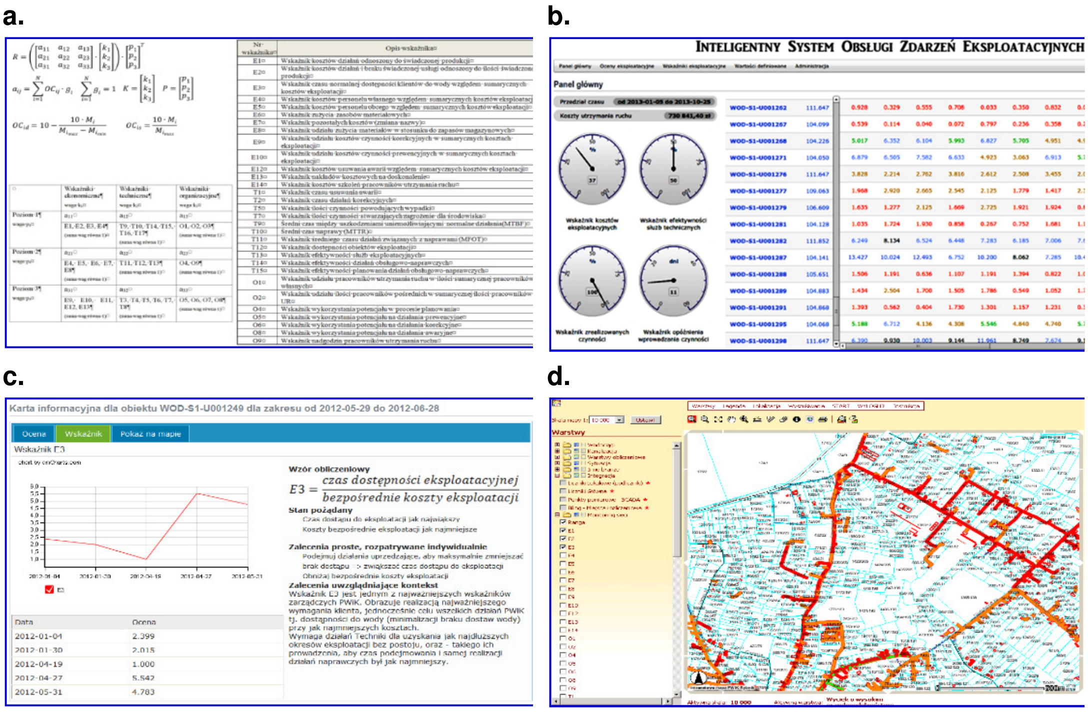

Fig. 5 An exemplary set of screens of the ISOZE tool
a. a list of exploitation measures used in the ISOZE tool, b. the basic screen of the ISOZE tool, c. graphical visualization and interpretation of the selected exploitation indicator, d. topological visualization of the selected exploitation indicator

Source: (Loska et al., 2016).

Its operation is based on the collection and processing of information resulting from the performance of maintenance tasks. Next, an there is performed assessment and visualization of the so-called operating activity of selected sections of the water supply network, based on ratings and ranks, built on the basis of the autor's exploitation analysis method (Loska, 2015). The analytical and decision-making possibilities of the developed IT solution rely on:

– combination of indicators in numerical form (values of measures),
– graphical and topographic visualization of the distribution of exploitation measures,
– interpretation of exploitation measures in relation to the decision-making process, whose criteria are defined directly by the decision-makers.

An exemplary set of screens of the ISOZE tool is presented on Fig. 5.

The third tool solution – SMOPE – supports long term exploitation decision-making process. It allows for assessment of exploitation policy on the basis of taxonomic aggregation of the key values of maintenance tasks (Fig. 6).

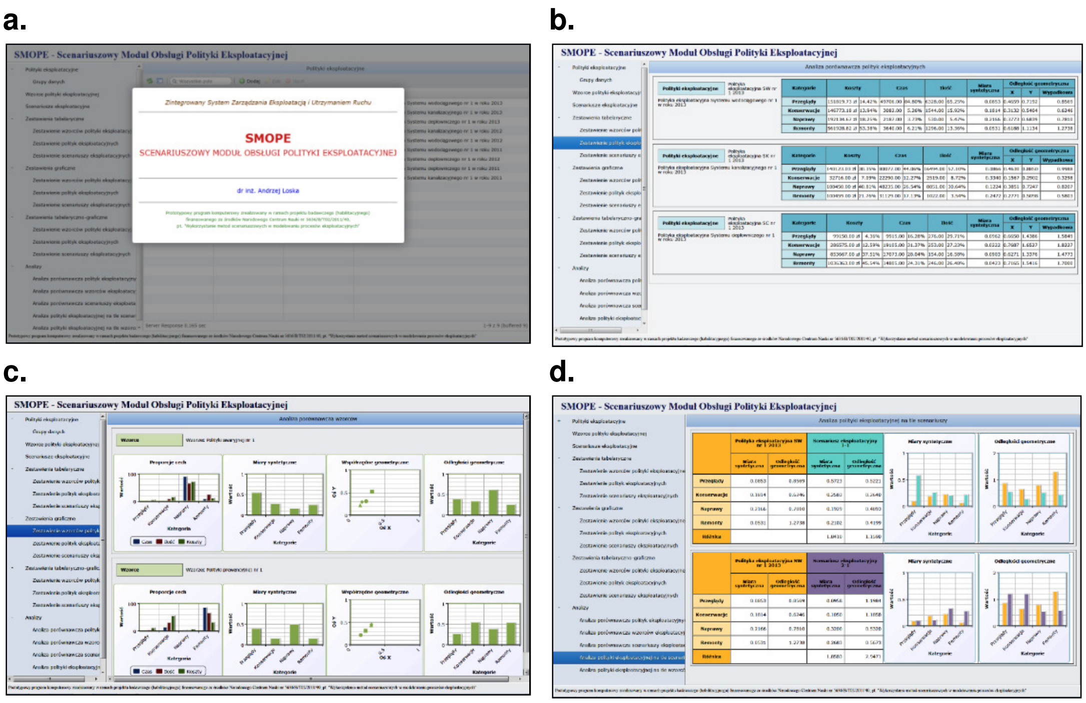

Fig. 6. An exemplary set of screens of the SMOPE tool
a. the starting screen, b. a set of pattern models of exploitation policy assessment of analysed technical systems, c. graphical set of pattern models of exploitation policy assessment, d. an analysis of selected models of exploitation policy assessment against the exploitation scenario models

Source: (Loska et al., 2017, Timofiejczuk et al., 2018).

The structure of the exploitation policy is determined, described by the types of maintenance and repair works (maintenance, inspections, repairs, overhauls). This structure is considered simultaneously in three categories: costs, time and number of completed maintenance tasks. Such a developed model allows for (Timofiejczuk et al., 2018):

– linear analysis of the operational policy based on developed positioning patterns,
– mutual comparative analysis of the exploitation policy for a maintenance organization with a similar activity specificity,

- time comparative analysis of exploitation policy, focusing on various maintenance cycles,
- simulation analysis of the operational policy, based on controlled change in the value of selected features and weights within future maintenance cycles.

SMARTCITY AS A DIRECTION OF DEVELOPMENT OF METHODS AND SUPPORTING EXPLOITATION TASKS

The analysis shows that the methods and tools, for supporting the exploitation of network technical systems, are usually directed at the use of quantitative analyses. On this basis there is carried out inference and assessment of the indicators. It allows for monitoring the exploitation condition of technical objects and plan maintenance tasks. The undertaken research works justifies need to include qualitative aspects of exploitation.

In the practical approach, the quality of the maintenance management process of the company's water supply system depends on the decisions made at various levels of competence: from the dispatcher to the management. Effectiveness of decisions (on different scales and in different time horizons) depends strongly on the availability of decision-makers to diversified information resources – of a technical and non-technical nature. In this context, we can distinguish the main categories of information resources describing the functioning of the water supply system:

- technical resources: operational parameters of technical facilities, indicators of monitoring and reliability of the operation of facilities, frequency of failures, etc.
- non-technical resources: parameters of water quality and consumption, system impact on the environment, environmental impact on the system, stakeholder interactions and behaviours, etc.

The problem in the exploitation decision-making process concerns most often the accessibility of a decision-making entity to diversified information resources. Due to the occurring needs, it may be necessary to identify parameters/indicators on the functioning of objects, to obtain processed information on system operation, or to assess the relationship and impact of different information resources on the exploitation process. The currently used tools for exploitation decision-process do not take into account the variability and impact of various environmental factors on the system, or the system's impact on the environment and stakeholders. In addition, apart from the lack of relations between the applied exploitation assessment indicators of technical facilities, there is a lack of interpretation of their importance in the effective management of the network technical system.

As part of the Smart City concept, the authors propose research in the field of global inclusion in the exploitation of various areas of the functioning of urban infrastructure (Angelidou et al., 2017). This idea fits into the improvement of the operation of facilities within network technical systems, which also refers to the quality of decision-making processes. The assessment of the impact of technical infrastructure of technical network systems on the local community and the environment has not been the subject of advanced research so far, therefore information resources of this type in network enterprises are unknown or are known only in the form of residual.

Therefore, the authors propose the development of a concept that can provide an innovative approach in supporting the exploitation decision-making process, with the possibility of using synergy of variable factors. Synergy, taking into account technical and non-technical aspects, significantly expands the issues of information resources and is an added value in supporting decisions into managing network technical systems. Inclusion of intelligent solutions to the maintenance management processes allows the use of modern technological solutions (eg remote data transmission, remote control of technical facilities, on-line interaction with stakeholders). Integration of various aspects with the orientation on improving the quality of life of residents in supporting decision-making processes is a holistic approach to the use of models, methods and tools according to the Smart City concept.

CONCLUSIONS

Intelligent support of management of the network technical system will allow to evaluate the effective use of media in terms of quantity and quality for various applications (eg. the demand for drinking water, industrial water, for business purposes). Requirements for maintaining quantitative and qualitative parameters at an appropriate level with a deepening tendency to reduce media resources justify undertaking in-depth and advanced research on the importance of network infrastructure impact on other aspects of quality of life, eg climate change, food, transport or soil. The integration of diversified information resources of a quantitative and qualitative nature in combination with the opportunities offered by modern technologies is a new approach to effective support of managing the network technical system.

Systematic procedural and classification of generated decisions in relation to the specificity of tasks of operation of network facilities in given time horizons (short, medium, long) allows to develop standardization of proceedings, which significantly contributes to improving the quality of maintenance management. The measurable effects of implementing standardization will include improving the quality of services provided to the community by the company, increasing the reliability indicators of network exploitation, economic efficiency of the company's operation.

The issues presented in the article are the effect of research carried out at the Institute of Production Engineering at the Faculty of Organization and Management at the Silesian University of Technology. These studies are a starting point for activities related to the development of a system supporting the processes of media distribution management in urban areas in line with the Smart City idea. It is assumed that the developed system will integrate both the technical area (control, monitoring and diagnostics, exploitation) and non-technical related to water distribution and the network's impact on the urban environment, i.e. acquisition, processing, exchange of information between the system and stakeholders.

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Abstract. The article discusses issues related to the management of the city's network infrastructure in the context of the Smart City idea. There was presented an overview of the possibilities and needs of supporting the maintenance management of network technical systems, as components of technical urban infrastructure. Issues related to the meaning of numerical models of various types of networks in comprehensive city management were discussed. Against this background, gaps and challenges in the implementation of modern technologies have been shown on the example of an important category of network technical systems such as water supply system

Keywords: maintenance management, network technical system, smart city, water supply system