International Congress on Environmental Modelling and Software

2nd International Congress on Environmental Modelling and Software - Osnabrück, Germany - June 2004

Jul 1st, 12:00 AM

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Abstract: During the preliminary stages of many engineering design tasks, the underlying search space is unbounded and inexact. Initial decisions are made when information is incomplete and many goals are contradictory. This sort of problem appeared in Catalonia for the identification of appropriate wastewater treatment systems in small communities, as well as for proposing appropriate operational and maintenance protocols to these facilities. In this case, the Catalan Water Agency proposed to develop two Environmental Decision Support Systems (EDSS), one to support the selection of the optimal treatment (EDSS-treatment) and another one to support the definition of appropriated operational and maintenance guides (EDSS-maintenance). This paper presents a methodology for supporting the automatic generation of protocols for small wastewater treatment plants operation and maintenance (EDD-maintenance) based on the reuse of available knowledge, acquired during the development an implementation of the EDSS-treatment.

***Keywords*:** Environmental Decision Support Systems; Knowledge Management; Operation; Reuse of knowledge; Wastewater Treatment

1. INTRODUCTION

The decision analysis field has often encountered difficulties in transforming theoretical ideas into practical decision support tools. However, the decision support systems developed in the laboratory have also been widely and successfully used in real life environmental problem solving, such as in the improvement of biological wastewater treatment plants operation [Genovesi *et al.*, 2000; Rodríguez-Roda *et al.*, 2002]. Nowadays, significant progress has been made in the Environmental Decision Support System (EDSS) development and application.

Wastewater treatment plants are one of the *hidden* necessities of life in populated areas. Thus, the European Water Directive 91/271/EEC specifies that Member States, by 31 December 2005, shall ensure that urban wastewater entering collecting systems shall, before discharge, be subject to a:

- Secondary treatment or equivalent treatment, if agglomerations have more than 2000 IE (Inhabitant Equivalents).
- Appropriate treatment if agglomerations have less than 2000 IE.

Appropriate treatment means treatment of urban wastewater by a process and/or disposal system which after discharge allows the receiving waters to meet the relevant quality objectives and the relevant provisions of this and other Community Directives. Consequently, the identification of the appropriate wastewater treatment demands the integration of different type of data (community, landscape, receiving environment and available treatment technologies) [Comas *et al.*, 2003].

In Catalonia (North-East of Spain) there are almost 3500 communities with less than 2000 IE. To deal with the complexity of defining the appropriate treatment for each community, the Catalan Water Agency (ACA, *Agència Catalana de l'Aigua*) developed an EDSS to support the selection of the optimal treatment (EDSS-treatment) [Comas *et al.*, 2003]. As a result of the EDSS-treatment application, the number of Small WasteWater Treatment Plants (sWWTPs) is expected to increase up to 1400 facilities.

In order to achieve the European Water Directive objective, the correct operation of these new sWWTPs must be assured. Thus, the Catalan Water Agency has proposed defining operation and maintenance protocols, which include preventive actions, corrective actions and a monitoring program. Experience shows that the operation and maintenance activities and the frequencies of these actions and measures differ from one sWWTP to another, even if the treatment technology is the same. This presents another complex problem and the Catalan Water Agency has proposed developing an EDSS (EDSS-maintenance) which supports the definition of guidelines for monitoring and maintenance, depending on the characteristics of each sWWTP.

At this point the question is: Once an EDSS is built and has acquired knowledge about a complex environmental process, how to reuse the methodology and how to share that knowledge with other systems?

The following paper presents an example of reutilization of knowledge and *know-how* gained during the development of an EDSS. Specifically, it presents the reuse of the knowledge and the methodology followed to develop the EDSS-treatment in the construction of the EDSS-maintenance.

2. METHODOLOGY TO DEVELOP AN EDSS

The methodology followed to develop the EDSS-treatment is proposed by Poch *et al.* [2003] in a previous paper. This methodology involves the following five steps (Figure 1): (i) problem analysis, (ii) collecting data and knowledge acquisition, (iii) model selection, (iv) model implementation and (v) validation.

2.1 Problem Analysis

How a particular EDSS is constructed will vary depending on the type of environmental problem and the type of information and knowledge that can be acquired [Cortés *et al.*, 2000]. Thus, the first step in the EDSS development must include the environmental problem definition and a review of available information and knowledge related to this problem.

2.2 Collecting Data and Knowledge Acquisition

Once the environmental problem analysis is finished, data collection and knowledge acquisition begin. This stage involves electing, analysing and interpreting data and knowledge that allow proposing a problem solution.

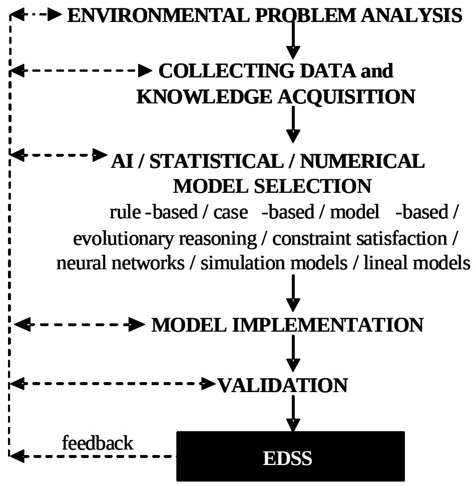

Figure 1. Flow diagram for the development of an EDSS [modified from Poch *et al.,* 2003].

2.2.1 Data collection and knowledge acquisition

In order to build reliable knowledge-bases, the methodology proposes the use of different sources of knowledge like interviews with experts, reviews of scientific and technical literature, historical data, etc. Thus, empirical, theoretical and historical information and knowledge is included in the knowledge-base. In the same way, the consultation of different sources facilitate the integration of the plurality of views and perspectives, as well as the goals, of each discipline involved in the environmental problem solution.

2.2.2 Data and cognitive analysis

Data collected and knowledge acquired from various sources are analysed. Different analytical techniques can be used: statistical analysis, data mining or machine learning, etc. The results of these analyses allow to build models of the processes or to identify relevant data and knowledge [Torasso and Portinale, 1997; Hernandez and Serrano, 2001 and Cortés *et al.*, 2003].

2.3 Model Selection

After the analysis of the available information and knowledge, a set of tools can be selected (Figure 1). This applies not only to numerical models, but also Artificial Intelligence (AI) methodologies, such as knowledge management tools. The use of AI tools and models provides direct access to expertise, and their flexibility makes them capable of supporting learning and decision making processes [Cortés *et al.*, 2000]. Expert systems (ES) is one of the sub-disciplines of AI that is used and applied more than any other AI technology [Turban *et al.*, 2001]. An ES is based on expert knowledge translated into rules, and these into terms that a computer can understand. ES are usually used when the expert knowledge is general. When this knowledge is more specific, case-based systems (CBS) become more used. CBS reuses some results and experience from previous particular situations that have affected the process performance [Kolodner, 1993]. Besides these AI models, other models can be used: neural networks, constraint satisfaction, lineal models, genetic algorithms, etc.

2.4 Model Implementation

The model implementation step entails the representation of the information and knowledge acquired, according to the selected model. This information and knowledge can be represented in decision trees, matrices, mathematical equations (algebraic or differential), etc. In some cases, like in neural networks, the representation needs to include the definition of the input and output layers as well as the type of function.

2.5 Validation

The main objective of the validation process is to guarantee the correct performance of the EDSS, while checking for compliance with user requirement specifications. The methodology to validate the system must be carried out through a two-stage validation procedure: laboratory testing and field testing [Rodríguez-Roda *et al.*, 2002].

2.6 Methodology Applications

The presented methodology has been successfully applied in the development of two EDSS which solve environmental problems related to wastewater treatment plants, but with different degree of complexity. The first EDSS corresponds to the supervision of a WasteWater Treatment Plant (WWTP). In this EDSS quantitative (obtained on-line and off-line) and qualitative information is used, there is an important participation of experts and there are no conflicts of interest: the aim is to improve the WWTP performance. This EDSS was constructed using rule-based and case-based systems. The second one (so called EDSS-treatment) supports the selection of wastewater treatment and disposal in Catalonia. In this case, GIS (Geographical Information Systems) and expert experience components become more important to support the appropriate wastewater treatment decision making. Unlike in the first EDSS, the EDSS-treatment presents conflicts between experts and the interactions between social and bio-geophysical phenomena become relevant [Poch *et al.*, 2003]. The EDSS-treatment was initially constructed using rule-based system.

3. EDSS-MAINTENANCE

As it has been pointed out in the introduction, a proposal was made to construct the EDSS-maintenance by re-using the knowledge and *know-how* gained during the development of the EDSS-treatment. Therefore, the first step in the construction of the EDSS-maintenance was the problem analysis stage, which includes two phases: (i) problem description and (ii) problem solution necessities.

3.1 Problem Description

In Catalonia, the number of sWWTPs is expected to increase up to 1400 facilities before 2006. Appropriate treatment of each plant was defined using the EDSS-treatment which was developed following the methodology proposed by Poch *et al.* [2003]. The EDSS-treatment proposes the most appropriate technologies taking into account the community characteristics, the receiving environment properties and the features of the 13 possible treatment units. It therefore represents the integration of different kinds of expertise and, in consequence, the plurality of views and perspectives, as well as the goals, of each discipline.

Figure 2 presents a scheme of the current situation. From the community, receiving environment and sWWTP treatment units' characteristics, EDSS-treatment has proposed a list of feasible sWWTPs. Once one of the proposed alternatives is accepted, the design step begins, followed by the construction of the sWWTP and finally the operation of the facilities.

As mentioned in the introduction, to guarantee the performance of each sWWTP, operation and maintenance procedures must be defined. Keep in mind that these protocols differ between plants, and with the expected increase of sWWTPs, the definition and up-date of these guidelines represents a new complex problem.

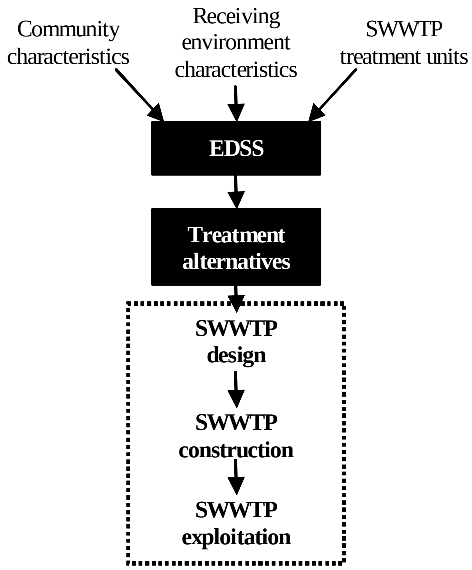

Figure 2. Scheme of the current situation.

3.2 Problem Solution Necessities

To define the necessary *elements* for the development of the EDSS-maintenance it was necessary to answer two questions: (1) which knowledge is needed to solve the problem? and (2) which knowledge and *know-how* from the EDSS-treatment can be reused?

3.2.1 Which knowledge is needed to solve the problem?

In order to answer the first question, a review of information related to sWWTPs operation and maintenance was done. After this revision, it was found that the following factors were involved in the variability among operation and maintenance protocols:

- sWWTP system: sequence of treatment units (i.e. Imhoff tank + constructed wetland; septic tank + rotating biological contactors; primary settler + intermittent sand filters; etc.)
- sWWTP design features: number of lagoons in a stabilization pond system, superficial or subsuperficial flow in a constructed wetland, number of section discs in a rotating biological contactor, etc.
- Climatic conditions: solar radiation, wind, temperature, precipitation, etc.
- Environmental conditions: available land for building sWWTP, average slope of this land, distances between the facility and the community, etc.
- Influent characteristics: number of IE, presence of industrial splits, seasonal population, etc.
- Receiving media properties: presence of natural ponds or aquifers, number of wells, sensitivity of the area, etc.

These variables were clustered into four groups:
1) Community characteristics (including climatic conditions, environmental conditions and influent characteristics)
2) Design features
3) sWWTP system or treatment units
4) Receiving environment characteristics

To describe an operation and maintenance procedure it is necessary to take into account all these factors. Variables included in the first three groups allowed the identification of causes that can unleash operational problems. From these causes, a set of preventive actions can be proposed. Once the operational problems are identified, monitoring programs can be described and corrective actions proposed by the system. From the list of operational problems and the receiving media characteristics, the effects on the environment once the problems occur, can be predicted. Figure 3 provides a schema in which we explain how from the factors is possible to define an operation and maintenance protocol.

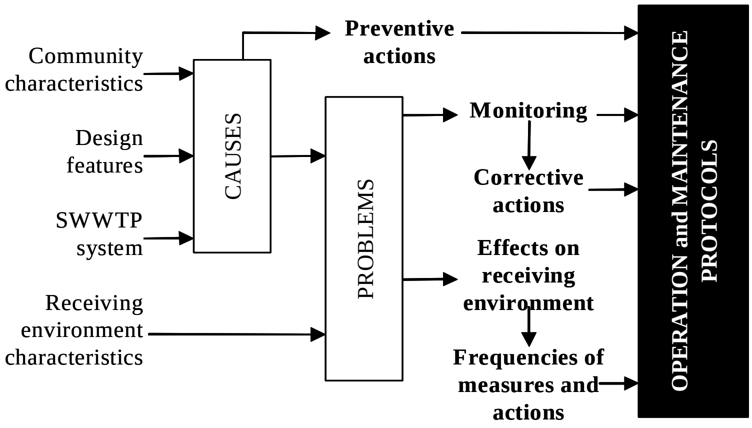

Figure 3. Proposed reasoning procedure to obtain operation and maintenance protocols.

Therefore, to solve the problem it was necessary to develop the following four knowledge-bases:

- Community characteristics
- Design features
- sWWTP system
- Receiving environment characteristics

3.2.2 Which knowledge and *know-how* from the EDSS-treatment can be reused?

The EDSS-maintenance requires the integration of different kind of knowledge for the definition of operation and maintenance protocols. As in the EDSS-treatment, the plurality of views and perspectives, as well as the goals, of each discipline must be considered together. In other words, the EDSS-treatment and the EDSS-maintenance try to solve environmental problems with similar complexity degree. Thus, the methodology used to construct the EDSS-treatment can be useful to build the EDSS-maintenance.

EDSS-maintenance will propose operation and maintenance protocols considering community characteristics, design features, sWWTP system and receiving environment characteristics (Figure 3). The comparison of the knowledge needed in both EDSS allows the possibility of reusing the three knowledge-bases built in the EDSS-treatment development. It is necessary note that the receiving environment and sWWTP treatment units' knowledge-bases must be completed and up-dated. The first one with information and knowledge that allow define measures and action frequencies. The second one, the sWWTP treatment units, must be completed with information and knowledge related with operational problems associated to each sWWTP treatment unit.

3.2.3 Real problem solution necessities

For the EDSS-maintenance building we can reuse the methodology followed in the EDSS-treatment development, as well as the knowledge acquired and structured in the three previously mentioned knowledge-bases. Two of these knowledge-bases must be completed with knowledge that allows defining problems and monitoring programs. Besides, EDSS-maintenance construction requires another knowledge-base to define design features. Figure 4 illustrates the knowledge needed to solve the environmental problem and presents how we can reuse the EDSS-treatment in the development of the EDSS-maintenance. Figure 4 allows somebody to see that operation and maintenance protocols can be obtained once the sWWTP system is defined and the design step finished.

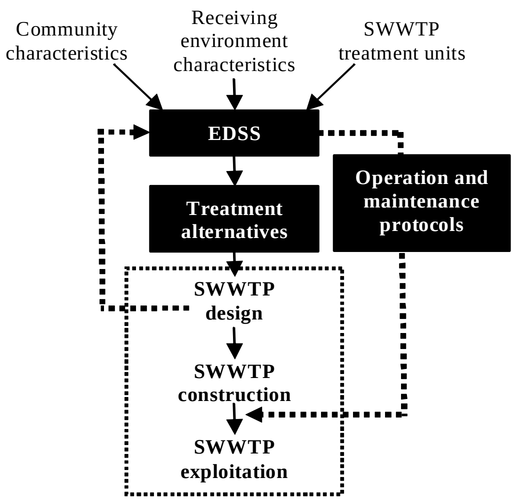

Figure 4. Scheme with the modification proposed for the EDSS-treatment to obtain the EDSS-maintenance.

4. CONCLUSIONS

EDSS allow the integration of several sources of data and knowledge, as well as the process of all this information in an objective, realistic and useful way. EDSS construction represents a use of resources (human and economic) and time. In this sense, sharing and reusing the knowledge and *know-how* acquired in an EDSS development can be a way to reduce the consumption of resources and time in the construction of another EDSS.

The proposed methodology to reuse the knowledge has the aim to define the problem, to know its complexity degree and the knowledge required to solve it. Thus this methodology involves two steps: (1) problem description and (2) problem solution necessities. The first step involves the definition of the problem and the identification of possible EDSS that can be reused. The second step involves the definition of the *elements* needed to solve the environmental problem. Results from both steps allow studying the possible reutilization.

Future research in this area should pay attention to understand how to handle exceptions and impasses in environmental processes where the infrastructure is not robust by definition as is the case in sWWTP treatment units.

5. ACKNOWLEDGEMENTS

This research has been supported by the Catalan Water Agency of the Government of Catalonia through the project "*Sistema de suport a la decisió per l'establiment de protocols d'explotació a les depuradores del PSARU 2002*".

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