IT System for Computer Aided Management of Communal Water Networks by Means of GIS, SCADA, Mathematical Models and Optimization Algorithms

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

Keywords
Water supply systems, complex management, computer aided decisions making systems, mathematical modeling, optimization and control.

1. INTRODUCTION
The world trend in computerization of waterworks is the implementation of integrated information systems for complex management of the whole objects and particularly of the water networks what is the simplest venture from the technical, organizational and financial point of view. An integrated management system for a water network consists usually from some 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 this strict cooperation under several programs all tasks of a water net management can be automatically executed or computer supported and these tasks concern the technical as well as organizational, administrative and economical problems (Studzinski, 2012). Under these latter problems the planning of water net revitalization is of a special importance for a right executed revitalization has got an essential impact on the reduction of damages falls of the water net (Saegrov, 2004). As a result the financial losses of the waterworks caused by the water leaks can be descended 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 from the city governments.

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2. THE MAIN COMPONENTS OF AN IT SYSTEM FOR WATER NETWORK MANAGEMENT
According to the mentioned trend in waterworks computerization at the Systems Research Institute an integrated IT system for complex water network management has been developed, whose structure is shown in Fig. 1.

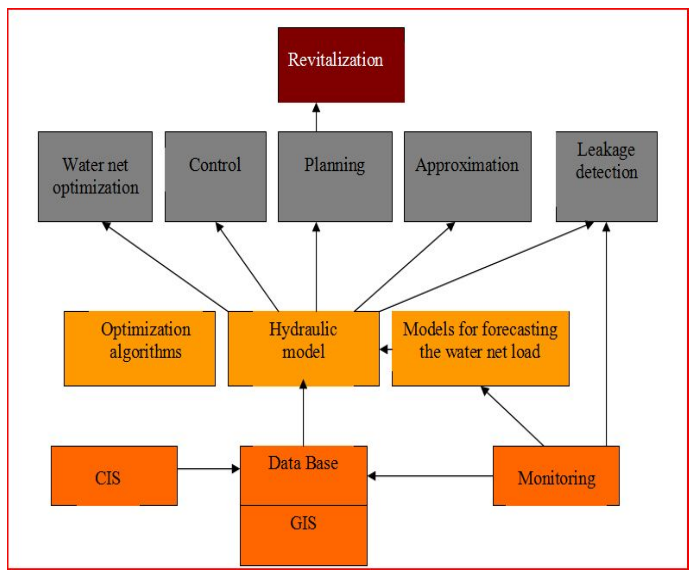

Figure 1. Block diagram of the IT system for water networks management.

The system is built in modular form and it consists of the following components:

- GIS – for designing the numerical maps of the water net investigated
- SCADA – for monitoring the water net parameters
- CIS – for recording the data of the water amounts bought by the end users of the water net
- hydraulic model of the water network – for calculating the water flows and pressures in all pipes and nodes of the water net
- 18 programs with algorithms for mathematical modeling,

optimization, approximation, control and planning destined for the solution of different tasks of the water net management.

The components GIS, SCADA and CIS are adopted from other firms and integrated with the remaining programs of the IT system. These latter programs are collected in 3 modules which are responsible for the realization of the management tasks solved by using the hydraulic model and optimization algorithms (module MOSUW, Fig. 2), by using the approximation algorithms (module ‘Kriging applications’, Fig. 3) and by using the algorithms of mathematical modeling (module ‘Objects identification’, Fig. 4).

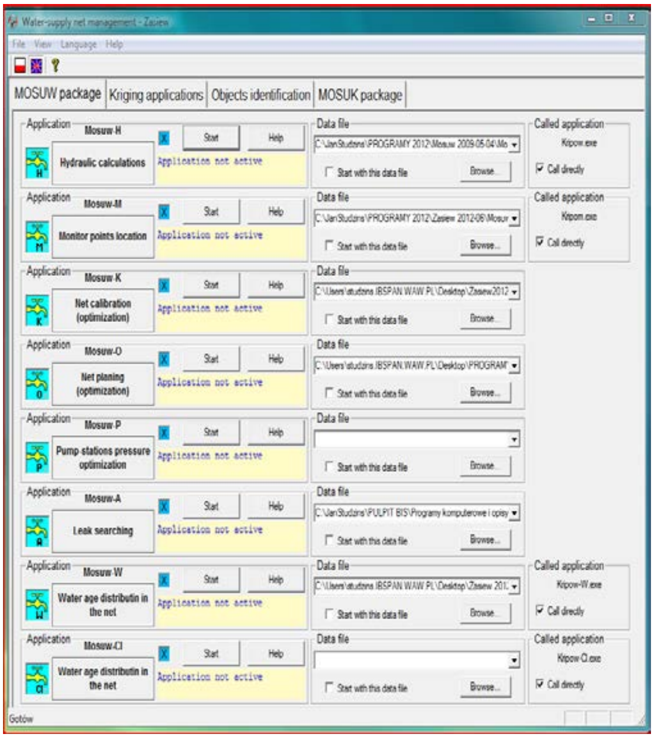

Figure 2. Module MOSUW of the IT system.

The more detailed description of these programs (with their names given) and of their functions is as follows:

Module MOSUW:

- hydraulic modeling of the water net (Mosuw-H)
- automatic calibration of the hydraulic model (Mosuw-K)
- optimization and planning of the water net (Mosuw-O).
- control of the pump sets installed on the water net (Mosuw-P)
- optimal planning of the SCADA system for the water net (Mosuw-M)
- discovering and localization of the leakage points at the water net (Mosuw-A)
- calculation of the water age in the water net (Mosuw-W)
- calculation of the chlorine concentration in the water net (Mosuw-Cl).

All programs of the MOSUW module work with the hydraulic model of the water net and while realizing the tasks concerning the model calibration, the water net optimization and planning, the pumps control and the planning of SCADA they use an multi criteria optimization algorithm (Straubel and Holznagel, 1999). By 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).

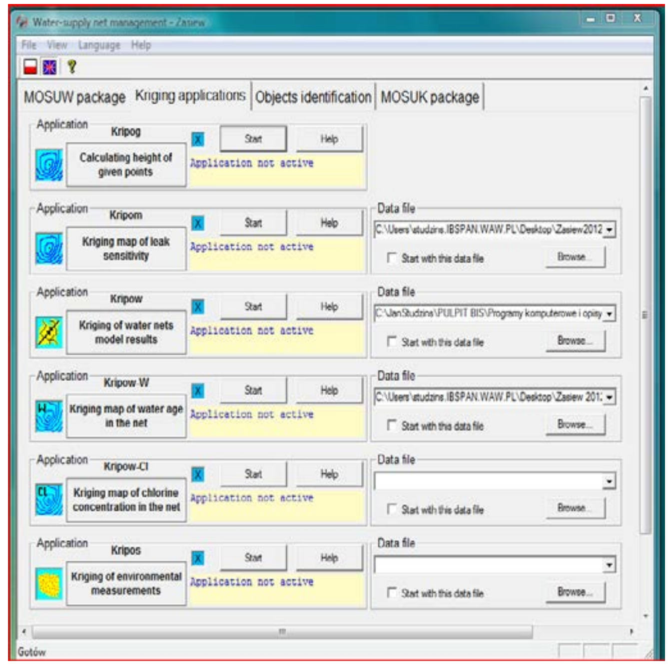

Figure 3. Module ‘Kriging applications’ of the IT system.

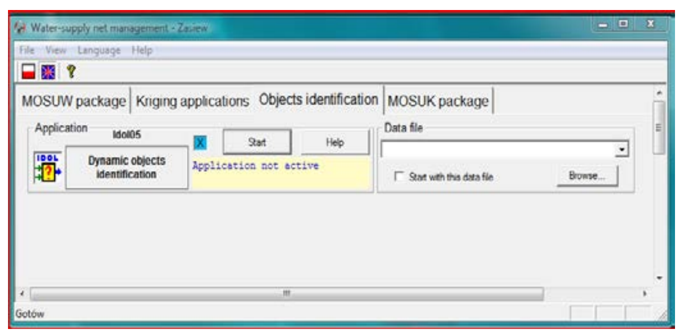

Figure 4. Module ‘Objects identification’ of the IT system.

Module ‘Kriging applications’:

- calculation of the height coordinates of the water net nodes (Kripog)
- drawing the maps of distributions of water flows and pressures in the water net (Kripow)
- drawing the maps of water net sensibility toward the leakage events occurring in the water net (Kripom)
- drawing the maps of water age distribution in the water net (Kripow-W)
- drawing the maps of the distribution of chlorine concentration in the water net (Kripow-Cl)
- drawing the maps of value distributions for some environmental parameters like temperature in the area of the water network (Kripos).

All programs of this module use the algorithms of kriging approximation that enable to picture in graphical form the value distributions of parameters connected with the water net and with its operation (Bogdan and Studzinski, 2007).

Module 'Object identification':

- calculation of mathematical model for forecasting the water net load (Idol).

In this module several programs are collected to mathematical modeling the dynamical processes by means of the time series methods with the least squares algorithms such as Kalman's, Clarke's, maximum likelihood, linear and nonlinear regression algorithms (Hryniewicz and Studzinski, 2006).

The IT system developed consists in all of 22 programs cooperating each other in different combinations depending on the tasks to be solved. The key component of the IT system is the Branch Data Base (BDB) of the GIS system that records all information and technical, technological and economical data of the water network, of its objects and of the water consumers accessed to the water net. The BDB is the main source of input data for the hydraulic model that supports the calculations of all programs collected in the modules MOSUW and 'Kriging applications'. All programs of the IT system communicate each other and with the Branch Data Base using some puffer files of established standard structure. These files are used e.g. to generate the water net graphs from the numerical map to the hydraulic model (Mosuw-H) or to export the results of hydraulic calculation to the optimization program (Mosuw-O) while optimizing the water net. Trough this cooperation of several programs while solving different management tasks for the water net a synergy effect arises that the efficiency of the running programs boosts essentially. In the following some functions of the IT system are mentioned that can be executed only due to the cooperation of several programs what shows on the necessity of integration of different programs in frame of an united IT system:

- hydraulic calculations of the water net (GIS, CIS, Mosuw-H)
- automatic calibration of the hydraulic model (GIS, CIS, SCADA, Mosuw-K)
- discovering and localization of the leakage points at the water net (GIS, SCADA, CIS, Mosuw-A)
- optimization and planning of the water net (GIS, CIS, Mosuw-O)
- control of the pump sets installed on the water net (GIS, CIS, Mosuw-P)
- optimal planning of the SCADA system for the water net (GIS, CIS, Mosuw-M).

The above functions are realized by the appropriate programs form the MOSUW module but they have to be supplied with the input data by GIS, CIS and possibly by SCADA systems.

3. TWO EXAMPLES OF THE IT SYSTEM FUNCTIONING

In the following two examples of the operation of the IT system while solving two tasks, i.e. the hydraulic calculation of the water net and the calculation of the water age distribution in the net will be shown. In both cases the first step of operation consists of exporting the data concerning the structure of the water net from the Branch Data Base of GIS to the program performing the hydraulic calculation (Fig. 5).

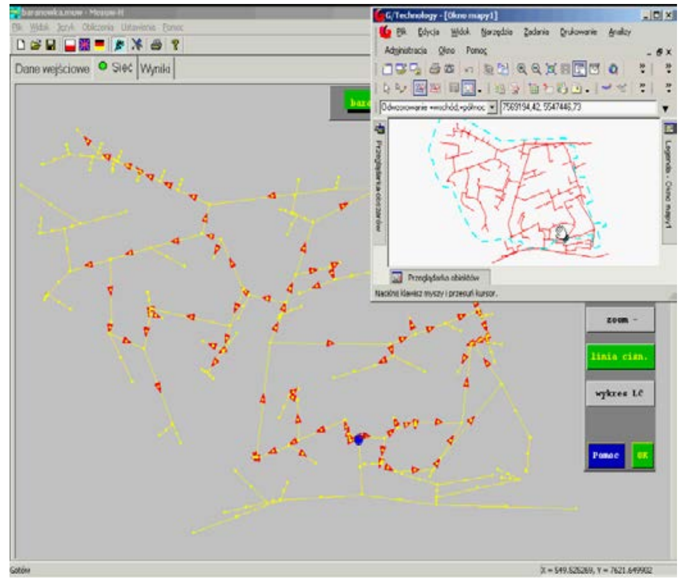

Figure 5. Export of the water net graph from GIS to the hydraulic model (Mosuw-H).

In the first example the program importing the data from GIS is Mosuw-H that calculates then the water pressures and flows for all elements of the water net. The calculation is mostly done for the static state of the water net work, i.e. for only 1 set of data concerning the water use in the end user nodes of the water net. This data set is won from GIS via the CIS system. The subsequent step of operation is the export of data resulted from Mosuw-H to program Kripow that draws the distribution maps for pressures and flows calculated using the kriging approximation (Studzinski, 2011) (Fig. 6 and Fig. 7).

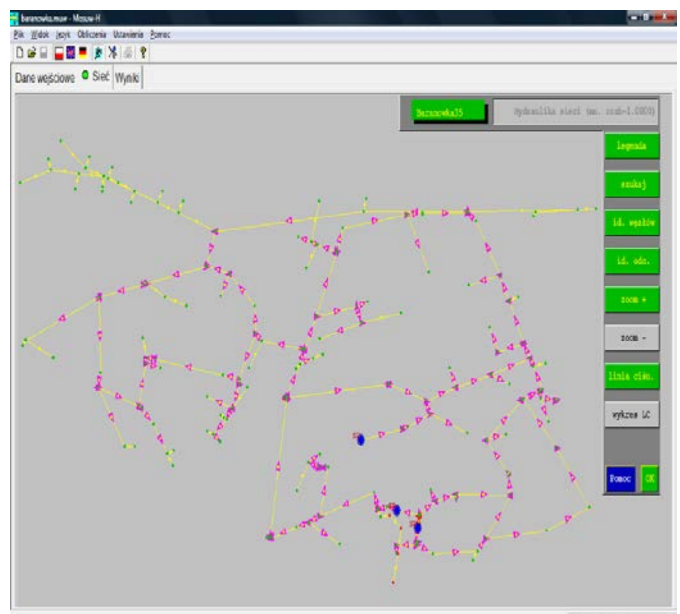

Figure 6. Hydraulic calculation of the water net by Mosuw-H.

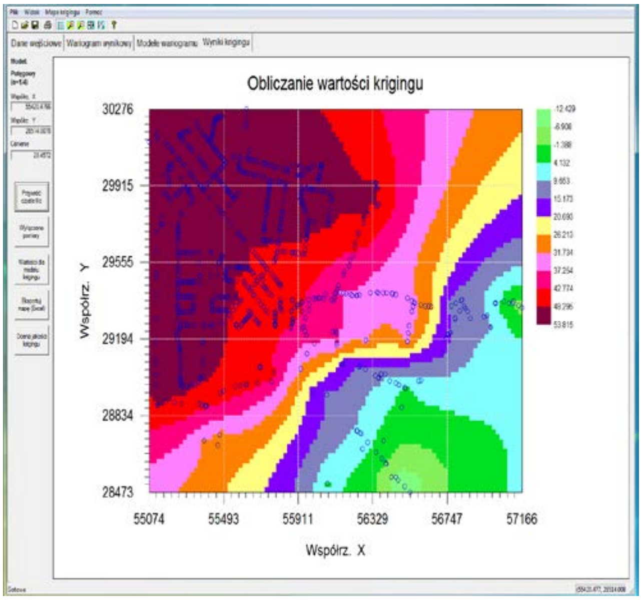

Figure 7. Drawing the map of distribution of water pressures in the net by Kripow.

In the second example the data from GIS are going to Mosuw-W that makes the hydraulic calculation and uses the results to compute the water age in all pipes of the water net. To do this the data concerning the loads of the end nodes have to be in form of time series and the time step between two neighboring nodes equals usually to 1 hour. Subsequently the data concerning the water age are sent to program Kripow-W that draws the map of water age distribution in the water net (Fig. 8 and Fig. 9).

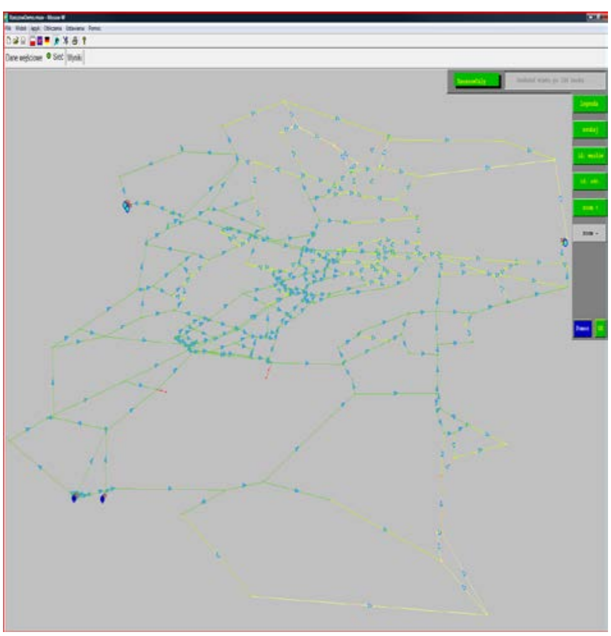

Figure 8. Water age calculation by Mosuw-W.

One can see that the execution of these two exemplary task needs the close cooperation of 4 different programs, i.e. of CIS, GIS, Mosuw-H and Kripow in the first case and of CIS, GIS, Mosuw-W and Kripow-W in the second one. This cooperation can occur fully automatically by starting the collaboratuion process between the modules MOSUW and 'Kriging applications' of the IT system.

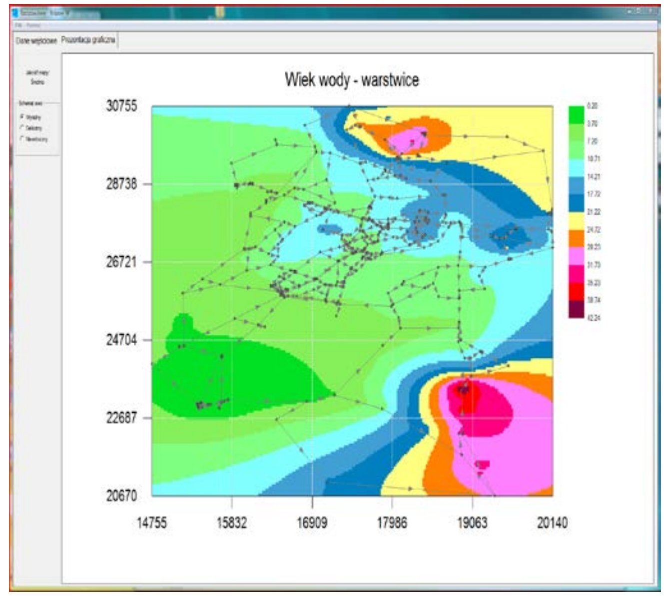

Figure 9. Drawing the map of water age distribution in the net by Kripow-W.

4. IMPLEMENTATION OF THE IT SYSTEM INTO THE PRACTICE

The implementation of the IT system presented occurs usually in 4 phases. Firstly, a GIS system has to be implemented in the waterworks under investigation. This operation can last up to 12 months depending on the size and complexity of the water net. After the structure of the network is successfully created in form of the numerical map of the network then the CIS system has to be integrated with GIS and its data concerning the water amounts taken by the water net users have to be assigned to the appropriate nodes of the network. The second phase means planning and implementation of SCADA at the water net. This is the most costly operation of the whole undertaking by the reason of the high costs of the construction works needed for making the SCADA measurements points and of the high costs of the measurement devises installed in these monitoring points. The measurement points of SCADA must be localized in special selected points of the network; they are called network characterized points and they make possible the future calibration and cyclical recalibration of the water net hydraulic model. The calibration of the hydraulic model is the third phase of the IT system implementation. To calibrate the hydraulic model exactly the properly planed SCADA shall be used and to plan a right SCADA an already calibrated hydraulic model shall be applied that enables to localize the characterized points on the network (Studzinski, 2009). To solve this problem the second and third phases are conducted iterative and returning in at least 3 steps: firstly, the hydraulic model is calibrated using the measurement data won by means of a measurement experiment executed on the water net; secondly, the SCADA system is planed with help of the hydraulic model calibrated this way; and thirdly, the hydraulic model is calibrated again with use of SCADA already installed on the water net. One can see that this three-phase process of the implementation of the IT system is rather time-consuming and arduous and it can take a lot of time, work and money into account.

When these 3 phases are at last completed then all data needed to realize the management tasks executable by the IT system are already available, i.e. the data from GIS (the water net graph), from SCADA (flow and pressure measurements from the measurement points of SCADA) and from the hydraulic model (the calculated flow and pressure values in all pipes and nodes of the network). The implementation of the programs that constitute the content of modules of the IT system is the fourth phase of the undertaking. This means that the operation of the module programs (apart from Mosuw-H) without previous implementing of GIS, SCADA and the hydraulic model makes no sense from the practical point of view.

The IT system presented is now under introduction in two waterworks in Poland whereas the one is a middle size enterprise with daily water production of ca. 60.000 m^3 and the second one is a small size enterprise with daily water production of ca. 6.000 m^3. In the first case the first 3 phases of the IT system implementation are realized and in the second case only a GIS system is now under implementing. It means that there is still too early to appreciate the advantages and benefits resulting from the operation in practice of the IT system developed.

5. CONCLUSIONS

A central production and distribution of water for a city realized by waterworks creates a complex research problem consisting of water network control belonging to technical tasks and of water network management belonging to organizational and administrative tasks. As a result the water produced has to be provided to its consumers in amounts needed, with an appropriate good quality and with a possibly small price. The implementation of the IT system in communal waterworks shall cut down the operational costs of the water net, boost its reliability and ensure a high and homogenous quality of the water produced. The integrated IT system shall also improve and make easier the job of water net operators and planners and also of the management staff of the waterworks. In case of the operators the improvements will concern the operational control of the water net, in case of planners they will concern the planning of the investment works regarding the repairs, the modernization and expansion of the water network and in case of the management staff the improvements will concern the complex and more effective waterworks management and under it the solution of such the problems like the determination of rational water prices. The development of the IT system shall be especially important and useful for city agglomerations running the complex and wide spread water networks which are characterized ordinary by great exploitation costs resulted from the considerable water losses caused by water net damages and from the great costs of the energy used (Waterworth, 20012).

6. ACKNOWLEDGMENTS

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