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Overhauls in Water Supply Systems in Ukraine: A Hydro-Economic Method of Socially Responsible Planning and Cost Management

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Keywords: Water supply systems; Water sustainability; Cost planning; Social responsibility; Latent-semantic analysis; Public management.

Highlights

- Analysis of statistical data failures on water networks;
- Introduction of an overhaul planning method, taking into account the aging factor of the public infrastructure;
- Implementation of the LSA model in water network overhaul planning;
- Investigation of sustainable cost optimization for financing overhauls in water supply systems;
- Exploration of social responsible factors that reduce the financial burden on local budgets.

Abstract

The poor technical conditions of the water supply systems complicate the quality of urban population life and create a burden on public budgets. We examine the water supply system factors in Ukraine and identify the main parameters that restrain their development. This study examines the development of overhaul planning in water supply systems in Ukraine, taking into account the network equipment-aging factor. We employ a method for optimizing the planned costs for overhauls in water supply networks by engaging the latent-semantic analysis model (LSA). The LSA model provides a novel approach to sustainable planning of several economic factors in water supply. The exhibited results underline prominent technical and economic similarities in Ukrainian water supply systems. These results allow us to reveal an unsustainable usage of public funding for overhauls. In addition, the overhaul planning method engaged, improves the Ukrainian water supply sector. It helps the country to abandon the current reactive water management approach and aims towards proactive and sustainable water management. This innovative approach could redefine the public managerial profile, calibrating it towards a socially responsible one, significantly raising the quality of the urban population’s living standards.

OVERHAULS IN WATER SUPPLY SYSTEMS IN UKRAINE: A HYDRO-ECONOMIC METHOD OF SOCIALLY RESPONSIBLE PLANNING AND COST MANAGEMENT

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1. Introduction

Water supply systems (WSS) in Ukrainian cities face a plethora of technical and economic issues primarily due to: i) high levels of water supply networks and equipment depreciation; ii) lack of financing, leading to water pipe failures and iii) high energy consumption and waste of

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Abbreviations: LSA, latent-semantic analysis; SVD, singular value decomposition; WSS, water supply system; NGO, non-government organization; MLR, multiple linear regression; ANN, artificial neural network; GRI, global reporting initiative.

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drinking water in WSS (Burak and Yurchenko, 2015). These issues cause a shortage of valuable drinking water resources of an average of 35-40% and excessive power consumption to 4.5 billion kWh or 3.9% of the total power consumption in Ukraine (Pokutsa, 2015). Specifically, Ukrainian water supply networks have the following average lifetime and percentage of the total WSS supply, as follows: i) more than 90 years at a percentage of 35.1% ; ii) 75-90 years at a percentage of 19.5% and iii) more than 50 years at a percentage of 22.1% (Statistics JKG portal, 2013). Therefore, water supply networks are in disrepair and urgently need substitution, as they contribute towards the financial, environmental and infrastructural damage of the municipal resources and their water supply schedules.

Simultaneously, the water purification scheme used in Ukrainian water companies consists of the following main stages: dosing of reagents (e.g., coagulant and oxidant), mixing and settling, filtering, feeding to the consumer (Lu and Pichat, 2013). All Ukrainian enterprises use chlorination for water disinfection. In addition, the type of coagulants used can be different: aluminum-containing or iron-containing. It is noteworthy that water treatment equipment is worn-out and in need of repair. All of the above economic and technical factors have a negative effect on the living standards in major Ukrainian cities (Vitale, 2012). Consequently, reactive treatment to repairs, overhauls, replacements or renewals in water supply networks signify unsustainable practices and development (Gazzola et al., 2014). Therefore, the introduction of new hydro-economic methods of planning overhauls and cost allocation for the fixed-assets improvement in WSS should reveal a socially responsible profile (Chandler, 2016) for all municipal and other public organizations in Ukraine. Redesigning the forecast of the number of failures and the necessary costs for their liquidation could upgrade Ukrainian water management and increase the socially responsible profile of the country (Jonkman et al., 2008).

2. Literature review

Historically, Shamir and Howard (1979) performed one of the first economic attempts to model pipe failures, using a regression model. In the same way, Asnaashari et al. (2013) created a predictive analysis of pipe failures. Both of these economic analyses employ multiple linear regression (MLR) modelling and Artificial Neural Network (ANN), modelling for developing failure rates of the water distribution infrastructure. Furthermore, Weifeng et al. (2011) developed an integrated system for the detection, early warning, and control of pipeline leakage based on geographic information. Their model estimates the probability of each pipe segment leaking based on historic leakage data, locating the leakage points based on leakage signals. Berardi et al. (2008) modeled pipe deterioration using Evolutionary Polynomial Regression. This model assists decision-support systems for pipe rehabilitation and replacement planning. Finally, failures of water pipes in urban societies compromise technical and financial abilities to meet ongoing needs for suitable water consumption (Weber, 2002).

Therefore, historic economic modeling reveals that water management was, is and will remain of prominent importance for decades to come (Rusca and Schwartz, 2017). Current sustainable designs should explicitly incorporate the ecological, social and economic perspectives. Socially responsible water planning demands a redesign aiming towards the efficient water use, waste elimination and decentralized controlling of the water supply systems and infrastructure. It is evident that there is little socially responsible contribution towards water usage, which results in water supply decrease while global population increases (Apul, 2010).

Concurrently, ecological design should explicitly incorporate the human factor due to: i) a growing world population and higher living standards ii) the increasing of importance of public opinion that could support or oppose a project (Valentin and Bogus, 2015) and iii) the positive organizational profile those sustainable projects create (Lee, Chen and Tiong, 2015).

Significant economic-related methodology and investment in water infrastructure are essential to directly address the water shortage and advance beyond mere environmental ideas. Water planning and management have to emphasize sustainable cost-efficient maintenances of the existing infrastructure, rather than the construction of new water supply systems (Harou et al., 2009; Ward, 2009). Controlling the use of the water resources is feasible through constructive co-operation among organizations, governments and researchers. Therefore, efficient management collaboration of water supplies could prevent a water crisis in the future (Uche et al., 2015). Water resources are essential to human life, vigorous environmental practices and higher living standards (Krenkel, 2012). Water is a valuable component of the natural capital, one of the five capitals of sustainable development (Gazzola and Querci, 2017). Water quality is essential for public health protection and provision of the ecosystem habitats (Gazzola et al., 2013). All these prominent factors reveal an ongoing concern to bridge main sustainability gaps, as failing water infrastructure directly affects people's lives.

Social responsibility represents the core values that define the commitment of an organization to society, economy and environment (Porter and Kramer, 2011). Thus, socially responsible activities should integrate into a sustainable development agenda (Oginni and Omojowo, 2016). The unsustainable practices of some organizations have created great concern and attention from public and private institutions, non-governmental institutions (NGOs) and international researchers that aim to promote sustainable development. National and international strategies for ensuring adequate supplies of potable water are essential to long-term societal sustainability. According to Bonn and Fischer (2011), sustainability should be considered during the strategic decision-making process as an integral part of the organizational strategy. By adopting a strategic approach to sustainability, organizations are more likely to include economic, environmental and social considerations in all aspects of their activities (Rosenberg et al., 2007; Vanderleeuw and Sides, 2014; Wong and Brown, 2009). These strategic approaches are also aligned with the ongoing and increasing levels of corporate disclosure, commitments and achievements in sustainability (Zuo et al., 2012).

The research methodology reveals necessary sustainable, urban development, planning and reporting (Smith, 2010) by focusing on the triple bottom line of economic, technical and social factors. The hydro-economic method introduced integrates a sustainable strategy, and significantly contributes towards a socially responsible profile of Ukrainian cities.

3. Research methodology

The aim of this study is to explore the cost management and socially responsible planning of the water supply network in Ukraine, using the latent-semantic analysis (LSA) method (Landauer, 1997). The research framework considers current hydro-economic and technical factors of the water supply systems in the country. It embraces sustainable managerial practices by engaging efficient and effective proactive cost planning and thus minimizing overhauls and repairs thereby empowering environmentally friendly water usage.

3.1 Research Objectives

The first research objective is to identify the optimum frequencies of overhauls in WSS. This objective takes into account the failure rate growth factor of the single-repaired equipment. Current managerial planning overlooks this sustainability factor, and it does not embed unpredictable future costs in the WSS budget (Mays, 2011; Zhang et al., 2008). It is also a compound factor to analyze, as every municipal water supply company in Ukraine has its own technical and economic variables as well as autonomous overhaul planning. Unfortunately, lack of proactive repair-management in water supply networks, in accordance with budgeted time schedules, is essential as the reactive managerial approach bears the danger of insufficient financial and technical allocation of resources to emergency overhauls (Draper et al., 2003). Proactive allocation management of water supply resources and network maintenance is necessary to enable and forecast the expected number of networks and corresponding costs of failures (Gurung and Sharma, 2014). Thus, the resolution of the optimum overhaul frequencies' factor empowers a socially responsible managerial approach, which is critical for sustainable management to further advance the financial planning of WSS.

The second research objective is the realization of a failure analysis in WSS. It is a critical planning factor to predict future occurrences of failure in water supply networks and the corresponding financial costs of their elimination (Kleiner and Rajani, 2001). This is a significant factor, not only for the context of sustainable reporting, but also for cost-effective and efficient goal-setting of sustainable water management in WSS planning as well as within their strategies for developing tighter relations with their municipal stakeholders (Mascarenhas et al., 2015).

This paper also examines the further development of the existing outdated overhaul planning system in Ukrainian water supply companies. Such an effort allows water supply companies to make socially value-added decisions to asset management and modernize their WSS economy (Martinez, 2015; Hutton et al., 2007), as current economic approaches are the derivatives of the country's bureaucratic economic era.

Finally, the third research objective is to establish sustainable public standards for socially responsible management in emergencies (Lambooy, 2011) by tackling improper planning of overhauls in WSS.

3.2 Research Hypotheses

The hypotheses of this research are the following:

i. Every municipal water supply system has its own optimal frequency of overhauls and the optimal amount of funding overhauls is dependent on the optimal frequency of overhauls.

ii. Past failure trends in the water supply networks and their characteristic functions for a particular type of WSS could predict the number of future failures in the water supply networks. Thus, we could plan for the optimal costs and eliminate them.

iii. Taking into account i) and ii) we could reduce the total costs for overhauls in WSS. Thus, by reducing the pressure on water supply companies and municipal budgets, we could improve the efficiency of public management and local water sustainability.

3.3 Study context

As the main WSS of research, we considered the WSS of two Ukrainian cities: Kyiv and Kharkiv. The research motives derive from the following reasons: i) Kyiv and Kharkiv are the first and second most populated cities of Ukraine; ii) the WSS sizes in these cities are the largest in Ukraine; and iii) Kyiv and Kharkiv municipal water companies, according to the nation's history, are the oldest in Ukraine. In Kyiv, the municipal water company has operated since 1872 and in Kharkiv since1881.

Kyiv is the capital and largest city of Ukraine, located in the north central part of the country on the Dnieper River with population nearly 2.9 million people[5]. Kyiv municipal water supply company serves more than 4,000 kilometers of water supply networks. Water pipes depreciation in Kyiv is 60-80% (Kyivvodokanal, 2017), which is a critical level for an impending accident.

Water supply networks are served from 11 water supply operating services. Kyiv receives drinking water from three water sources – the rivers Dnieper and Desna, and underground sources. In the overall water supply scheme in Kyiv, the following infrastructure is involved: i) 34 water pumping stations; ii) 364 artesian wells and power supply facilities and iii) 129 transformer substations. The total capacity of the drinking water supply in Kyiv is 2 million 100 thousand m3 per day. The main problem of the Kyiv WSS is the irrational use of financial resources for repairs in water supply networks (Kyivvodokanal, 2017). We discovered certain consequences relating to this irrational water usage. On the one hand, we discovered insufficient funding of repairs, and, on the other hand, an unsustainable and ineffective planning system for repairs in Kyiv WSS.

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[5] Чисельність населення м.Києва (in Ukrainian). UkrStat.gov.ua.1 November 2015. Retrieved 9 January, 2016.

The Kharkiv WSS, where we also propose the implementation of a planning system for failures in the water supply network with planned costs for their elimination, follows. Kharkiv is the second largest city in Ukraine. It is located in the northeast of the country and has a population of about 1.43 million people[6]. Kharkiv WSS is the largest municipal WSS in Ukraine. It is of prominent ecological importance, as the ecological state in Kharkiv as well as the ecological states of five small rivers and Seversky Donets River depend on its operation. These water resources comprise the main source of drinking water in the Kharkiv region. Kharkiv WSS provides intake, filtration (Goncharuk et al., 2011), transportation and sale of drinking water to the population of Kharkiv city and the Kharkiv region. Unfortunately, water supply networks and water treatment technology in the region are in need of modernization. In 2016, the municipal company's equipment and pipes depreciation estimates are calculated at an average of 75%. The total length of Kharkiv's water pipes and water network system are estimated at a total of 2,657.9 km, including: i) 802.7 km of water pipes, accounting for 30.2% of the city's total water supply network length and ii) 1,855.2 km of water supply networks, accounting for 69.8% of the city's total water supply network. The length of technically worn-out water pipes and water supply networks in Kharkiv WSS is 1401.3 km, accounting for 52.72% of the total water supply network length, including 391.6 km of water pipes and water networks of 1,009.7 km. (Kharkiv City Council. Development Program of CE "Kharkivvodokanal", 2015). Every year Kharkiv's water supply networks exhibit an increasing trend towards a greater amount of damage.

The effectiveness of WSS economic activity depends primarily on the level of fixed assets and technical conditions which are characterized by high depreciation (Miller, 2007). In the current study, we analyze the condition of water supply networks and research factors that affect them. We conclude that the company's system of overhaul planning and financing has some significant defects and does not fulfill the demands of sustainable management.

Among the most important issues revealed are: i) the lack of strategic socially responsible goals and objectives of fixed assets reproduction (Papagiannis, 2017); ii) lack of funding for planned overhauls; iii) embryonic functions and sustainable reporting of predicting failures and planning overhauls in WSS; and iv) fragmented information reporting of the water supply networks status.

To solve these issues, we propose to calculate an optimal amount of funding overhauls based on an annual repair frequency in Kharkiv WSS. Simultaneously, in the water supply networks, we attempt the implementation of a forecasting system for failures with planned costs that eliminates existing mismanagement. Current fixed-assets maintenance in Kharkiv does not exclude the possibility of network failures, although it could reduce emergencies in WSS (Gurung et al., 2016). It is important that public maintenance management consider a tight time schedule of overhauls. Therefore, this research explores the establishment of a sustainable and effective system of overhaul planning in the two largest cities of Ukraine. Finally, as current literature reveals, overhaul planning for Kiyv's and Kharkiv's WSS is strongly advisable (Yates et al., 2005).

4. The Hydro-economic Method and Model Analysis

We tested the developed model on WSS of the Ukrainian cities of Kyiv and Kharkiv. Then we communicated multiple times with the managers and engineers of the related water supply companies in order to discuss the model outcomes. As a result, we received documentation confirming the operability of this proposed model. The model contains a cost-based approach and it takes into consideration the probabilistic factor of accident occurrence on networks.

4.1 Calculating the optimal amount of funding overhauls based on overhaul frequency

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[6] "Major Cities in Ukraine by Population (2014)". World Population Review. Retrieved 2014-04-14.

In general, the following formula could determine the overhaul costs and costs to cover economic losses from elimination of failures in water networks, as follows:

$$C = Co + Cr * F(t) \tag{1}$$

C - overhaul costs and elimination of failures;
Co - planned overhaul costs;
Cr - repair costs in case of failure;
F (t) - function that characterizes equipment failure (e.g., expectation of failures in water networks or equipment failures);

The repair costs in the event of failure can be determined as follows:

$$Cr = Crec + Ccons \tag{2}$$

$Crec$ - cost of recovery equipment;
$Ccons$ - cost for eliminating the consequences of failure

The function that takes into account possible equipment failures, up until the present time, and in turn depends on the intensity of previous (cumulative) equipment failures can be expressed by the formula:

$$F(t) = \int_0^t x(t)dt \tag{3}$$

$x(t)$ - Intensity of the water equipment failures or accidents in water supply networks.

$$x(t) = x0 + k * t \tag{4}$$

$x0$ - initial failure rate value;
k - index that taking into account the aging equipment rate.

The parameters k and x0 we obtained after statistical processing technical data about equipment and water networks in WSS.

To optimize overhaul performance periods in the analytical model, we use specific repair costs (costs per unit of time):

$$Cp = C/t \tag{5}$$

Cp - Costs per unit of time. Substituting equation (1 - 4) to formula (5), and solving them, we get:

$$Cp = (Co + Cr * (x0 * t + k * t^2/2))/t \tag{6}$$

Since it is advisable to minimize unit costs over time, $Cp \rightarrow 0$, we find the equation of the optimum frequency of overhauls in this analytical model:

$$t = \sqrt{2/(\frac{Cr}{Co} * k)} \tag{7}$$

Using empirical data of the company’s actual costs in the event of failure and planned overhaul costs, we may determine the optimal frequency of fixed assets’ overhauls in WSS.

In case of annual performance for water network overhauls in WSS (t = 1), the simplified formula is the following:

$$Co = Cr * k/2 \tag{8}$$

Based on this formula, there are certain characteristics that are important for determining the aging equipment rate index k. According to formula 4, it can be defined that:

$$k = \frac{x(t)- x0}{t} \tag{9}$$

Then we consider the basic situation of failures in relation to sequential and parallel water pipe systems. Consecutively, any failure of any component in water pipe systems leads to failure of the whole system. As a result, the system of logical equations (Gottman, 1990) for sequential water pipes system is:

$$\begin{cases} y1 = x1 \\ y2 = y1 \wedge x2 \\ y3 = y3 \wedge x3 \end{cases} \qquad (10)$$

Where: y1, y2, y3, x1, x2, x3 are elements of sequential water pipes system. The calculated mathematical probability (Ps) of failure-free operation Ps in this case is:

$$Ps = P1 * P2 * P3 \qquad (11)$$

In water pipe systems with parallel structure, failure usually occurs in the case that all parallel system elements fail. The system of logical equations for parallel system is calculated as:

$$\begin{cases} y1 = x1 \\ y2 = x2 \\ y3 = x3 \end{cases} \qquad (12)$$

The calculated mathematical probability (Ps) of failure-free operation Ps in this case is:

$$Ps = 1 - (1 - P1) * (1 - P2) * (1 - P3) \qquad (13)$$

Kharkiv WSS technically refers to a system with a different set of sequential and parallel production elements, such as pumps, which are parallel production elements, and water pipes of different types, which are considered sequential production elements. Although a mathematical description of such a system is difficult, it is a type of system with (n, m) elements (Gottman, 1990). The calculated probability in system containing n elements with m elements, which work perfectly, can be expressed by the formula:

$$Ps = \left(\frac{n!}{m!(n-m)!}\right) * p(t)^m * q(t)^{n-m}\text{, m}=0,1,2\ \ldots n \qquad (14)$$

Where p(t) is the probability of individual elements in system success work and q(t) is defined as 1– p(t). Thus, returning to the formula for determining k, which is the aging equipment rate (9) and by using the probability formula (14) for determining the properties parameter x(t) - probability of WSS failure, we could note that the probability of equipment failure will not be linear but exponential, with the following exponential formula:

$$x(t) = x^q \qquad (15)$$

Therefore, formula (9), which takes into account the factor of aging equipment together with the mixed sequential and parallel water pipes system would form the following formula:

$$k= \frac{x^q - x0}{t} \qquad (16)$$

Now, if the initial value x0 is negligible failure rate, and duration of annual overhauls is t = 1, the index that takes into account the aging equipment rate will increase annually under exponential law, as:

$$k = x^q \qquad (17)$$

Based on the company’s previous year’s water network data (planned overhaul costs and repair costs in case of failure) using formula (8) we receive results for the index k (k = 1.04), which takes into account the rate of the aging water supply network in Kharkiv WSS. Using the k value for Kharkiv WSS, we could calculate that if $k = 1{,}04^q$, (q=1,2…T), then, after just 10 years the old water supply network failure rate will increase by 48%, and, in 20 years, equipment will begin to fail almost 220% more. Therefore, we could propose that the amount of planned cost for overhauls has to adjust.

4.2 Predicting the future failure occurrences in water supply networks

Each WSS has its own ecological and economic factors. In Ukraine, many water supply companies do not schedule overhaul maintenance in accordance with their plan. Overhaul sustainability is in effect either in case of failures (see Table 1) or in case of emergencies in WSS, or according to the financial surpluses available for repairs. Such a deficit in socially responsible planning carries a negative environmental effect and additional financial losses in WSS (see Tables 5 and 6).

Table 1

Percentage of WSS fixed assets that need immediate overhaul due to failures.

Ukrainian water supply company	%	Ukrainian water supply company	%
CE "Vinnytsyaoblvodokanal"	33	CE "Infoxvodokanal" Odessa	37
CE "Lutskvodokanal"	33	CE "Poltavavodokanal"	25
CE "Dnieprovodokanal"	43	CE "Rivneoblvodokanal"	24
CE "Zhytomyrvodokanal"	27	CE "City Water" Sumy	24
CE "Vodokanal, Uzhgorod"	11	CE "Ternopilvodokanal"	40
CE "Vodokanal" Zaporizhzhya	38	CE "Harkivvodokanal"	35
CE "Ivano-Frankivskvodoecotechprom"	30	CE "VUVKH Kherson	23
CE "Bilotserkivvodokanal"	20	CE "Hmelnytskvodokanal"	38
CE "Dnipro-Kirovograd"	49	CE "Chernivtsivodokanal"	33
CE "Lvivvodokanal"	50	CE "Chernihivvodokanal"	23
CE "Mykolayivvodokanal"	29	JSC " Kyivvodocanal "	38

To eliminate this planning deficit, it is necessary to forecast the number of failures in water networks and the costs for their elimination. As a forecasting tool, in calculating the future failure occurrences and corresponding cost we consider using the Latent Semantic Analysis (LSA). LSA is a contemporary method, which is widely used in information technology and machine information analysis. The LSA has its roots in factor analysis principles, including detection of latent relationships and studied phenomena or objects (Landauer, 1997). The clustering variables of this method are used to extract context-dependent variables using statistical processing resources.

Like our economic approach, LSA uses a matrix that describes the data set used for training systems (Landauer, 1997). The elements of this matrix have typical scales, taking into account: i) the frequency of use of each variable in each direction; and ii) a variable part in all directions. The most common version of LSA is based on a diagonal matrix decomposition by singular value (SVD - Singular Value Decomposition). Using SVD of any matrix, which decomposes, into many orthogonal matrices, a linear combination of which is a sufficiently accurate approximation to the original matrix (Hansen, 1987). Singular value decomposition matrix of size M x N called its representation in the form:

$A=USV^t$ (18)

Where U is an orthogonal matrix with the size of N x P,

V^t – is an orthogonal matrix with the size P x M,

S is a matrix with the size of P x P, in which the main diagonal are inseparable numbers arranged in descending order and all the elements outside the diagonal equal zero:

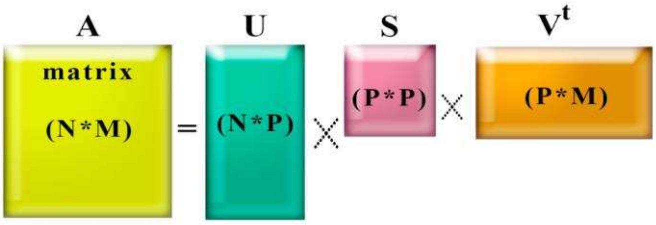


Fig. 1. General Schematic View.

During a singular matrix decomposition the main search procedure approaching the largest dimension of the matrix (N*M). A=($x_{i,j}$) is to form the matrix $\overline{b \oplus a} = b_i a_j$, where b_i–m-dimensional vector, a a_j – n-dimensional vector by least squares method:

$$F(b,a) = \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{n}(x_{i,j} - b_i a_j)^2 \rightarrow min \qquad (19)$$

The solution to this problem is solved by successive iteration formulas for fixed vector $a = a_j$, meaning $b = b_i$ give the minimum function F (b, a), and determined by the following equations:

$$\frac{dF}{d\,b_i} = 0; \qquad (20)$$

$$\frac{dF}{d\,b_i} = -\sum_{j=1}^{n}(x_{i,j} - b_i a_j) * a_j = 0; \qquad (21)$$

$$b_i = \frac{\sum_{j=1}^{n}(x_{i,j} a_j)}{\sum_{j=1}^{n} {a_j}^2}; \qquad (22)$$

Similarly, a fixed vector $b = b_i$ is determined by the value of vector $a = a_j$ through the formula:

$$a_j = \frac{\sum_{i=1}^{m}(x_{i,j} b_i)}{\sum_{i=1}^{m} {b_i}^2} \qquad (23)$$

First we approach vector $a = a_j$ and we take random vector unit length, second we calculate vector $b = b_i$, third we calculate this vector $a = a_j$, etc. Each iteration step reduces the value of F (b, a). The criterion to halt these consecutive iterations is the relative decrease of the functional value F (b, a) for an iteration step or a small value of F. As a result of the matrix A=($x_{i,j}$), we receive the best approximation matrix F^1 to form $\overline{b \oplus a} = b_i {a_j}^1$ (superscript number indicates iteration). Next from the matrix A=($x_{i,j}$) we deduct matrix F^1, and, for the resulting matrix, again we look for the best approximation to F^2 until $A_к$ becomes sufficiently small. It is important that the SVD is a convenient method for working with matrices (Golub, 1965). It shows the geometric structure of the matrix and allows visualization of the data. Singular value decomposition is used in solving a variety of tasks such as: i) approximation method of least squares solutions; ii) equations and the methods of encryption; and iii) archiving data.

The SVD peculiarity highlights the key elements of the matrix, allowing us to ignore the "noise" (Samet, 2006). According to simple rules of matrix multiplication displays, the columns and rows corresponding to smaller singular values provide the smallest contribution to the final result. For example, we could discard the last column of the matrix U and last lines of the matrix V^t, leaving only the first two. It is important that such consecutive iterations ensure an optimal result.

5. Hydro-economic Model Results

First, the received data information on the actual number of equipment and network failures and company’s actual overhaul costs for preventing these failures are sourced from Kharkiv and Kyiv WSS. To verify the results of the LSA forecasting system for WSS failures, we performed a comparison between the results of the LSA model and the actual results at municipal companies. We had multiple meetings and discussions over several years in order to analyze these results. These meetings took place at the management headquarters of the related water supply companies.

5.1 Data input

The calculations of the optimal frequency of overhaul failures’ data on Kharkiv WSS could be categorized as:

- information about the water supply network objects (their implementation dates);
- data on failures, data on consequences of failure (type of damage, event, cause);
- additional technical data;
- data on repair costs in the case of equipment failure;
- data on actual costs of overhauls (from the municipal company).

Thus, observing the failures of Kharkiv WSS objects for a number of years (2009-2014), taking into account their technical condition, the implementation period, and having actual data on overhauls, using the formulas (7, 8, 17), we obtain the following results* (Table 2):

Table 2
Calculating planned overhaul costs (Kharkiv WSS).

Type of costs	2009	2010	2011	2012	2013	2014
Repair costs in case of equipment failure, in thousands UAH	18300	24499	25452	29177	31035	41292
Planned overhaul costs, in thousands UAH (based on model)	9515.5	12739.5	13235	15172	16138.2	21446
Company's actual overhaul costs, in thousands UAH (municipal company data)	8450	9213	9810	10814	12173	17463

* k = 1.04 - index that takes into account the rate of aging equipment

According to Table 2, in 2012 the actual overhaul costs in the overall cost of service "central water supply" accounted for 10.814 million UAH; in 2013 - 12.173 million UAH, i.e., 71.3% and 75.4% of the needs of the municipal company estimated by our economic model (formulas 8, 17). In 2014 the actual overhaul costs according to the company data amounted to 17.463 million UAH; it was financed at only 81% obtained by model planned overhaul costs (21.446 million UAH), and it does not take into account the effect of underfunding accumulated overhauls. Due to insufficient financing of overhauls in accordance with the results of the model, there is an increase in the statistics of accidents on Kharkiv WSS. In the case of full funding (100%) for overhauls, the municipal company could significantly minimize repair costs in case of equipment failure and eliminate failures.

The management of the Kharkiv WSS was acquainted with the research results and agreed that economically justified financing of repairs would help to avoid high costs associated with the elimination of consequences of failures. Finally, the management expressed an interest in developing a hydro-economic model for predicting cases of failures and costs relating to their elimination.

5.2 Constructing a forecasting system for WSS failures, repairs and their related costs

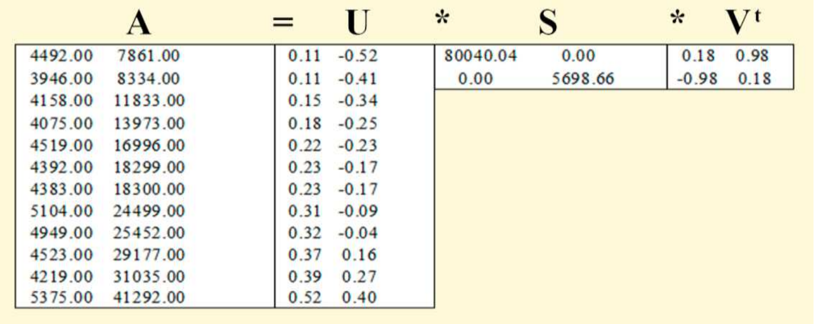
As input data, we use the number of failures in the water supply network (Kharkiv WSS) over a number of years (Table 3).

Table 3
Number of failures in water supply network and repair costs (Kharkiv WSS).

Years	Numbers of failures in water supply network	Repair costs in the case of network failures, thousands UAH	Years	Numbers of failures in water supply network	Repair costs in the case of equipment failure, thousands UAH

2003	4492	7861	2009	4383	18300
2004	3946	8334	2010	5104	24499
2005	4158	11833	2011	4949	25452
2006	4075	13973	2012	4523	29177
2007	4519	16996	2013	4219	31035
2008	4392	18299	2014	5375	41292

We use the LSA and SVD methods for constructing the model and determine a socially responsible connection between water network failures cases and estimated costs for their elimination. This approach optimizes financial resources of WSS and allows the municipal company to avoid excessive financial losses, in a sustainable manner. Output matrix A, based on the data for the number of accidents to the water supply network and related costs for their elimination in the SVD will look like (Figure 2):



$$A = U * S * V^t$$

$$\begin{array}{|cc|}\hline 4492.00 & 7861.00 \\ 3946.00 & 8334.00 \\ 4158.00 & 11833.00 \\ 4075.00 & 13973.00 \\ 4519.00 & 16996.00 \\ 4392.00 & 18299.00 \\ 4383.00 & 18300.00 \\ 5104.00 & 24499.00 \\ 4949.00 & 25452.00 \\ 4523.00 & 29177.00 \\ 4219.00 & 31035.00 \\ 5375.00 & 41292.00 \\ \hline\end{array} = \begin{array}{|cc|}\hline 0.11 & -0.52 \\ 0.11 & -0.41 \\ 0.15 & -0.34 \\ 0.18 & -0.25 \\ 0.22 & -0.23 \\ 0.23 & -0.17 \\ 0.23 & -0.17 \\ 0.31 & -0.09 \\ 0.32 & -0.04 \\ 0.37 & 0.16 \\ 0.39 & 0.27 \\ 0.52 & 0.40 \\ \hline\end{array} * \begin{array}{|cc|}\hline 80040.04 & 0.00 \\ 0.00 & 5698.66 \\ \hline\end{array} * \begin{array}{|cc|}\hline 0.18 & 0.98 \\ -0.98 & 0.18 \\ \hline\end{array}$$

Fig. 2. The mechanism of SVD (Kharkiv WSS).

Note, that matrix U reflects the SVD mechanism with an internal latent structure of the indices of matrix A (Samet, 2006). We investigated matrix U, which reflects the internal structure of the latent correlation data. The first column of matrix U contains a variable (Var1), and the second column reflects the function of the argument (Var2). Matrix U reveals a functional connection of distribution matrix indices. We chart these distribution matrix values of left singular vectors in Figure 3.

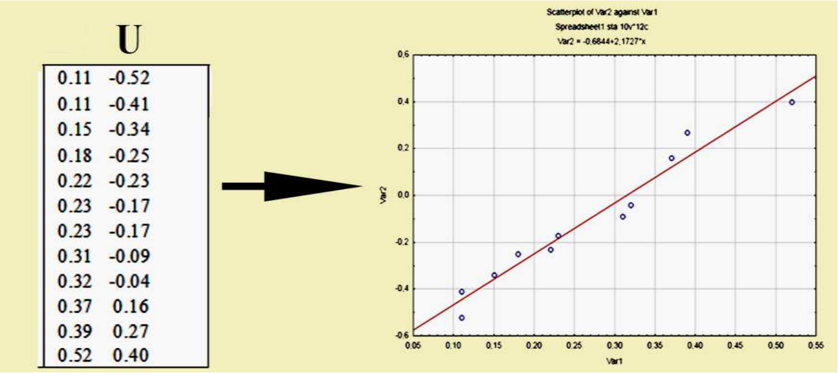


Fig. 3. Matrix U data correlation of left singular vectors (Kharkiv WSS).

For Kharkiv WSS in a given period, this function will be:

$$Var2 = -0.6844 + 2.1727*Var1 \qquad (24)$$

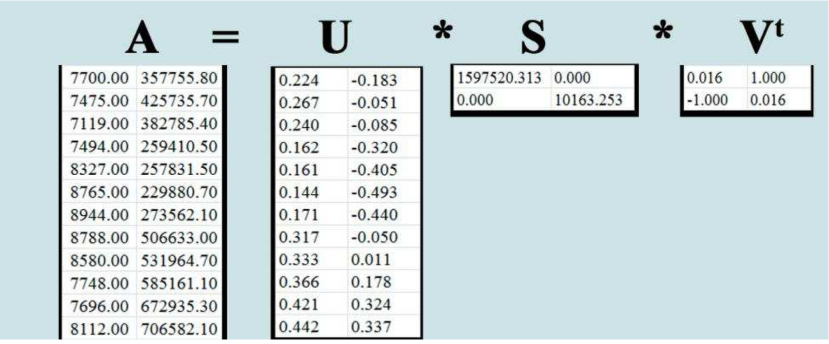
Thus, we produce a formula that can serve as a basis for predictive model of failures in WSS. Using input data on Kyiv WSS (see Table 4), we perform similar mathematical operations.

Table 4

Numbers of failures in water supply network and repair costs (Kyiv WSS).

Years	Numbers of failures in water supply network	Repair costs in the case of network failures, in thousands UAH	Years	Numbers of failures in water supply network	Repair costs in the case of equipment failure, in thousands UAH
2005	7700	357755.8	2011	8944	273562.1
2006	7475	425735.7	2012	8788	506633.0
2007	7119	382785.4	2013	8580	531964.7
2008	7494	259410.5	2014	7748	585161.1
2009	8327	257831.5	2015	7696	672935.3
2010	8765	229880.7	2016	8112	706582.1

Similar to the previous operations, we construct matrix A that contains the number of failures in water supply network (Kyiv WSS) and the costs of their elimination. The next step is the application of the LSA and SVD methods to matrix A (Figure 4).



$$A = U * S * V^t$$

$$\begin{bmatrix} 7700.00 & 357755.80 \\ 7475.00 & 425735.70 \\ 7119.00 & 382785.40 \\ 7494.00 & 259410.50 \\ 8327.00 & 257831.50 \\ 8765.00 & 229880.70 \\ 8944.00 & 273562.10 \\ 8788.00 & 506633.00 \\ 8580.00 & 531964.70 \\ 7748.00 & 585161.10 \\ 7696.00 & 672935.30 \\ 8112.00 & 706582.10 \end{bmatrix} = \begin{bmatrix} 0.224 & -0.183 \\ 0.267 & -0.051 \\ 0.240 & -0.085 \\ 0.162 & -0.320 \\ 0.161 & -0.405 \\ 0.144 & -0.493 \\ 0.171 & -0.440 \\ 0.317 & -0.050 \\ 0.333 & 0.011 \\ 0.366 & 0.178 \\ 0.421 & 0.324 \\ 0.442 & 0.337 \end{bmatrix} * \begin{bmatrix} 1597520.313 & 0.000 \\ 0.000 & 10163.253 \end{bmatrix} * \begin{bmatrix} 0.016 & 1.000 \\ -1.000 & 0.016 \end{bmatrix}$$

Fig. 4. The mechanism of SVD (Kyiv WSS).

For Kyiv WSS, we also investigate the matrix U, which reflects the latent correlation data. The first column of matrix U contains a variable (Var1), and the second column contains the function of the argument (Var2). From matrix U, we find a functional connection of distribution and chart the distribution matrix indices of left singular vectors (Figure 5).

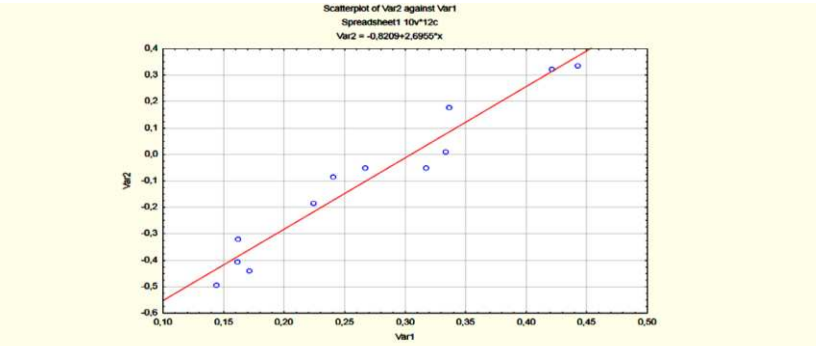


Fig. 5. Matrix U data correlation of left singular vectors (Kyiv WSS).

For Kyiv WSS, the function of distribution input matrix indices, which characterizes the researched data latent correlation, is:

$$Var2 = -0.8209 + 2.6955*Var1 \qquad (25)$$

Due to the obtained functions that contain the internal correlation of matrix U indices, it is possible to construct a model for predicting future values. Using inverse operations of the SVD method, we can acquire the optimal number of costs for eliminating failures in the water supply network. This allows us to "clean out noise" and optimize the data.

5.2 Data output

The next step is the performance of inverse iteration of the SVD process. We added Var1 indices (0.60; 0.65; 0.70; 0.75; 0.80) values for Kharkiv WSS in the next five years in received function (24). We need these indices to interpolate the values according to the characteristics function (Figure 6).

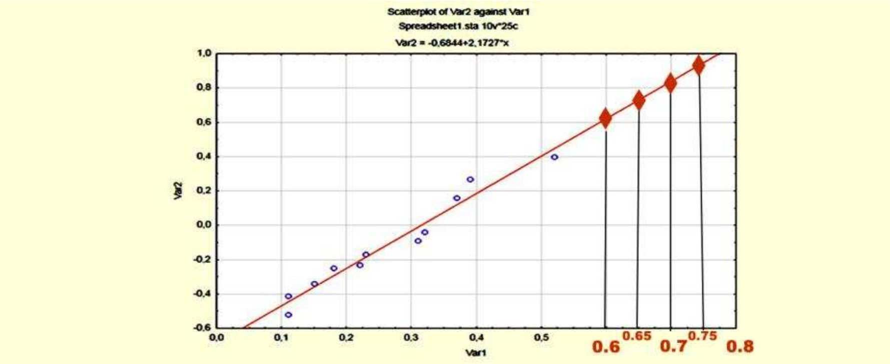
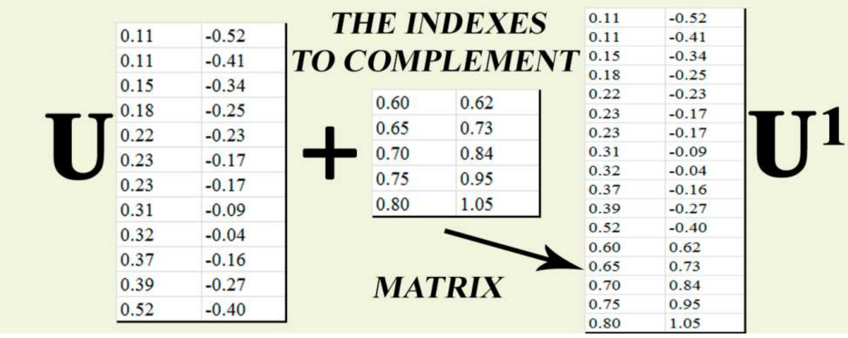


Fig. 6. Interpolation the values according to the characteristics function (Kharkiv WSS).

With the function and inverse iteration of SVD process and by adding new data values, we construct matrix U^1 (Figure 7).



0.11	-0.52
0.11	-0.41
0.15	-0.34
0.18	-0.25
0.22	-0.23
0.23	-0.17
0.23	-0.17
0.31	-0.09
0.32	-0.04
0.37	-0.16
0.39	-0.27
0.52	-0.40

0.60	0.62
0.65	0.73
0.70	0.84
0.75	0.95
0.80	1.05

0.11	-0.52
0.11	-0.41
0.15	-0.34
0.18	-0.25
0.22	-0.23
0.23	-0.17
0.23	-0.17
0.31	-0.09
0.32	-0.04
0.37	-0.16
0.39	-0.27
0.52	-0.40
0.60	0.62
0.65	0.73
0.70	0.84
0.75	0.95
0.80	1.05

Fig.7. Construction of the matrix U^1.

In inverse iteration, we calculate the matrix A^1 - a matrix of accidents on water supply network and repair costs. It is noteworthy that the sequence of matrix multiplication is essential.

$$\mathrm{A}^1 = U^1 * S * V^T \qquad (25)$$

Matrix A^1 exhibits the predicting numbers of failures in WSS in the following years of the water supply company (2015-2019) and the corresponding optimum costs for their elimination. The next step is the construction of the comparison table; it includes the yearly estimated costs for future elimination of failures according to the LSA model (Table 5):

Table 5

LSA model estimating cost of failures elimination in water supply networks (Kharkiv WSS).

Years	Numbers of failures in water supply network	Repair costs in case the of network failures, in thousands UAH	The optimum repair costs in the case of network failures according LSA model,	Excessive (+) or the lack of (-) water supply networks financing, in thousands UAH

		(company data)	in thousands UAH (model data)	
2003	4492	7861	8133	-272
2004	3946	8334	8246	+88
2005	4158	11833	11470	+363
2006	4075	13973	13926	+47
2007	4519	16996	17098	-102
2008	4392	18299	17947	+352
2009	4383	18300	17947	+353
2010	5104	24499	24333	+166
2011	4949	25452	25172	+280
2012	4523	29177	29317	-140
2013	4219	31035	31005	+30
2014	5375	41292	41382	-90
2015*	5220**	-	47911	-
2016*	5329**	-	51963	-
2017*	5439**	-	56016	-
2018*	5548**	-	60068	-
2019*	5713**	-	64110	-
Total	76164	247051	526044	**+1075**

* - the forecast years

** - obtained the forecast quantity of failures cases in water supply network.

Overall, based on received data, the constructed model analyzes the costs for failures elimination in water supply networks and the establishment of their tight degree of correlation. The LSA model allows us to identify the optimal annual repair costs in the case of network failure in water supply networks in order to minimize the total costs f**or all municipal and other public planning. The data obtained in Kharkiv WSS (Ukraine) indicates** that the funding is inadequate and leads to significant financial waste (e.g., for the last decade the excess amount of 1075 thousands UAH) while the number of failures remain high. We perform similar calculations using the second model (e.g., Kyiv WSS matrix A). As a result, we manage to limit the maintenance time intervals until 2016, without substituting indices corresponding to future years, as in the Kharkiv WSS LSA model. The produced model examines the LSA and SVD models' adequacy and correctness, based on received data from any municipal water supply company. The forecasted results obtained on the second model for Kyiv's WSS (see Table 6) allow for their comparison with the actual Kyiv WSS data and the provision of conclusions in relation to funding distribution. Due to the model's successful forecasting, Kyiv WSS management intends to provide further data for budget planning and sustainable resource allocation in relation to their water system network.

Table 6

LSA model estimated costs of failures elimination in water supply networks (Kyiv WSS).

Years	Numbers of failures in water supply network	Repair costs in the case of network failures, in thousands UAH (company data)	The optimum repair costs in the case of network failures according LSA model, in thousands UAH (model data)	Excessive (+) or the lack of (-) water supply networks financing, in thousands UAH
2005	7700	357756	357815	-59
2006	7475	425736	426530	-794
2007	7119	382785	383391	-606

2008	7494	259411	258746	+664
2009	8327	257832	257135	+697
2010	8765	229881	229963	-82
2011	8944	273562	273104	+458
2012	8788	506633	506406	+227
2013	8580	531965	531976	-11
2014	7748	585161	584721	+440
2015	7696	672935	672609	+327
2016	8112	706582	706159	+423
Total	96749	5190238	5188555	**+1683**

The data obtained by the second model (Kyiv WSS) also indicates an irrational and unsustainable distribution of funds for water supply networks repairs. Based on the results of the model, we observe an over-expenditure of funds of 1683 thousand UAH.

Summarizing the results and corresponding calculations of the established hypotheses (i) - (iii), it could be concluded that:

(1) In the case of annual overhauls, Kharkiv municipal WSS had the optimal number of planned overhaul costs according to the funding and the network rate of aging as indicated in Table 2 with k index (k = 1.04). In the Kyiv WSS, due to lack of integrated reporting, we failed to reach transparent data for the rate of water supply network aging.

(2) For both cities of Kyiv and Kharkiv, and based on the LSA model, we managed to obtain the optimal planned number of costs for WSS failures elimination (see Tables 5-6). The LSA model takes into account past trends in failures in the water supply network and the characteristic function for a particular type of water supply network (see formulas 24-25).

(3) The total cost reduction for overhauls, according to our model, in the Kyiv WSS was by 1683 thousand UAH and in the Kharkiv WSS was by1075 thousand UAH.

6. Discussion

This research takes into account the main hydro-economic factors when managing the level of water supply equipment aging in terms of use and accumulated depreciation. There are similar studies, such as Gao et al. (2014), which also explore similar factors related to our study. According to this study and based on our extensive experience with multiple meetings over a period of several years, however, we include several parameters which are missing from other hydro-economic models. Therefore, for the completion of this study, we are considering a series of sustainable factors (e.g., technical, social and ecological) besides the economic ones, which are essential for socially responsible water usage and directly affect the WSS networks. Furthermore, based on this diversity of sustainable factors, we examine scenarios that we had considered together with the management of water companies. For example, for calculating the optimal amount of overhauls' funding, we agreed that the annual overhauls be carried out as initially planned by the water supply companies, which is not always the case. Based on these scenarios, the overhaul frequency and the optimal costs of repairs are also calculated. Thus, optimal maintenance costs and optimal frequency or repairs provide fertile ground for efficient and effective water-related managerial decision making.

Another important set of parameters is i) that both methods employed (LSA and SVD) cohesively test the same water supply networks (Kyiv's and Kharkiv's) through the years, which are the largest water networks in Ukraine; and ii) that this study also considers several micro-factors, which similar studies ignore. These micro-factors are the products of our lengthy and valuable experienced gained through these years of this study. They relate to the presence of a wide variety of fixed assets (e.g., pumping equipment and electrical substations), which are essential for Kyiv's and Kharkiv's WSS as they both have their own specificities of overhaul planning (Vieira and Ramos, 2009).

For the LSA and SVD models' analysis, two types of input data are used. For the first model (the LSA model), as exhibited in Figure 2, the set of input data considers: i) the number of failures in the water supply network; and ii) the actual company's repair costs in the case of network failures. Both types considered are not exhaustive. Theoretically, this approach simplifies the data presentation and methodology. Empirically, many of the sustainable factors (e.g., technical, financial, environmental) influence the forecasted number of WSS overhaul costs, there are others that must also considered in the analysis. Thus, the originally constructed LSA matrix is derived from a larger set of input data. As a result, the second model analyzed (the SVD model) could become more complicated in real life than the theoretical scenario calculations presented. These discrepancies between theory and practice are present in Ukraine because budgeting has a reactive managerial approach, rather than a proactive approach as the model requires. Nevertheless, even if we increase the input parameters, based on the current reactive managerial approach, the LSA matrix and the algorithm for performing the prediction procedure still produce reliable results. These results simultaneously remain the same and cohesive with the proposed methodology.

Other similar works devoted to predictive maintenance based on predictive failure on equipment-in-use most often use neural networks and multi-criteria decision making methods (Rezazadeh, 2013). These methods are used while more accurate and efficient numerical methods are not available, although it is critical for performing optimization (Wu et al., 2013). In our study, the LSA model allows us to solve similar problems with insufficient or even incomplete data, which is very often the case in Ukrainian municipal enterprises. As mentioned earlier, there is, however, the drawback that there is an amount of inaccuracy in the LSA model results, when dealing with reactive managerial practices and thus incomplete data for our model. Nonetheless, there is a significant advantage that adds social and economic value to this model and we should not overlook it. The LSA model is ideal for our Ukrainian cities, as, unlike other prediction models, it works effectively with sparse, ambiguous, and contradictory data (Graesser and Karnavat, 2000).

It is noteworthy that Kharkiv's and Kyiv's WSS input data for the LSA model are slightly different over the years, but the level of their discrepancies is not significant, and it does not in any way undermine the results exhibited in this study. This study was initiated at Kharkiv's WSS in 2003 and in Kyiv's WSS in 2005. This lengthy record of historical study is primarily due to the peculiarity and existing reporting problems of accounting for the extraction of other sustainable, actual data on water network repairs. Unfortunately, this is a common phenomenon in many Ukrainian public or municipal enterprises. Finally, in addition to the slight differences in data over the years, models have common time periods that have allowed the research team to compare their adequacy and accuracy.

This study's limitation is the lack of informational reporting of water supply networks status. Ukrainian water supply enterprises lack integrated and sustainable reporting (Chandler, 2016) of technical and financial data, and thus they are sometimes reluctant to publish their statistical data. It would have been highly beneficial for this study if the Ukrainian public sector considered the application of the Global Reporting Initiative (GRI) principles in its reporting, as a minimal standard for sustainable hydro-economic management. Factors with valid metrics under consideration are: i) water withdrawal; ii) water recycling; and iii) water recharge. They all could aid the environmental awareness of sustainable practices. These practices could significantly improve minimum strategic goal setting and water quality strategy of Ukrainian public companies (Kleinman et al., 2017). Reporting activities relating to energy and material efficiency are important for bridging the gaps that surfaced through this research (Ritala et al., 2017). Therefore, due to the absence of minimum integrated reporting, there is a lack of transparency in financial municipality funds and the distribution system as well as to social responsibility in Ukraine (Bartocci and Picciaia, 2013; Greiling and Grüb, 2014). GRI process could include, in our case, a novel typology of selected hydro-factors (e.g., economic, social and environmental) affecting the municipal WSS in both cities under discussion. Such factors could strengthen the clarity of direction towards the overhaul management in water supply in the country (Zhao, 2012). A future research priority is to obtain a complete set of information on water supply networks and equipment of other large WSS in Ukraine. Further studies in this area could advance and refine the level of this analysis, bridging the gaps relating to sustainable consumer-driven plan in WSS. Unfortunately, extensive discussions in public corporations focusing on the creation of socially responsible and economic value-added propositions require a long term process with several stages of market-product iterations (Baldassarre et al., 2017).

Finally, we continue to study the LSA model results in other large cities of Ukraine. Currently, we are studying and analyzing the results from Vinnitsa city WSS. This further research aims to explore the features of the LSA model and its parameters in other Ukrainian cities. In this way, we could elevate this hydro-economic domain, painting the framework for a sustainable future picture for the country's water supply.

7. Conclusions

This paper presents a new approach to planning costs in relation to WSS networks failures, taking into account the number of failures in water supply networks and predicting optimum repair costs for the elimination of failures. It proposes a sustainable and socially responsible method for forecasting and planning (LSA) in order to achieve a higher degree of hydro-economic efficiency (Cai et al., 2002). The impact of the proposed method is significant because market externalities, including industrial monopolies, are leading to strategic failures, both economically and environmentally (Brouwer and Hofkes, 2008). This study reveals a method to define the optimal number of funding overhauls based on overhaul frequency, assuming that the aging equipment rate will increase annually under the exponential law.

The data provided in our research are the product of a lengthy research effort in order to extract and regularly update the necessary information from the Ukrainian water supply companies (Kyiv and Kharkiv WSS). The input data, due to multiple testing though the years of our research, allow us to optimize the frequency of overhauls and their costs considering several micro-economic and sustainable factors. In contrast to existing approaches to planning overhauls, it allows us to take into account these hidden factors of accumulated aging and depreciation of water supply network and equipment, which are of prominent importance for socially responsible water supply systems.

The LSA model forecasts expected number of failures in WSS in the following years and the corresponding optimum costs for their elimination (Kyiv and Kharkiv WSS). Latent factors of the correlation between these indicators, which are determined by the parameters embedded in the water supply network model, include the following: i) the age of the infrastructure; ii) the terms of use; iii) depreciation of the infrastructure; and iv) structural composition of several fixed assets. Thus, all historical records received and examined for both cities are included for the calculations and linear iterations of this model. Conclusions obtained on the research hypotheses are summarized in the following arguments:

1) In Ukraine WSS, an overhaul planning of water supply networks and equipment operates in order to ensure the continuity of a safe water supply. Due to several years of failures and the aging of the water network, overhauls do not allow a full restoration of WSS. The annual overhaul plan adapts to current municipal water supply conditions, prohibiting full water network restoration. Such short-term municipal planning limits the hydro-economic factors concerned and deters the achievement of a socially responsible water supply. As a result, such practices jeopardize a city's quality of life and its sustainable future. To fulfill the research aim and the hydro-economic and sustainability-related research objectives, a lengthy empirical and comprehensive effort was implemented. Based on this research effort, we propose to control overhaul frequency in accordance with the formula (7). For the potential scenario that the repairs

are carried out annually the aging index (k) could be determined (e.g., Kharkiv WSS) by calculating the planned repair costs through our model as exhibited in Table 2.

2) The proposed LSA model allows us to predict the optimum repair costs in the case of water network failures. The reflection of these results for both Kyiv WSS and Kharkiv WSS are exhibited in Tables 5-6. In addition, the proposed LSA model enables us to predict the quantity of failures in the water supply network (e.g., Table 5, see forecasting year column). Unfortunately, as explicitly discussed in the previous section, due to lack of transparent technical and economic data at Ukrainian water supply companies, it is not possible to build a complete forecasting LSA based model. We should note that the water supply systems infrastructures in most, if not all, Ukrainian cities are characterized by similar limitations.

3) The results obtained for optimum repair costs in the case of network failures, according to the Ukrainian cities' factors embedded in our LSA model, indicate financial waste and lack of sustainable planning and social responsibility, imposing an excessive burden on local budgets. For example, in the Kyiv WSS and Kharkiv WSS, the LSA model shows that total costs for overhauls could reduce their budgets by 1683 and 1075 thousand UAH, respectively.

Therefore, the research results indicate that the socially responsible planning of capital repairs (overhauls) and their costs should begin with a meticulous failure analysis and assessment, as underlined throughout this report. The model reveals that technical durability of water supply pipes could significantly exceed the depreciation period, but not under these diagnosed circumstances. Finally, the cost of overhauls should contextualize and adjust the hydro-economic and technical factors under discussion, with consideration of sustainable reporting principles. Monitoring data and comparison of the water supply network failures and the costs for overhauls could provide any country with sustainable water use.

The proposed forecasting approach provides the optimal costs for repairing the water supply networks, could reduce the potential consequences of accidents and protect its surrounding social (e.g., municipal residents) and environmental stakeholders from negative consequences (e.g., water supply failures). The exhibited optimum frequencies of overhauls and failure analysis in WSS underline this triple bottom line for socially responsible management, leading to the redesign of the city's sustainable profile. Results also reveal that proactive maintenance managerial practices are vital for a sustainable strategy with novel and environmentally friendly parameters that have to be engaged in water usage planning. On the basis of this knowledge, corporate managers and academics could further understand the relationship between social responsibility and decision making within and among different municipalities in Ukraine. This study also concludes that social responsibility relates to a variety of hydro-economic and technical factors that public or private companies should consider for their sustainable water supply and consumption. The proposed LSA model results obtained with the help of the SVD method reveal existing gaps in contemporary practices that could economically minimize network failures and repairs in the water supply. From the LSA model, we observe that repair costs, which exceed1075 thousands UAH for Kharkiv and about 1683 thousands UAH for Kyiv, could be saved in their water supply systems. The results of the study contribute towards an alternative development path, which underlines the modern, market-driven, social responsibility for forecasting water use and planning.

Finally, increasing the WSS efficiency and reliability in large cities leads to an integrated and sustainable hydro-economic management. An important element of water supply is the assurance of technical reliability. Proactive and reliable management is the sustainable approach to overhaul planning. In sum, this research reveals a novel hydro-economic model for determining, planning and predicting the overhaul costs. It contains valuable recommendations for public administrators and water managers towards an efficient water supply provision with respect to socially responsible managerial practices. Based on these proposals, Ukraine stakeholders could further improve their outdated bureaucratic overhaul planning system, optimizing environmental values and benefits.

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