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INFORMATION TECHNOLOGY FOR CLEANER WATER

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Abstract
The goal of the work presented in this paper is to develop a systematic approach to the assessment, selection and optimisation of water remediation schemes and to implement this approach in a decision support system that can be used by environmental professionals, policy makers, site owners and other stakeholders. Our decision support system can simultaneously evaluate various remedial action alternatives for multiple contaminants, taking into account user's specific needs and preferences, and provide a ranking of the best options. The system is based on a heterogeneous, hybrid software architecture integrating together a variety of information technologies and targets the development of an integrated, holistic approach to environmental decision making.

Key Words
Aquatic ecosystems, decision support systems, ecosystem management, natural resource management

1. Introduction

During the last two decades the scarcity of water resources is exponentially growing worldwide. As a result, there has been a serious and growing concern about the sustainability of aquatic ecosystem, resulting in substantial progress in different aspects of water resource development and management in different parts of the world. The problem of the scarcity of water and pollution abatement is especially severe in the developing world, where it is significantly aggravated by the difficult economic situation of the countries. Therefore, the need for the careful and efficient application of the environment preservation investment is very high. In order to obtain a moderate investment, environmental engineers need to prove to the stakeholders (federal, regional and municipal authorities as well as owners and management of industrial enterprises) that their investment decisions and recommendations will result in a substantial improvement of the environment. When the aquatic ecosystem is concerned, an integrated water resources management strategy should be adopted, that implies that these decisions have been achieved by systematically incorporating the conflicting aspirations of different decision makers, actors stakeholders, institutions and representations of the public in the process. To make well-founded, objective, efficient and easily justifiable decisions it has become necessary to use experts and/or computer models in the decision making process. Owing to the unprecedented growth and development in information technology, even the most sophisticated areas, like artificial intelligence and decision support systems (DSS) are drawing a lot of attention (and finances). Decision support systems are computer-based systems that facilitate the use of data, models, and structured decision processes in decision making. The optimal environmental DSS should have a balance between the sophistication needed to address the wide range of complicated sites and site conditions and ease of use (e.g., the system should not require data that is typically unknown and should have robust and simple problem definition through input, etc.).

The environmental decision support systems have been applied in six major areas:

1. Site characterization data analysis
2. Nature and extent of contamination analysis
3. Remedial action analysis which includes comparison between different alternatives optimization of design as well as
4. Human health risk analysis (compliance with regulatory limits)
5. Economic cost/benefit analysis.

At the ICS-UNIDO we have started the development of the set of environmental decision support tools, which belong to the areas 3 and 5. listed above. Operational prototypes of the DSS for waste oil regeneration technology selection and soil and water remediation technologies assessment and selection have been already developed (area 3). The last one will be described in detail in the sections to fallow. A DSS enabling cost/benefit analysis based on environmental (i.e. "green") accounting principles is in its inception phase (area 5).

Water remediation is a difficult, time-consuming and expensive operation. A variety of mature and emerging water remediation technologies is available and future trends in the remediation industry will include continued competition among environmental service companies and technology developers, which will definitely result in further increase in the cleanup options. Consequently, the demand has developed for a decision support system that could help the decision makers to select the most appropriate technology for the specific contaminated water resource, before the costly remedial actions are taken. Therefore, we have conceived CCR (Credence Clearwater Revival), a decision aid for water remediation technology assessment and selection, that works closely with human decision makers involved (site owners, investors, local community representatives, environmentalists, regulators, etc.) to assess the available technologies and select the preferred remedial options. The selection is based on technical, financial, environmental, and social criteria. These criteria are ranked by all involved parties to determine their relative importance for a particular water remediation project.

To provide an information base for such a decision support system, the ICS-UNIDO continually compiles, analyses, and disseminates laboratory-, pilot- and full-scale case study information for a variety of mature and innovative technologies for water remediation and purification. As a result, a Compendium [1] of waste water treatment and water purification technologies has been published, and an experimental prototype of the complementary information technology tool (software package CCR) for technology assessment and selection has been conceived.

The ICS-UNIDO compendium [1] (and the corresponding computer database) is not represented as being final, nor are all the technologies included screened in detail to completely verify their validity, quality, or "success" in remediation. Rather the Compendium, and resultant computer database and software tool for technology assessment and selection are intended to provide members of the water remediation community, especially in developing and transition economy countries with basic information on both mature and emerging water remediation and purification technologies, and with a comprehensive software tool for the preliminary, course – grain filtering of the most suitable technologies for the further, more detailed evaluation.

The software is based solely on the information in the current version of the ICS-UNIDO compendium on water treatment and purification technologies, based on compilation of readily available information from the literature or personal communications with involved parties. However, it could be easily extended in the future to reflect additional information compiled, and/or updates/revisions/additions to the ICS-UNIDO database of best available technologies. The software is extremely user friendly – after defining the contaminant present in the water, user is presented with only those technologies that are, at least to the certain extent, capable of eliminating those contaminants. Then, the users selects the criteria he considers the most important and their relative weights and preferences. System ranks the available remedial options according to the chosen set of criteria.

Software provides a repository of the best available water remediation technologies, a set of indicators for criteria for evaluating those technologies, and default values of weighting factors, that could be easily adjusted to suit the user's specific needs and preferences. It

- Enables its users to identify and systematically compare information about innovative and conventional technologies to meet water remediation goals,
- Establishes a structure of technology evaluation and selection process, which simplifies the decision making and streamlines the variety of factors involved in the remediation process
- Defines consistent, measurable indicators for key technical, environmental, and economic criteria that influence selection and deployment of technologies
- Provides documented evaluation which can be updated as needed information becomes available
- Provides a flexible, multicriteria optimization approach allowing tradeoffs among criteria on the basis of contaminant type and user's specific needs
- Fastens development of a feasibility study of remedial options
- Provides site owners, environmental managers and other stakeholders with the opportunity to explore alternative remedial options quickly, etc.

Users are also allowed to choose the preference functions and define their shapes. Besides, it is very easy to add new technology or even a category of technologies, or change the parameters of the existing ones, or introduce new preference functions, etc. Our DSS is Web-based application, hosted at our server in Italy, so that our target beneficiaries from the developing countries from all over the world, could easily access it, once they are properly authenticated.

2. Web-Based Decision Support System

The purposes of decision support systems (DSS) are to [2]:

- Improve decision-making ability of managers, investors, environmentalists and other stakeholders by allowing faster or better decisions within the constraints of cognitive, time, regulatory and economic limits
- Increase productivity of decision makers
- Supplement one or more of a decision maker's abilities (i.e. knowledge collection, knowledge derivation, problem recognition and solution)

- Facilitate one or more of the decision-making phases (technology intelligence, assessment, selection)
- Facilitate problem-solving flows and better structuring of the decision process
- Aid a decision maker in addressing unstructured or semi-structured decisions
- Enhance a decision maker's knowledge management competence, supplementing human knowledge management skills with computer-based knowledge capabilities.

It is necessary to distinguish decision support systems from other kinds of computer-based systems such as data processing and management systems. The main difference is that one DSS must have the ability of knowledge acquisition, selection ability of related knowledge and generation of new knowledge. Newly created knowledge can be used as new input data for the decision support system.

The basic architecture of a decision support system consists of:

- A knowledge subsystem – this subsystem consists of different heterogeneous knowledge sources (database systems, textual files, Internet based Unique Resource Identifiers (URI) for uniquely identifying every knowledge source element)
- A knowledge representation system – the knowledge must be structured in related forms (i.e. organization of data in XML files, or in relational database systems)
- A presentation subsystem – the available knowledge must be presented to the end user (a decision maker), and also to the system engineer (responsible for the collection of knowledge)
- A problem solving subsystem – a decision maker activates this subsystem and starts the process of generating the best recommendation and ranked alternatives.

To be able to reuse as much source code as possible in various DSS applications that we develop at ICS-UNIDO we have opted for the development of the generic framework, called WISE (Web-based Intelligent Systems Environment) that could be easily configured for the specific DSS at hand, no matter which DSS paradigm is chosen - multicriteria decision making, heuristics and production rules, or even fuzzy sets and fuzzy production rule, or arbitrary combination of these paradigms.

WISE framework facilitates a development of multiparadigm intelligent systems, that combine conventional expert systems, fuzzy logic, multicriteria decision making, etc. It has been widely recognized that complex decision domains are rarely homogeneous, so that they could be captured within a single programming paradigm. Real world problems need a combination of techniques to be solved efficiently. Therefore, our framework offers the toolset allowing for every sub problem of a complex problem to be solved within the most appropriate intelligent paradigm (expert system, fuzzy logic, MCDM, etc.) and their results combined easily. Although, these paradigms were supported by different software vendors before, the unique advantages of our system is the possibility to combine them freely, and smoothly, the reusability of a great percentage of business logic, problem domain independence, and the possibility to be fed by data/and or knowledge from various types and/or locations of sources. Besides, an extra functionality could be added easily without any disturbance of existing modules. A vast majority of decision domain could be covered, and up to 50 percent of business logic reused. Only specific domain knowledge and data should be fed (no matter of original format or location) into the system and the GUI tuned according to the user preferences (if necessary).

WISE represents a set of Java packages with specific organization and usage, that could be freely and easily combined into a consistent whole, according to the specific problem at hand. The following are the three main functional packages:

- WISE.ES – the package facilitating the development of conventional, rule-based expert systems in Java language
- WISE.MCDM – the package facilitating the multicriteria decision making process, offering the two most widely used methods, PROMETHEE II and ELECTRE III [3], [4]
- WISE.FUZZY – the package facilitating fuzzy sets, fuzzy production rules, and fuzzy linguistic functions (usually used together with WISE.ES package).

Using WISE packages it is very easy to crate the skeleton of every web based intelligent decision support system (Fig 1. shows the core WISE-based DSS architecture).

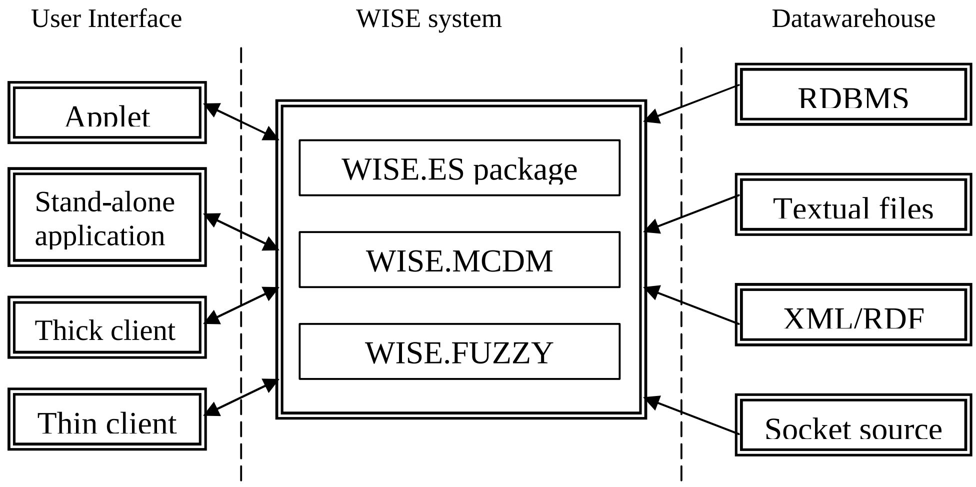

Fig. 1. WISE based decision support system architecture

A concrete web based decision support system consists of graphical user interface (GUI), central WISE layer and knowledge and data warehouse. GUI can be realized as:

- Standard Java applet [5] - that can be embedded within a standard Internet browser (Internet Explorer, Netscape Navigator etc.)
- Stand alone Java application - when that application has a direct access to WISE packages (WISE functions must be called explicitly within the source code of target desktop application)
- Thick Java client - a client with a significant share of business logic in it, where the access to WISE packages is performed through the client side of system
- Thin Java client – a server side subsystem is using WISE packages in the complex, multiple-tier Java application
- Standard Web application – realized using standard script languages (it is possible to use Java Server Pages and also Active Server Pages technologies with JavaScript and VBScript languages).

The central part represents the core of WISE system and consists of three types of packages. It facilitates a direct access to related packages and their functionality (for a stand alone application), and support for using Java Beans [5] technologies as an infrastructure for data interchange between clients and servers. Knowledge warehouse consists of heterogeneous data sources. The system also supports direct communication through TCP/IP protocol and a special high level protocol for data transmission.

Knowledge sources within WISE environment can encompass heterogeneous types of data storage. It is possible to use:

- Standard database systems, with connection through Java Database Connectivity (JDBC) interface
- Standard textual data files with a related data structure
- XML files (also in the RDF/XML format) with related schema structure.

This knowledge source organization facilitates reusability of system skeleton. For a new system creation it is only necessary to adjust the user interface and to feed a new data into the knowledge base. In our concrete application, i.e. DSS for water remediation technology assessment and selection, WISE.MCDM package represents the core module.

The choice of the method for multicriteria decision making depends on the problem at hand, decision-makers familiarity with the MCDA methods, and the time they are ready to invest in getting acquainted with the chosen method. The method used has to be easily and quickly understood by the decision-makers who often have a minimal mathematical background and no knowledge about decision analysis. Having consulted various potential users of our decision support system, we have found out that PROMETHEE method seems to be easier understood and accepted, what made us choose it for our implementation. Moreover, talking to various potential users we have also realized that the decision problem immediately becomes clearer after it has been formalized in terms of alternatives and criteria. The MCDA formulation provides a comprehensive framework for storing all relevant problem information, and makes the requirements for new information more explicit.

3. Demonstration prototype

The software is based solely on the information in the current version of the ICS-UNIDO compendium on water remediation technologies [1], that compiles readily available information from the literature or personal communications with involved technology owners/vendors/inventors. However, it could be easily extended in the future to reflect additional information acquired, and/or updates /revisions/additions to the ICS-UNIDO repository of best available technologies (BATEV).

The software is extremely user friendly – after defining the contaminant present in the polluted water, user is presented with only those technologies that are, at least to the certain extent, capable of eliminating those contaminants. Then, the users selects the criteria he considers the most important and their relative weights and preferences. System ranks the available remediation options according to the chosen set of criteria

The software presents its users with a variety of configuration and input parameters from which to choose. Several are mandatory (such as identifying technologies to be evaluated), but there are many that the user can choose to leave blank or use the supplied default values. This way, the user decides how to tailor the analysis to satisfy his/her specific needs.

Application configuration and data entry process encompasses several tasks:

- *Entering available technologies and their descriptions*. Initially, technologies are classified three broad categories – biological, physicochemical, and thermal technologies. Within these three categories, technologies are further classified into two categories, *in-situ* and *ex-situ* treatment. User is allowed to select a subset of technologies to be considered in certain interactive session. New technologies can easily be entered during the interactive session, while those that have become obsolete could easily be cancelled. Also, the parameters describing the performance of the existing technologies against certain criteria can easily be change (if technology has been improved in certain aspects during the software life cycle, etc.).
- *Entering criteria to be considered simultaneously*. Demonstration prototype uses various technical, environmental and financial criteria for technology assessment and comparison. It is extremely easy to add new criteria. However, the major bottleneck is the acquisition of the reliable criteria values (scores of technology performance against these criteria) for all the technologies considered. The technology vendors are reluctant to give precise data for those criteria that do not represent comparative advantage of their technology.
- *Setting weights of chosen criteria and selecting the type of preference function*. Not all the stakeholders are equally interested in the criteria listed above. Investors are more interested in capital cost than the environmental acceptability of certain technology, while the local community and/or the environmentalists have exactly the opposite viewpoint. Therefore, the system enables its user to select the subset of the criteria offered by the system to be taken into account in particular MCDM session, as well as to put the relative weights to the chosen criteria that best reflect their specific preferences.

The application's main window (see Fig. 2) consists of the current state of configuration, and a few dialogs for data entry purposes.

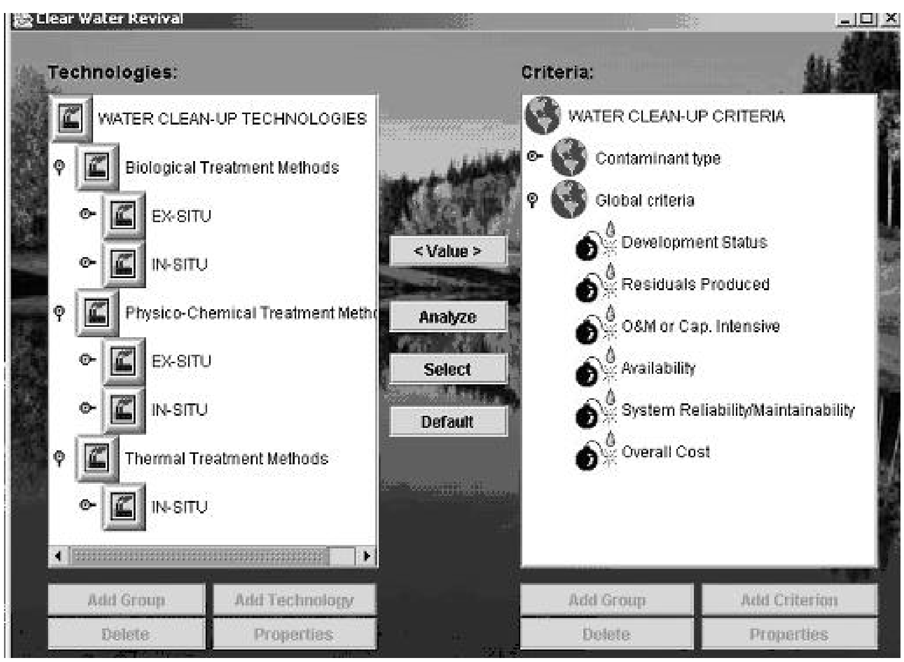

Fig. 2. Main application's window

An application main window consists of the following sections:

- *Technologies* tree structure
- Buttons for manipulating nodes of the *technologies* tree
- Button for selection of the *contaminants* present in the polluted water
- *Criteria* tree structure
- Buttons for manipulating nodes of the *criteria* tree
- Button for setting weights (relative preferences) of the selected criteria
- Button for starting multicriteria decision making process

After the criteria are selected and their relative preferences set by the user, clicking on *Analyze* button on the application main window starts the multicriteria decision making process, and the system recommendation as well as ranked alternatives are presented to the user. This result is not shown in the paper, since we would like to remain an honest and objective technology broker and not to publicize any particular technology (that would come up as a recommendation from a particular session with our decision support system).

First version of the prototype was stand-alone Java application, developed in compliance with J2EE standard [2], with a relational data base as a knowledge sources. The GUI and business logic have not been encapsulated in different modules (only database layer was separated) in the first version of the system. The manpower invested into development and testing was almost 6 person-months. Building a new application with WISE.MCDM package took only 2 man months since almost 50 percent of source code for business logic was in the generic packages. Besides, a new version is much more flexible, able to use different types of knowledge sources and select the most appropriate algorithm for multicriteria analysis. A small wizard is currently being developed, using the MCDM.ES package, that will help WISE user to select and tune the configuration parameters according to his/her problem domain.

4. Conclusion

Our aim was to develop an interdisciplinary, intelligent and flexible decision support system addressing the highly complex problem of the remediation of water resources in developing countries. The choice of a water remediation strategy is a difficult decision in a realm of uncertainty. In recent years a large amount of work has been ongoing to develop methods to assist in such decision making. Most of this work concentrated on optimizing a specific technology choice for a single remedial problem. However, there has been little work looking at the choice between different technologies, especially considering various conflicting criteria and stakeholedrs points of views in an optimization context. That in part has been due to the computational burden associated with such problem solving. The work here is a preliminary investigation into the above problem: optimization between remediation options, considering multiple criteria and differen stakeholders needs and preferences. Reliability, cost, social acceptance, clean-up time, etc. are the factors in the objective function used in a multicriteria optimization.

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