A knowledge-based decision support system for river basin management

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Abstract

The paper describes recent results achieved in the project AQUIN which purpose is to investigate possibilities of controlling certain complex water management situations. The research has been initiated by a practical problem related to water consumption from the river Uhlava in the Western part of the Czech Republic. On the river, there is a reservoir Nýrsko situated 95 km upstream from the consumption place in the town Plzeň. It is a multipurpose drinking-water reservoir, especially used for compensation and also for energy production. Until now, flow deficiency in the consumption place was solved by over quantity of water discharge experimentally. A knowledge-based decision support system, which is being developed recently in the scope of the project, will be able to find really suitable and economically endurable manipulations in Nýrsko reservoir to reduce unused river-flows in water consumption place Plzeň during dry periods.

The paper is devoted to a brief presentation of the problem solved, followed by a description of the solution, which is being developed in the scope of the AQUIN project. An analysis of information and knowledge sources about the river Uhlava and its characteristics has been performed and the suitable knowledge has been codified, organized and stored in an appropriate knowledge repository. This repository serves as a basis for a knowledge-based part of the decision support system, helping the river basin operators and dispatchers to create as accurate decisions as possible. The draft architecture of the system and some details about its implementation will be presented.
1 Introduction

The paper describes recent results achieved in the project AQUIN which purpose is to investigate possibilities of controlling certain complex river basin management situations on a particular Czech river.

The research has been initiated by the following practical problem from the Czech Republic: consumption of Water Treatment Plant Plzen is realized from the river Uhlava without local accumulation. On the river, there is a reservoir Nyrsko situated 95 km upstream from the consumption place. It is a multipurpose drinking-water reservoir, especially used for compensation and also for energy production. Until now, flow deficiency in the consumption place was solved by over quantity of water discharge experimentally.

We propose to use a knowledge-based decision support system, which is being developed recently in the scope of the AQUIN project. The system will be able to find really suitable and economically endurable manipulations in Nyrsko reservoir aiming to reduce unused river-flows in water consumption place Plzen in dry periods.

As the goal of the AQUIN project is an expansion of expert system technology into still very rare water management applications, we have intensively examined various related approaches, which could be employed for this task. Methodical procedures of genetic algorithms, artificial neural networks and fuzzy logic have been utilized as well.

The paper is devoted to a brief presentation of the problem solved, followed by a rather detailed description of the proposed solution, which is being implemented in the scope of the project. An analysis of information and knowledge sources about the river Uhlava and its characteristics has been performed and the suitable knowledge has been codified, organized and stored in an appropriate knowledge repository. This repository serves as a basis for a knowledge-based part of the decision support system, helping the river basin operators to create as accurate decisions as possible. The draft architecture of the system and some details about its implementation are presented as well. As the project is still an ongoing one, we hope to be able to present some new results shortly. Some first results can be found in [1], [2] and [3], more recent results from another perspective are in [4].

2 Knowledge based approaches in RBM

Using expert systems for control of complicated elements is eminently progressive even if certain risks of their lapses exist. The utilization of expert systems is very intensive in many research disciplines. Applications of expert systems for control of complex closed blocs like water treatment plants and wastewater plants are designed and utilized also in water resources management in the world. Expert systems that evaluate ecological impacts of different constructions are another type of their utilization. The largest utilization of expert systems is in medicine (diagnostic systems), in the control of complex
technological industry processes, in energy industry, in the space research (NASA) and in military applications. Some of the important AI techniques have already been discussed at various relevant conferences, particularly in the scope of the series of the International Conferences on the Application of Artificial Intelligence (AI) in engineering disciplines (in July 1995, in Udine, Italy; in July 1996, in Florida, USA; in July 1997, in Capri, Italy; in July 1998, in Galway, Ireland). The conferences revealed concrete results to indicate that expert systems, genetic algorithms and neural networks can directly be utilized in water resources management as well as in river basin management, and documented its perspective.

The development in advanced countries has aimed to optimize their control of water resource management by artificial intelligent methods. The utilization of computers and robotics applications has been supported. The software preparation and verification of the intelligent support of the decision making process of dispatchers in complex systems has to be very realistic. The control of these systems requires processing of large amount of data, operational knowledge and experience. It means the development of expert or knowledge-based systems. Until now, progressive methods have only been asserted in practice, leisurely and with difficulties, in the Czech Republic, but good assumptions have created for their application. For example, companies managing river basins have already put into operation semiautomatic information systems for the data collection and transmission back to dispatch centers. Additionally they are preparing these information systems for real-time operation.

The first Czech application of expert systems in water resources management has been solved at the Faculty of Civil Engineering of Czech Technical University in Prague in 1995 and 1996. The applicable expert system was developed using the professional environment NEXPERT Object. The developed knowledge-based system has aimed to water resource management of the system of three reservoirs based on the adaptive principle in dry periods. It has been tested using the water reservoirs Kruzberk, Sance and Moravka hydrological data [5], [6]. The second one was a knowledge-based system, which plans optimal manipulations on water schemes cascade Slezska Harta, Kruzberk and Podhradi in order to reach maximum of water energy production on small hydropower plants [7].

However, these water management applications of expert systems are still rare in our country. They have not been tested in practice, but they advantage is in the fact, that after their suitable replenishment they can help in automatization of decision processes in river basin dispatch centers. They can rapidly decrease, although not exclude, the influence of subjective elements in decision process of dispatchers. They can also help in their decision distinctly, especially in the case of young newcomers. Here we can take into account some approaches and solutions of knowledge management area as well. These all are, among others, the reasons why we have focused on this research area also in here described project AQUIN.
3 Problem description

As already mentioned in the introduction, the underlying research has been initiated by the following practical problem from the Czech Republic: consumption of Water Treatment Plant Plzen is realized from the river Uhlava without local accumulation. On the river, there is a reservoir Nyrsko situated 95 km upstream from the consumption place. It is a multipurpose reservoir, especially used for compensation and also for energy production. Until now, flow deficiency in the consumption place was solved by over quantity of water discharge experimentally.

A couple of initial discussions with the river basin dispatchers led to the decision to propose a knowledge-based decision support system in the scope of the project. This system could be able to find really suitable and economically endurable manipulations in Nyrsko reservoir aiming to reduce unused river-flows in water consumption place Plzen in dry periods.

4 Proposed solutions

As a solution of the previously described practical problem we propose to design and implement a knowledge-based decision support system aiming to act as an intelligent aiding tool to the river dispatch managers in solving complex practical situations.

Developed application of knowledge-based decision support system intends to cover also previously achieved research results. For example, mathematical modeling of hydrological data, mathematical models for optimization and control of reservoirs from the hydrological point of view, from energy utilization point of view, models of water management in dry periods, rainfall-runoff terms for outflow forecasting and elementary models of pollution effusing in rivers. Pieces of knowledge from this research activity are being integrated into developed knowledge base that will be tested in real operations of River-basin Vltava public corporation, branch Berounka in Plzen.

5 Proposed decision support system

The developed system consists of three main parts:

- **Knowledge base** covering research results of given problems, current relations, models and rules used by dispatch centers
- **Data base** containing data gathered from existing reports, textbooks and preprocessed raw data
- **User interface** giving user-friendly consultations and suggesting decisions to operators.

The developed knowledge-based decision support system will be able to process more situations in real operation under condition of stochastic uncertainty and also to work with verbally expressed heuristic knowledge and experience. Intelligent knowledge system combines the advantages of machine
with the human like reasoning (exact computations, processing of large amount of data, using of models etc.).

5.1 Knowledge base

Knowledge base covers research results of given problems, current relations, models and rules, which dispatch centers use, written using a suitable formalism.

The control of the reservoir is currently performed according to the dispatcher look-up tables based on flow rate history series. When taking a decision, the dispatcher takes into account flow rate and rainfall data of the day as well as of several preceding days. He or she uses his/her experience in climatical dynamics of the river basin and together with an official short-time meteorological prediction decides on keeping constant, increasing or decreasing the reservoir outflow. The codified general ontological, causal, behavioral and operational knowledge on controlling the reservoir include principal goals and manipulation rules to obey, flow rate manipulation practices, best practices suggestions and also look-up tables for reservoir outflow regulation for three different water level intervals.

Heuristic knowledge and experts’ experience of water quality monitoring and influence will also fall into this knowledge base.

5.2 Data base

Data base contain hydrological, economical and technical characteristics and stages of the reservoir and other technical object on the river such as water plant and weirs. Basic goals and functions of the reservoir are included as well.

A large part of the data base consists from geographical, climatical and hydrographical characteristics of the river basin, furthermore historical data such as average daily, monthly and yearly flow rates based on time series of a 30-year-long time span, average rainfalls, all of them at several points of interest along the river.

All the data collected from various sources and of different formats had to be organized and processed in order to make it compatible and complementary. Because of multiple sources for some data, inconsistencies had to be resolved, contradictions had to be removed and missing data had to be supplied, estimated, simulated or skipped.

The resulting data collections suggest a utilization of semiautomatic information system for the data collection and transmission back to dispatch center of the River basin Vltava public corporation.

5.3 User interface

The user interface gives consultations in a friendly dialogue form and suggests the solution of the problem to dispatch managers. It will allow the dispatch manager to set priorities of manipulation goals and to foresee possible system
responses to different decision making scenarios. It will also explicate possible conclusions by verbal or graphical form.

6 Functional model definition

The proposed knowledge structuralisation and functional organization can be seen at the Figure 1. The core part of the system will be a deep and empirical knowledge-based simulation of the system. The knowledge-based simulation will serve as a base for modules dealing with forecasting, goal management and decision suggesting. Two auxiliary modules will be also used: numerical simulation module and data mining module.

The flow rate history series together with time series on rainfalls, flood waves and other hydrological data are essential for simulation building that will be used for off-line running, validation and testing of the system being developed. Using auxiliary numerical simulation module real historical data can be extended while preserving statistical properties of the real data series. Some useful yet directly not observed data can be gained from the numerical simulation as well. Real historical and simulated data on flow rates, rainfalls, weather forecasting and dispatcher decisions serve as a basis for a generation of possible system evolvement scenarios by the forecasting module.

As the reservoir has multiple purposes, several manipulation goals exist. A particular goal fulfillment may require manipulation actions that will be obstructive for other goal achievement. The goal management module is responsible for goal ranking according to their priorities set by the dispatcher, resolving goal conflicts and for smooth following the resulting goal list.

An important part of the decision support system is the decision suggestion module. This module tightly cooperates with the goal management module. It takes into account possible scenarios of system evolvements and it infers consequences of a set of manipulation actions selected according to the goals set.

A neural network is proposed as a mean for this simulation that can be used as a prediction tool once the system is embedded in the real environment and ceases the need for simulation. Eventually data mining module will be deployed to unshed hidden knowledge in real historical data on flow rates, rainfalls, and weather forecasting as well as dispatcher decisions.
7 Implementation

The realization of a prototype of the system is carried out in a professional multi-featured (object-oriented, rule-based and procedural) expert system developing environment G2, although this solution can serve only for research and academic purposes, while having an older academic version of G2 [8]. While G2 is primarily used for development of knowledge-based real-time industrial applications, it has been successfully used for the supervision and control of a wastewater treatment pilot plant [9] as well.

The last year work was concentrated on the processing of background research, accessible data analysis from the river basin managing corporation, and knowledge and experience analysis of chosen problem task and also on the study of the latest literature and software.

Recent research is concentrated more on simulation and supporting models of problem task creation, and on formalizing the knowledge in the selected expert system developing environment. Some experiments with using fuzzy logic approaches towards capturing certain types of dispatcher managers’ knowledge, especially uncertain knowledge based on managers’ judgment of the particular situation, are being prepared recently. The first experience with these approaches is quite promising.
8 Concluding remarks, future works

Extract the encoded knowledge from the unique, highly specialized and seldom G2 environment into an easily transferable description form XML or other ontology language.

We hope to continue in complex problem solving in the area of the river basin domain in the frame of a subsequent project possibly aimed at water quality improvement.

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References


University in Prague, Faculty of Civil Engineering, Internal grant No 2027, Prague, 1997.


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