On the way to knowledge-based water management

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INTRODUCTION

Knowledge management applies systematic approaches to find, understand and use knowledge to create value. It is also the formalisation of and access to experience, knowledge and expertise that create new capabilities, enable superior performance, encourage innovation and enhance customer value. There have been only a few attempts to use knowledge technologies on this topic (see Baeza, Gabriel and Lafuente, 1998; Nacházel and Toman, 1995; Nacházel and Toman, 1997; Ponce, 2001)); knowledge management approaches have also not been used very often although, together with suitable e-learning techniques, could play a significant role (Mikulecký, 2003; Mikulecký, Ponce and Toman, 2003b).

Our on-going research, which began in 2001, has focused on applying recent popular approaches, methods and tools of knowledge management to the water resources of a particular Czech river.

We first analysed the data, information and knowledge sources relevant to the Czech river Uhlava catchment, identifying what knowledge is already available and where it resides. The next step has been to use some approaches of ontological engineering to describe the knowledge structure of water resources management. Simultaneously, we gained relevant knowledge from experts — experienced river basin operators. The knowledge extracted has then been represented in a knowledge-based system demonstration, and later in the system prototype, based on a combination of the commercially available environment G2, as well as a freely available development shell CLIPS.

Having done that, a basis for a knowledge-based decision support system has been established, aiming to help river basin operators to produce better and more reliable decisions when facing routine or out of the ordinary situations. A detailed description of the approaches used in the development of the knowledge-based decision support system can be found in (Olševicová and Ponce 2003).

In this paper, we intend to advocate the knowledge-based approach to a river basin water resources management as having a number of advantages when compared to some classical approaches based on mathematical formulae and models. Of course, mathematical models and simulations may be used in our approach as well but merely playing a supporting role in the essential knowledge-based approach.

As an ultimate goal, we intend to create a complex knowledge-based system, accumulating the most important if not all the necessary (and of course that which is available) knowledge related to the river basin water resources management. Such a system should be able to support the decision-making process of river operators intensively, leaving just small margins for erroneous decisions. The system could be used also for training new operators who are novices in the area; using this system, they will be solving real world problems, which is one of the best ways of learning (Ahmed *et al*., 2002).

A demonstration and a prototype of the knowledge-based decision-support system have been developed recently, exploiting suitable knowledge management approaches. These are now described briefly and a more technical description of the system development process can be found in Olševi ová and Ponce, (2004). The project is not yet finished, however it is a very beneficial feature of knowledge-based systems that they can be put to use nearly immediately, frequently during the development process itself which then contributes to the development process, while first feedback from the users can be taken into account in the very early stages of the development.

KNOWLEDGE MANAGEMENT APPROACHES

Water management, to be efficiently applied in everyday practice, needs knowledge, as does any other knowledge-intensive activity. This knowledge is usually possessed only by a narrow group of specialists (experts in the area) who know when, how, and what must be done to provide proper water supply, or to cope with dramatic consequences of floods. This knowledge may not be available whenever it is necessary for various reasons:

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- the experts may not be always available when necessary,
- the experts can suffer from various human problems, or their knowledge can be lost suddenly because of mortality or retirement,
- the experts can differ in their opinions on how to solve a particular situation, etc.

Experts operate or produce decisions when solving real world problems in such a way that they will certainly use problem-specific data, mathematical models of the real situation, simulations, etc. The problem arises when the necessary data are not available, are incorrect, or are incomplete. In these cases all the classical approaches fail; neither algorithmic solutions nor exact formulae can be used.

Moreover, the complexity of many real world problems is such that they are intractable via some traditional approaches, such as mathematical modelling or various methods of simulation. In many cases, when we try to employ a mathematical model, the results are inadequate to the real situations, mainly because of the necessity of using high degree of abstraction in the model construction.

These obstacles can be solved frequently by employing suitable approaches from the area of soft computing; some experience in this direction can be found in Nacházel and Toman (1995) or Nacházel and Toman, (1997) although Hynek and Slabý (2002) show that even these approaches are sometimes inadequate.

All of these and other reasons support our opinion that various knowledge management solutions using proper knowledge-based tools, which have already proven their usefulness in other areas, could be very beneficial for water management.

Knowledge management (see e.g. Davenport and Prusak, 1998; Morey *et al*., 2000; O'Leary, 1998) applies systematic approaches to find, understand, organise, store, disseminate and use knowledge to understand various processes, problems, relationships, etc. better and to create new value. It is also the formalisation of and access to experience, knowledge and expertise within an organisation that creates new capabilities for that organization, enables superior performance of their workers, encourages innovation throughout the organisation and enhances its customer's value. Recently, various organizations have begun to introduce at least some pieces of the big palette of knowledge management principles, methods or tools.

The ultimate goal of a knowledge management effort in an organisation is to collect all the organisational knowledge (explicit as well as tacit) and to make it available — sharable — throughout the organisation. If we consider a typical river basin management organization, we can identify a lot of knowledge on various levels that is accumulated throughout such an organisation.

Given current problems of water resources management, research should be promoted, suitable methodological procedures should be sought and new scientific disciplines should be developed that join together, for example, hydraulics and hydrology with modern knowledge and information technologies to simulate the operation of water management structures in various situations and under different environmental conditions and influences. We tried to investigate this within a recently finished project, AQUIN. The project investigated the possibilities of using knowledge-based systems for control and optimisation of elements of water management operation in real time. As the use of expert and knowledge-based systems touches only the technological point of the view of the whole problem area, we have investigated also much broader aspects of the possible impacts for water management. We took into account knowledge creation or knowledge acquisition, as well as knowledge organisation and storage in suitable knowledge-based systems or their knowledge bases. The main knowledge processes in water management have been analysed and certain procedures for these processes were formulated and tested.

An effective exploitation of knowledge and experience specific to water management control requires identification of concrete knowledge sources. The identification is closely related to a so-called knowledge audit, i.e. a thorough examination of what types of knowledge are available, what other knowledge may be needed and where to obtain it. For those types of knowledge where the audit shows their accessibility (in documentation, manipulation guides, experiences of a person disposed to formulate and hand over his/her knowledge to the project investigators, etc.), a collection process may be started immediately. They are written down using an appropriate formalism and stored in a systematically developed knowledge base where they can be explored and used at any time. For those types of knowledge that will be indispensable for the ultimate solution but at the same time will not be accessible in any available sources, an external source will have to be identified and negotiation over knowledge acquisition will become necessary (e.g. whether to purchase or exchange the knowledge for other types of knowledge).

Keeping in mind the objectives of the project, we differentiate between important, moderately important and unnecessary types of knowledge. Important types of knowledge will gradually gain in importance as the work on the project proceeds and the objectives of the project are broadened. The moderately important types of knowledge may also become important in the case of modification of the project goals.

SOURCES OF RELEVANT KNOWLEDGE

To make use of knowledge related to the Uhlava river basin management, particular sources of essential knowledge must be identified. The knowledge sources relevant to the problem domain, to the problem itself and to the project AQUIN, cover knowledge of variable relevance, profundity, availability and reliability.

Considering the goals of the project we have to distinguish between important and not so important knowledge, e.g. water quality parameters and historical measurements. This type of knowledge may become important in future project extensions. The knowledge sources to hand vary highly in their profundity. Some take the form of professional textbooks capturing the basic domain knowledge while others consist of lookup-tables and so-called manipulation graphs that are based on analysis of historical data characterising the river and the reservoir behaviour. The most valuable knowledge is the heuristic knowledge of operators who have gained remarkable insight into the behaviour of the whole river basin ecosystem and the related control system after years spent operating it. The sources of this heuristic knowledge are, naturally, the operators themselves.

When identifying potential suitable knowledge sources, an important criterion was the availability of the source. Expectations and the reality do not match perfectly and some eventual sources of knowledge turned out to be unavailable. Examples are the series of measurements that were recorded at only a few of the many possible checkpoints or a collection of historical data analysis reports that can only be purchased obeying some financial constraints of the river basin company. Another important factor is the reliability of the knowledge sources used. The majority are fully reliable, containing complete and correct measurement series, although some data may be missing or mis-recorded when transferred from one recording medium to another one. Further, a large amount of knowledge is uncertain, e.g. weather forecasting and operators' heuristic knowledge. On the other hand, the latter is the most valuable and should form the essence of the developed system and the task of capturing this kind of knowledge was one of the most difficult and the most important aspects of the AQUIN project.

Identification of other relevant knowledge sources includes those based on more theoretical as, for example, mathematical modelling of hydrological data, mathematical models for optimisation and control of reservoirs for both the hydrological and energy utilisation points of view, models of water management in dry periods, rainfall-runoff terms for flow forecasting and elementary models of river pollution.

KNOWLEDGE ACQUISITION AND STORAGE

The knowledge acquisition process began with the first meeting with the personnel of the river basin company. At that meeting, our research staff learned the basic principles of operation of the river, responsibility delegation at various decision levels and possible actions that can be taken to control the reservoir. We also observed the river and the reservoir system, including its control system *in situ*. Afterwards, we explored general textbooks related to the problem domain and the sources of codified specialised knowledge from materials given out at the first meeting. We held several internal meetings to organise, clarify and set down the knowledge gained. Preliminary, partial implementation experiments were performed also. We then reformulated the transferred knowledge on our own and pointed out unclear issues. A functionality proposal was set and the directions for further knowledge acquisition were agreed.

Currently, we have had an important meeting with experienced operators in operating the reservoir and predicting the behaviour of the river and its ecosystem. This meeting will be followed by a series of operator-shadowing visits, as it is important to observe how the operator decides in real situations.

An important aspect of the whole process is in having co-operative operators, willing to participate in the project, who do not hesitate to share their knowledge with the system deployed. In a sense, this is usually one of the most difficult conditions to fulfil to ensure the success of the project (Morey *et al*., 2000)). As one of the project partners is the river basin company itself, this fact seems to ensure the experts' collaboration and experiences with them so far have been positive.

Current practice in the storage of the operational knowledge within the company is multi-faceted and there is no unique strategy for knowledge management that also includes storage. Knowledge in the form of data is mainly stored as discrete or continuous historical data on paper. Indeed, the AQUIN project provided an impetus to transform data recorded manually or by an analogue device into digital records. Some data (e.g. forecasts) coming on a daily basis are not stored at all. However, this information may be an additional source of knowledge better characterising the circumstances and factors that impact on the operators' decision-making. As these data are supplied by third parties, there may exist a legal constraint on their storage. A small amount of data is read automatically at checkpoints and stored in an electronic file. General operating rules and suggestions are stored as paper look-up tables and graphs: no decision-support system is used. The heuristic knowledge of operators is not stored at all: in no way is it captured and the company runs a risk that if an operator retires, his/her expertise will be lost.

CONCLUSIONS

The main goal of the AQUIN project was to support operators in their decision-making by better knowledge management. The resulting system will also make available and usable such knowledge sources that are currently used stand-alone and individually. An important aim of the project was to make the resulting decision support system as transferable as possible for future use with similar problems within the domain. Therefore, separating the storage of general and problem-specific knowledge will become important. Some more technical descriptions of the knowledge-based system developed within the AQUIN project can be found in (Olševicová and Ponce, 2004). The most important features are as follows:

- A knowledge base covering research results of given problems, current relations, models and rules, as used by dispatch centres, written using a suitable formalism. Heuristic knowledge and experts' experience of water quality monitoring and influence will also fall into this knowledge base.
- A data base with characteristics and stages of reservoirs, rivers and other elements of water resource systems. It lends itself to the use of a semi-automatic information system for data collection and transmission back to the river basin management company.
- A user interface, which will give consultations using friendly dialogue and recommending the problem solutions to operational managers. It will also present possible conclusions in verbal or graphical formats.

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

Recent experience with application of a modern, very popular knowledge management approach has shown that it can be used successfully for water resources management. Indeed, there is considerable shallow as well as deep knowledge accumulated within river basin companies which have experienced experts, operating manuals, best practices and other important but not easily accessible or even inaccessible sources of knowledge. Better utilisation of this knowledge, (or even its discovery in many cases where the knowledge is hidden in the brains of very experienced staff!), is a way towards a modern, knowledge-based water management company.

We are deeply convinced, and our recent experience support this feeling quite strongly, that introducing knowledge management approaches into water resources management could help substantially in solving many of the problems related to more efficient and effective operations in a number of important or even dangerous situations which sometimes occur in river basins. The project still requires further continuation, but we have shown that the knowledge management approach based on much broader and more precise collection of relevant data, on careful acquisition and sharing of as many available and relevant knowledge inputs as possible, and on the cooperation of all the river basin management staff in thorough exploitation of the shared knowledge, could be a way to an ultimate goal — knowledge-based water management.

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