COMPUTER AIDED PLANING OF WATER NETS REVITALIZATION

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ABSTRACT
A concept of an integrated information system for complex management of water networks and especially for computer aided creation of plans for water nets revitalization is presented in the paper. The ICT system is under development at the Systems Research Institute (IBS PAN) in Warsaw for a couple of years and it is gradually tested in some Polish communal waterworks of different sizes.

INTRODUCTION
The world current trend in computerization of waterworks is the implementation of integrated information systems for complex management of whole enterprises or their key objects. Among others this concerns water networks and it is the simplest venture from the technical, organizational and financial point of view. An integrated management system for a communal water network consists usually of GIS (Geographical Information System), SCADA (System of Control and Diagnostics Analysis) and CIS (Customer Information System) systems which are integrated strictly with some modeling, optimization and approximation algorithms (Studzinski, 2007). Due to the strict cooperation among several programs all tasks of the water net management concerning technical, organizational, administrative and economic problems can be automatically solved or their solution supported by computer calculations (Studzinski, 2012). Among the mentioned problems the planning of water net revitalization is of a special importance because the right executed revitalization has an essential impact on the reduction of damages in the water net (Saegrov, 2004). As a result the financial losses of the waterworks caused by the hidden and open water leaks can be decreased and the reliability of the water net can be boosted. The possibility of financial austerities resulting from the waterworks computerization is particularly important for the management boards of communal enterprises which depend in their strategic financial decisions on the city governments.

THE MAIN COMPONENTS OF AN IT SYSTEM FOR WATER NETWORK MANAGEMENT
According to the mentioned trend in waterworks computerization an integrated ICT system for complex water networks management has been developed at the Systems Research Institute and its structure is shown on Fig. 1. The system is built in modular form and it consists of the following components:

- GIS – for generating the numerical maps of the water net investigated
- SCADA – for monitoring the water net parameters, i.e. pressures and flows of the water
- CIS – for recording the water consumption of the end users of the water net
- 20 computing programs with algorithms of mathematical modeling, optimization and approximation for solving the water net management tasks.

Figure 1. Block diagram of the ICT system for water networks management.

The components GIS, SCADA and CIS are adopted from other firms and integrated with the computing programs via data files or data tables. The computing programs are collected in 3 modules which are responsible for realization of all management tasks by means of water net hydraulic model and optimization algorithms (module MOSUW, Fig. 2), approximation algorithms (module ‘Kriging applications’, Fig. 3) and time series algorithms of mathematical modeling (module ‘Objects identification’, Fig. 4). The more detailed description of these 20 programs and of their functions follows:

Module MOSUW:
1. hydraulic modeling of water nets (Mosuw-H)
2. optimal planning of SCADA systems for water nets (Mosuw-M)
3. automatic calibration of hydraulic models (Mosuw-K)
4. optimization and planning of water nets (Mosuw-O)
5. control of pump stations in water nets (Mosuw-P)
6. control of pumps installed in pump stations (Mosuw-P2)
7. detecting and localization of leakage points in water nets (Mosuw-A)
8. calculation of water age in water nets (Mosuw-W)
9. calculation of chlorine concentration in water nets (Mosuw-Cl)
10. planning of water net revitalization (Mosuw-R)
11. control of network valves changing the water flows distribution in water nets (Mosuw-Z).

All programs of this module use the algorithms of kriging approximation that enable to show in graphical form the value distribution of parameters connected with water nets and their operation (Bogdan and Studzinski, 2007).

Module ‘Object identification’:
Calculation of mathematical models for forecasting the hydraulic load of water nets and of their end-user nodes by means the following time series methods (Hryniewicz and Studzinski, 2006):
1. Least squares method of Kalman
2. Generalized least squares method of Clarke

Figure 2. Module MOSUW of the ICT system.

All programs of the MOSUW module work with the water net hydraulic model and while realizing the tasks concerning the model calibration, water net optimization and planning, pumps control and planning of SCADA they use an heuristic algorithm of multi criteria optimization (Straubel and Holznagel, 1999). For the solution of other tasks only multiple simulations of the hydraulic model under different work conditions of the water net are executed (Stachura et al, 2012).

Module ‘Kriging applications’:
1. calculation of height coordinates for the water net nodes (Kripog)
2. drawing the maps of water flow and pressure distributions in water nets (Kripow)
3. drawing the maps of water net sensibility toward the leakage events occurring in water nets (Kripom)
4. drawing the maps of water age distribution in water nets (Kripow-W)
5. drawing the maps of the distribution of chlorine concentration in water nets (Kripow-Cl)
6. drawing the maps of value distributions for some environmental parameters like temperature in the area of the water network (Kripos).

Figure 3. Module ‘Kriging applications’ of the ICT system.

Figure 4. Module ‘Objects identification’ of the ICT system.

Due to the cooperation of several programs while solving different management tasks a synergy effect arises that boosts essentially efficiency of the running programs. In the following some functions of the ICT system are shown that can be executed only by the cooperation of several programs what shows on the necessity of integration of different programs in form of an united ICT system:

- hydraulic calculations of water net (GIS, CIS, Mosuw-H)
- automatic calibration of water net hydraulic model (GIS, CIS, SCADA, Mosuw-K)
- detecting and localization of leakage points in water nets (GIS, SCADA, CIS, Mosuw-A)
- optimization and planning of water nets (GIS, CIS, Mosuw-O)
COMPUTER AIDED WATER NET REVITALIZATION

Water net revitalization belongs to the planning tasks that can be divided into 3 types: hydraulic optimization, drawing up new networks or extension of the old ones and revitalization or renovation. In the first two types of tasks computer simulation of the water net hydraulic model as well as optimization algorithms must be used to secure right hydraulic conditions of the water net operation. They mean relevant water pressures in the end user nodes of the network and possibly fast velocities of water in the network pipes. In case of revitalization the network works right from the hydraulic point of view and the reason to undertake the action is an old age of water net objects, mostly of pipes, or their wrong technical state causing the risk of failures. The susceptibility of water nets to accidents can cause in older municipal waterworks the water losses reaching even up to 30% of the water production what means essential financial losses for the enterprise (Saegrov 2004).

In the presented algorithm the revitalization task means the exchange of several pipes in the water net because of their wrong technical state and against the pipes with the same diameters. While planning the revitalization with such approach only multiple simulation runs of the network hydraulic model are done for the exchange of old pipes against new ones with reduced roughness values does not worsen but improves the hydraulic conditions of the water net. The goal of the algorithm is to reduce the liability of the network to break down and, in result, to reduce the potential water losses in the water net.

While planning the revitalization one must decide which pipes are to be exchanged to minimize the water net susceptibility to accidents and at the same time to secure proper functioning of the whole network. The following factors are taken into consideration when calculating the revitalization indicator for each pipe and checking the cost constraints in order to choose the set of pipes to be replaced:

- Technical state of the pipes characterized by their roughness.
- Current durability of the pipes calculated as the difference between the year of pipe construction and the normative pipe durability.
- Pipe liability to break down in percent defined on the base of historical data concerning the pipe damages.
- Risk of the water losses calculated as the pressure in the pipe modified by the pipe diameter: \( p \times \frac{(1 + d / 500)}{500} \).
- Costs of the pipe revitalization which consists of two components: the costs of the pipe installation and the costs of buying the new pipes.

The revitalization indicator is calculated from the following formula:

\[
IR = w_c \times Cn + w_t \times (1.0 - Tn) + w_a \times An + w_r \times Sn
\]

where \( w_c, w_t, w_a \) and \( w_r \) are weights coefficients, \( Cn \) means pipe roughness, \( Tn \) means current pipe durability, \( An \) is pipe liability to break down and \( Sn \) is risk of the water losses defined for the pipe concerned. The weights coefficients can be chosen arbitrary by the program user and all factors in the formula are normalized in the standardized range of values from 0.0 to 1.0.

After the revitalization indicators are calculated for all pipes a ranking list is prepared according to the diminishing indicator values. Depending on the financial funds which are at the management disposal one can make choice of the set of pipes for the exchange taking the pipes from the top part of the ranking list and summarizing the costs of their revitalization up to the funds limit.

When the pipes to be exchanged are already selected then the effects of the planned revitalization can be verified by performing the hydraulic calculation for the whole water net with roughness values equal to null for the selected pipes. When the revitalization action is done then the vulnerability of the water net to the accidents will be reduced and the water pressures in some end-user nodes as well as flow velocities in some pipes will be enlarged.
values are highest in the areas where the pump stations and tanks are situated.

Figure 6. Pressure (up) and flow (down) distributions in the water net after its hydraulic calculation.

Figure 7. The graph of the water net with the pipes selected for revitalization.

In Fig. 6 the pipes selected for the exchange are marked with the green color. According to formula (1) and to data assumed concerning all relevant factors 31 pipes from 398, i.e. 8% of the whole, have been taken for the replacement. The effects of the revitalization after performing the hydraulic calculation for the whole water net with roughness values equal to null for the selected pipes are shown in Figures 8 and 9. In Fig. 8 the curves received before the revitalization are marked with the blue colour.

One can see from Figures 8 and 9 that in accordance with expectation the values of pressures and flows in the water net have increased after the revitalization. Nevertheless the changes of pressure values are very small and insignificant towards the changes of the flows. In that case not only the values but also the flow directions changed as the result of revitalization.

Figure 8. Comparison of water flows (up) and pressures (down) before and after the water net revitalization performed for 31 pipes.

Figure 9. Pressure (up) and flow (down) distributions in the water net after its revitalization performed for 31 pipes.
To see it better in another step of revitalization all pipes of the water net have been replaced. The hydraulic results received are shown in Fig. 10 and in Table 1 for exemplary pipes and nodes. Once again one can see that the pressure values increased but in a very small and practically marginal degree. Against it the flows increased their values essentially and also the flow directions have been changed in many pipes.

### CONCLUSIONS

Planning the revitalization for the water net in the form presented here means the exchange of some pipes against the ones with the same diameters. To do it the pipes for the exchange have to be chosen according to formula 1 in which 4 factors are taken into consideration. Depending on the importance of a particular factor its weight coefficient shall be defined greater than the other ones. The advantage of this approach is such, that there is no need to optimize the network after the revitalization is done what is the standard procedure by other planning tasks like hydraulic optimization or extension of water nets. After the revitalization is completed the hydraulic conditions of the water net running are better than before and only simulation runs of the water net hydraulic model are needed to realize the approach. There are also some tries to join optimization and revitalization tasks into one algorithm in which an optimization procedure helps to find out the pipes for the exchange (Fajdek et al. 2014). But it is right only in the cases when the water net needs revitalization in the wake of frequent failures or of old age of the pipes and at the same time when its hydraulic conditions are wrong. The algorithm presented here can be used assuming correct hydraulic conditions of the water net.

However, an important precondition for effective operation of the described algorithm is its use in strict cooperation with GIS, SCADA and CIS systems in frame of an united ICT system. In this structure SCADA and CIS systems are data bases of historical and current measurements concerning the flows, pressures and consumptions of water and GIS system is the base of all technical data of the water net and of its objects. GIS system generates also hydraulic graphs of the network and exports them to the hydraulic model. All these data make possible the correct calibration of the water net and it is the condition for right performance of the revitalization task.

Such the approach to this planning task is more complicated and expensive than individual use of only water net hydraulic model what sometimes is practised either but it makes sure that the revitalization will be done fast, easy, suitably and faultless.

The integrated ICT systems for waterworks additionally extended with some algorithms for mathematical modeling, optimization and approximation are for a couple of years under development at the Systems Research Institute of the Polish Academy of Sciences and are tested in some Polish communal waterworks (Wojtowicz et al, 2014A, 2014B).

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BIOGRAPHIES

Marek KUROWSKI was born in Warsaw, Poland. He studied Electronic Engineering at Warsaw University of Technology, in 1969 he received his M. Sc. Degree in the field of Automatic Control and Computers. After studies he started to work at the Systems Research Institute of the Polish Academy of Sciences and simultaneously he grounded his microenterprise WINDSOFT dealing with programming of complex ICT systems.

Jan STUDZINSKI, born in 1946 in Warsaw, educated at the Technical University of Warsaw at the Faculty of Electrical Engineering and at the Warsaw University at the Faculty of Mathematics. He is working at the Systems Research Institute of Polish Academy of Sciences, where he has obtained his PhD. and Sc.D. degrees and where he leads the Center for Applications of Informatics in Environmental Engineering. Author of 3 books and more than 250 scientific papers, he is dealing for many years with mathematical modeling and computer simulation of complex dynamical systems, with development of optimization and control methods and of computer aided decision support systems for management of communal waterworks. Awarded for his work with several prices at the Belgian and International Trade Fairs for Technological Innovation held in Brussels, board chairman of the Foundation for Development of System Sciences of Polish Academy of Sciences.