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Complex model of fixed assets reproduction in municipal water supplying and sewerage systems

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Abstract

The aim of the paper is to find the functional relationship between economic losses from the equipment failures in the municipal water supplying and sewerage systems and planned costs for preventive maintenance, also taking into account the frequency and failure rate of equipment and its aging. The proposed economic model allows determining both the optimal frequency of the preventive maintenance, given by the intensity factor of equipment failures, and the optimal amount of planned costs for preventive maintenance. The proposed model allows finding the optimum amount of planned preventive maintenance, considering the average rate of aging equipment, and the company ability to minimize the annual costs for liquidation economic losses and accidents. The reform of the existing municipal water supplying and sewerage systems in Ukraine should take into account the current economic realities and the problems that have accumulated for the years - an objective necessity for the future sustainable development of enterprises.

Lo scopo di questo lavoro è quello di trovare il rapporto funzionale tra perdite economiche derivanti dalla inefficienza delle attrezzature per la fornitura di acqua comunale e per I sistemi fognari e i costi pianificati per la manutenzione preventiva, anche prendendo in considerazione la frequenza e il tasso di malfunzionamento delle apparecchiature e il loro invecchiamento. Il modello economico proposto permette di determinare sia la frequenza ottima della manutenzione preventiva, considerate sia l'intensità di guasti alle attrezzature sia la quantità ottimale di costi pianificati per la manutenzione preventiva. Il modello proposto consente di trovare la quantità ottimale di manutenzione preventiva programmata, considerando il tasso medio di invecchiamento delle attrezzature nonchè la capacità dell'azienda di minimizzare i costi annuali di liquidazione delle perdite economiche e degli incidenti. La riforma dei sistemi comunali esistenti in Ucraina per la fornitura delle acque e della rete fognaria dovrebbe prendere in considerazione la realtà economica attuale e i problemi che si sono accumulati negli anni che rappresentano una necessità oggettiva per il futuro sviluppo sostenibile delle imprese.

Keywords: municipal water supplying, sewerage systems, planned preventive maintenance

1 – Introduction

The current condition of water supple and sewerage systems of most cities in Ukraine are in crisis or emergency condition. This condition has a direct impact on living standards, development of human settlements, industry and agriculture. This problem objectively caused by many factors:

- *technical* (emergency condition of many water and sewerage systems),

- *economic* (insufficient funding sector, low level of payments for water supplying and sewerage ser-

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vices, low wages in the sector, lack of skilled staff on enterprises),

- *legislative* (imperfect legislative framework in regulation the activity of the municipal water supplying and sewerage systems, low government control over the implementation of existing state programs of development and reform this sector and etc.).

2 – Literature review and objectives of this study

Issues of fixed assets' reproduction, planning their preventive maintenance were considered in scientific works: S. Kuznets (1967), J. Levitt (2006), also in scientific works of Ukrainian scientists: V. Petrosov (2007), O. Tishchenko (2008), T. Yurieva (2007).

The scientific school of T. Yurieva is focused on theoretical and methodological aspects of fixed assets renewal in the system of housing and communal services of Ukraine, in particular water supplying and sewerage companies. Numerous scientific developments of V. Petrosov were used in creation of the preventive maintenance system at water supplying and sewerage companies in Ukraine. O. Tishchenko has made a contribution to the development of municipal services the city of Kharkiv (Ukraine) due to his theoretical and methodological works, which are focused on development the housing services.

In the current economic conditions in Ukraine the process of fixed assets management at water supplying and sewerage companies become more important, including planning system overhauls and preventive maintenance (Yurieva, 2007).

One of the biggest problems in this sector is unsatisfactory technical condition of equipment, a substantial depreciation of fixed assets (60%), high specific energy consumption, great losses of drinking water (35-40%).

These problems are common throughout the country, due to the inefficient operation of facilities, outdated, worn-out equipment. Electricity consumption in water and sewerage systems is about 4.5 billion KWh., or 3.9% of total electricity consumption in Ukraine (National report on drinking water quality in 2013, Ukraine, Minregionbud, 2013). So building the complex model fixed assets renewal in municipal water supplying and sewerage systems is extremely important task at the present stage of economic development.

3 – Quantitative analysis

A necessary condition for the proper accounting and planning reproduction, including planning preventive maintenance of fixed assets, is their classification.

For real material characteristics fixed assets are divided into: houses, buildings, transmission equipment, machinery and equipment, vehicles, tools, land and other fixed assets.

Since the elements of fixed assets are unequal for playing role in the production process, their division into two parts is grounded. The active part of fixed assets is directly involved in the production process and thus provides the proper amount and quality of products. The passive part of fixed assets only creates conditions for the production process.

The active part consists of working machines and equipment, tools, gauges and fixtures, some technical facilities - those basic tools that are directly involved in the provision of water and sanitation services. Value of certain types (groups) of fixed assets, expressed as a percentage to their total cost determines technological structure of company.

Technological structure of fixed assets is more progressive and effective if there is a greater proportion of their composition active part. It can change due to many factors. The most significant of which are:

– industrial and technological features of the enterprise;

– scientific and technological progress and caused them technical level of production;

– development level of different forms of production;

– reproductive structure of capital investments and creation new fixed assets;

– territorial location of the company.

To create an effective complex model of fixed assets renewal at municipal water supplying and sewerage systems we need to take into account the characteristics of the existing technological structure of companies fixed assets (Tishchenko and Yurieva, 2008).

Preventive maintenance system at water supplying and sewerage companies is the set of technical measures and construction works aimed at restoring or replacing worn-out structures, components, equipment, facilities or pipelines (Nyman and Levitt, 2006). System of scheduled preventive maintenance – is a combination of organizational and technical measures for repair of all types of pipelines, structures and equipment at the enterprises.

Analysis of water and sewer systems in Kharkiv region shows that the technical condition of pumping equipment is not the best - about 38% of the pump power equipment of water pumping stations has a 100 percent depreciation wear. About 20% of pump power equipment needs whole and immediate replacement. Number of accidents associated with poor fixed assets conditions at water systems in the Kharkiv region increased from 2.6 to 3 per 1 km. water supply pipeline.

Not the best situation is observed with sewage systems. In the 56 units pump power equipment of

sewage pumping stations has a 100 percent depreciation, immediate replacement needs 33 units of equipment (National report on drinking water quality in 2013, Ukraine, Minregionbud, 2013).

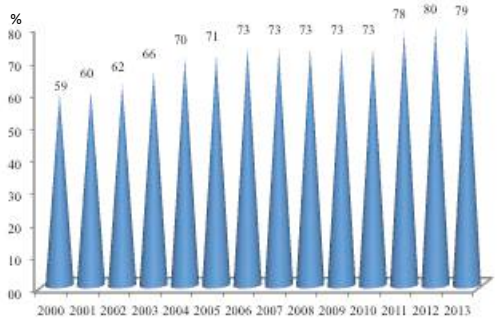
It's advisable to include the following data of analyzing the depreciation conditions at water and sewerage enterprises in the Ukraine as a whole, (**Figure 1**).

Figure 1 - Water supply and sewage enterprise in Ukraine

№	Water supply and sewage enterprise in Ukraine	Total length, km	The length of the pipeline by the degree of depreciation (years), km				
			< 25	26-50	50-75	76-90	>90
1	"VPVKH m. Kerch"	612,5	167,6	80,0	47,3	42,0	275,6
2	"VPVKH South Coast" Yalta	674,8	38,5	35,6	119,9	392,5	88,4
3	"VPVKH Yevpatoriya"	418,2	44,5	42,1	62,4	68,7	200,5
4	"VPVKH Feodosiya"	460,5	73,7	188,2	151,3	11,1	36,2
5	"VPVKH Simferopol"	962,0	135,5	196,4	128,5	134,8	366,6
6	CE "Vinnytsyaoblvodokanal"	575,0	196,0	223,3	137,3	17,1	1,3
7	CE "Lutskvodokanal"	310,4	3,6	18,1	147,8	59,2	81,6
8	"Gorvodocanal" Dnipropetrovsk	746,8	204,3	97,5	57,7	51,2	336,0
9	CE "Kryvbasvodokanal"	1 848,5	300,6	324,9	369,9	268,1	585,1
10	CE "Dnieprovodokanal"	1 990,8	153,5	320,1	959,2	386,1	171,9
11	CE "Nikopol VUVKH"	527,0	26,6	82,8	0,0	9,7	407,9
12	CE "Zhovtovods'ka Vodokanal"	188,5	0,0	0,0	23,0	30,5	135,0
13	CE "Company" Water of Donbass	10 155,0	573,8	1	1	1 769,5	4 753,9
14	CE "Mariupol VUVKH"	1 789,1	222,1	172,0	182,0	740,1	472,9
15	CE "Kramatorsk Vodokanal"	558,9	152,9	73,0	43,2	38,3	251,5
16	CE "Donetskmiskvodokanal"	3 138,6	30,7	50,7	170,6	190,1	2 696,5
17	CE "Zhytomyrvodokanal"	521,7	72,3	0,0	0,0	449,4	0,0
18	LLC "Vodokanal Karpatviz"	32,2	0,6	18,0	8,4	5,3	0,0
19	CE "Vodokanal, Uzhgorod."	283,8	6,0	24,7	37,6	82,4	133,1
20	CE "Vodokanal" Zaporizhzhya	2 528,7	105,2	269,2	242,9	723,6	1 187,9
21	CE "Berdyanskvodokanal"	391,1	18,2	118,2	209,4	45,3	0,0
22	CE "Vodokanal" m. Melitopol	419,8	164,9	19,0	133,9	41,5	60,5
23	"IvanoFrankivskvodoecotechprom"	551,7	216,2	335,5	0,0	0,0	0,0
24	CP BIS "Bilotserkivvodokanal"	315,4	6,2	89,5	97,5	33,9	88,3
25	OKVP "Dnepr-Kirovograd"	1 640,2	183,2	203,7	425,1	332,5	495,6
26	CE "Alchevsk VUVKH"	293,4	31,7	261,8	0,0	0,0	0,0
27	LLC "Luganskvoda"	6 890,3	241,2	1	1	1 302,5	2 492,7
28	LLC "TOWN SERVICE"	249,7	3,5	0,5	86,4	39,4	120,0
29	CCE "Lvivvodokanal"	1 859,7	196,6	669,6	613,3	267,3	113,0
30	CE "Drohobychvodokanal"	230,2	3,9	13,0	81,2	97,3	34,9
31	CE "Mykolayivvodokanal"	1 195,0	327,0	156,1	92,3	81,9	537,7
32	LLC "Infox" branch	1 658,4	78,6	329,6	492,8	323,7	433,7
33	CE "Kremenchukvodokanal"	445,3	1,2	0,0	440,6	3,5	0,0
34	CE "Poltavavodokanal"	815,7	43,7	116,7	351,3	221,8	82,3
35	ROVKP VCG	619,5	79,2	157,4	199,6	64,8	118,5
36	CE "Gorvodocanal" Sumy	525,6	192,3	192,7	118,0	22,5	0,0
37	CE "Ternopilvodokanal"	342,0	45,6	23,2	60,9	92,2	120,2
38	CE "Harkivvodokanal"	2 625,3	71,9	192,6	685,0	804,9	870,9
39	CCE "VUVKH Kherson"	888,0	38,4	77,2	290,4	193,2	288,7
40	CCE "Hmelnytskvodokanal"	522,4	13,6	22,6	27,2	102,6	356,4
41	CE "Miskteplovodenerhiya"	305,9	1,1	0,3	232,0	0,0	72,5
42	CE "Cherkasyvodokanal"	464,3	54,0	160,3	160,9	89,1	0,0
43	CE "Umanvodokanal"	403,2	110,3	52,7	31,1	27,6	181,4
44	CE "Chernivtsivodokanal"	405,8	111,0	53,0	31,3	27,8	182,6
45	CE "Chernihivvodokanal"	533,9	233,0	256,8	7,7	22,8	13,5
46	JSC "AK" Kyivvodocanal "	4 134,9	113,7	469,2	1	1 440,7	1 075,1
47	CE "Sevmisvodokanal"	1 098,7	103,1	105,5	229,1	199,1	461,9
	Total, km.	**58 148,4**	**5**	**8**	**12**	**11347,9**	**20382,1**
	Percentage %	**100,0**	**8.9**	**14,4**	**22,1**	**19,5**	**35,1**

In general, the Ukraine has about 35.1% of water and sewage pipelines with the lifespan more than 90 years, 19.5% operated pipelines 75-90 years, and 22.1% pipelines over 50 years. Most of these pipelines are in disrepair and need preventive maintenance or replacement (**Figure 2**).

Figure 2 – Depreciation of water supplying pipelines, %



This conditions are called by many factors, one of which is the not optimal frequency of preventive maintenance at enterprises. It is advisable to take into account the factor of growth failure rate of equipment and facilities, so that most future unpredictable costs not considered by management. In Kharkiv technical conditions (the level of depreciation, %) of water supplying pipelines are extremely difficult.

4 – The proposed model

To eliminate these factors, the following construct mathematical model is proposed. Analytically costs of preventive maintenance and to cover economic losses from the accident liquidation can be determined by the following formula:

$$Z = Zk + Za\,F(t) \quad (1)$$

where:

Z - costs of preventive maintenance and accident liquidation,

Zk - cost of planned repairs,

Za - repair costs in the case of an accident,

$F(t)$ - a function, that allows for equipment failure (expectation cases of accidents or equipment failures on the water pipelines),

The cost of the accident, which occurred, can be determined as follows:

$$Za = Zv + Zu \quad (2)$$

where:

Zv - cost of equipment recovery,

Zu - the economic costs of the accident's consequences.

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

$$F(t) = \int_0^t x(t)dt \quad (3)$$

where:

x (t) - the intensity of the water equipment failures or accidents on the network.

$$x(t) = x0 + K * t \quad (4)$$

where:

x0 - the initial value of failure rate,

K – index which taking into account the rate of aging equipment.

The parameters K and x0 are available due to technical processing of statistical data on particular types of equipment or facilities at water supplying or sewerage enterprises.

To optimize performance periods of preventive maintenance in the analytical model we use the specific repair costs (costs per unit of time)

$$vp = V/t \quad (5)$$

where:

vp - costs per unit.

Substituting equations (1-4) to formula (5), and solving them, we get:

$$vp = (Zk + Za * (x0 * t + K * t^2/2))/t \quad (6)$$

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

$$t = \sqrt{2/(\frac{Za}{Zk} * K)} \quad (7)$$

Using empirical data of the actual costs of the companies' emergencies at water pipeline and planned costs for preventive maintenance of equipment, we may determine the optimal frequency of fixed assets' repairs at water-supply and sanitation enterprises.

At the annual performance of fixed assets preventive maintenance (t = 1), the formula can be simplified to the following:

$$Zk = Za * k / 2 \quad (8)$$

Based on statistic data of past years Kharkiv municipal water supplying and sewerage systems work, using the formula (8), we obtain the following results for the average index (k = 1,04), which takes into account the pace of aging equipment (**Figure 3**).

For comparison, in 2013 and 2014 the actual cost for major fixed assets repairs in the overall cost of water supply service made up 71.3% and 75.4% of the calculated needs of enterprises. It does not take into account the effect of incomplete funding accumulated repairs over the years. In the case of full cost funding preventive maintenance as in the proposed model, the company can significantly minimize the annual cost for emergency response.

Figure 3 - Statistic data of Kharkiv municipal water supplying and sewerage systems, UAH

Costs	2009	2010	2011	2012	2013
The costs of emergency response, thous. UAH	18299	24499	25452	29177	31035
The estimated cost of preventive maintenance, thous. UAH	9515,5	12739,5	13235	15172	16138,2

5 – Suggestions and financial aspects

For complex solving these problems is necessary to define a method of calculating depreciation at the water supplying and sewerage companies. Depreciation method should take into account the economic situation and the characteristics of each individual enterprise. We use mathematical tools offered systematic approach to decision making for choosing the method of depreciation. One such tool is the method of analytic hierarchy process (Saaty, 1992). It allows clear and rational structure complex decision problem (in our case - the choice of method of depreciation) as a hierarchy and perform a quantitative assessment of alternative decision. Hierarchical structure is a graphical representation of problems in the form of a diagram, where every element except the highest, depends on one or more elements located below. Hierarchical structures are used to better understanding the problems of any complexity (Saaty, 2001). They divide the problem into its component parts, then parts, decomposed into simpler elements. In the detailed analysis of the complexity comes the understanding of subject that is studied.

The criteria for selecting the optimal method of depreciation at water supplying and sewerage companies should be allocated factors influencing the choice modeling purposes. These factors that influence the size and amount of depreciation in the company are:

– amount and value of assets that are depreciated;

– structure of companies' fixed;

– the age of fixed assets;

– the performance and productivity of fixed assets;

– depreciation mechanism and government regulation;

– movement of fixed assets at the enterprise;

– the frequency of preventive maintenance, etc.

As the more criteria will be taken into account, as well as criteria for the second, third and so on orders in the tree hierarchy construction, so the more accurate will be defined and calculated main goal hierarchy - the most cost-effective method of depreciation for each company.

Information to determine the criteria and priorities on these criteria should be collected from all participants in the decision making process, experts and specialists of the water supply companies and brought to the hierarchical model. It should be noted that the construction of the model hierarchy for selecting the method of depreciation in the company should consider all factors internal and external environment and characteristics of the industry.

Depreciation influences and increases the share of capital investment (R. Peterson, 2002). Funds should be used for technical renovation, repair and reconstruction of fixed assets.

The economic purpose of a depreciation fund at the municipal water supplying and sewerage enterprises is to accumulate financial resources of fixed assets reproduction and to provide the replacement of fixed assets. Statistics in Ukraine shows that the annual amount of depreciation is much larger than the corresponding disposals of fixed assets.

The possibility of depreciation on the expanded reproduction is one of the most difficult questions in modern economics. Many researchers, recognizing the direct economic purpose of depreciation fund as a source of simple reproduction, not however exclude the possibility of using it for extended reproduction.

In market conditions there are the specific requirements for reproduction of fixed assets due to increasing production capacity. Trends in Ukraine show the slow rate of replacement worn-out fixed assets, accumulation in water supply significant quantities of obsolete equipment with all this following negative effects. Due to scientific and technical progress in increasing productivity the cost of reproduction of fixed assets should decline. As a result, compensation for their use value requires less money than accumulated in the depreciation fund. To recover the aggregate capacity of fixed assets, we should spend less money than provided by depreciation fund. In this case, the size of accumulated depreciation allow for needs both simple and expanded reproduction of fixed assets.

Removing the excess depreciation is unacceptable, because it makes difficulties in reproduction of fixed assets. In accordance depreciation process to real value transfer process the depreciation fund shall be used only for its intended purpose.

Depreciation, which accumulates, should be fully available to companies and sent them to finance the simple reproduction of fixed assets, i.e. financing the preventive maintenance at water supplying and sewerage enterprises.

6 – Environmental aspects of fixed assets reproduction

Water supply reproduction is a component of ecological safety areas, particularly - water systems.

Negative changes in the technical condition of water supply causes further increasing their chemical pollution and water losses. Therefore ground water level rise, urban areas are inundated and destruction of underground facilities appears. Improving the preventive maintenance system should lead to a reduction in economical and environmental damage.

To ensure a holistic approach in environmental safety of the water supply systems it needs to develop more actual funding ratios repair costs. The timely financing of preventive maintenance system provide economic and environmental impact. But to transfer business operation to environmental safe mode it is necessary to increase amounts of funding.

Ukrainian enterprises have to implement elements of social responsibility in their business activity.

7 – Conclusions

The main focus of optimizing the fixed assets renewal at water supplying and sewerage enterprises should be:

- carrying linking stages of fixed assets reproduction and terms of water supplying and sewerage service,
- to review the existing preventive maintenance system with current Ukrainian economic realities: a high degree of depreciation accumulated over the years, imperfect mechanism of financing,
- take into consideration the environmental factors, social responsibility of municipal enterprises to the population of the city.

In Ukraine reproduction of fixed assets is mostly spontaneous. Fixed assets, facilities and equipment to be renovated and the funds allocated for the purchase of new equipment - are not subject of systematic planning, coordination or control. Renewal of fixed assets is basic material factor of production and service delivery at water supplying and sanitation enterprises. So optimization the reproduction process and preventive maintenance system requires complex systematic scientific and technical research.

Under the influence of scientific and technological progress, with the advent of new technology and equipment reproduction cycle moves to a new level, so the question of changing the planning system, organization and control of its effectiveness, and the simultaneous reduction these processes in time must also be modified to a new level.

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