A SOFTWARE TOOL FOR THE ECONOMIC OPTIMISATION OF
WASTEWATER TREATMENT PLANT DESIGN AND OPERATION USING SIMULATION

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ABSTRACT

This paper presents MoSS-CC (Model-based Simulation System for Cost Calculation in wastewater treatment plants), a software tool to optimise wastewater treatment plant design and operation by means of simulation and cost analysis. The scenario analysis procedure is encoded in the software as a VPL (Virtual Product Life-cycle). Roughly, the scenario consists of two phases: the design phase and the dynamic analysis phase. Cost functions are used to determine investment costs as well as operating costs. A case study illustrates the procedure.

KEYWORDS

design; dynamic modelling; economic analysis; operation; optimisation; simulation software.

INTRODUCTION

In the design phase of a new wastewater treatment plant (WWTP) or when upgrading an existing one, a complete scenario evaluation including economic analysis is usually too time-consuming to consider different possible alternatives. Computer-aided systems have been developed to design cost-effective WWTPs (McGhee et al., 1983; Spearing, 1987; Gasso et al., 1992); however they suffer from two major drawbacks:

1. the cost indices used are often restrictive: only investment or specific operating costs are considered;
2. the time-varying characteristics of the wastewater are not taken into account directly but rather through the application of large safety factors. This conservative approach entails an often significant though not necessary increase in the costs. Moreover, the use of adequate operating strategies such as real-time control is rarely investigated, despite the economical benefits that may be achieved (Vanrolleghem et al., 1996; Ekster, 1998).

An automated procedure, which aggregates investment and time-varying operating costs, would thus be useful to evaluate different treatment alternatives and operating strategies.

This paper describes MoSS-CC (Model-based Simulation System for Cost Calculation in wastewater treatment plants), a software developed for this purpose. The principle of scenario analysis using this tool is presented, as well as the software features. An example of optimising an industrial treatment plant design is used to illustrate the procedure.
MoSS-CC FEATURES

Principle of scenario analysis implemented in MoSS-CC

To optimise a new plant or the expansion of an existing one, the evaluation of the different possible alternatives should integrate the following aspects:
1. Integration of the plant design procedure and the simulation of the plant’s dynamic behaviour.
2. Extension of the steady state (design) models as well as of the dynamic models with cost functions. Practically, cost functions are developed to assess the economic impact of the different choices. Investment costs as well as operating costs -fixed or variable- are quantified as a function of the process size or variable (e.g. volume, area, flow rate) (Tyteca, 1977; Wright and Woods, 1993 - 1994, Fels et al., 1997). The total cost of the plant (cost index) is determined by the present worth method (White et al., 1989).
3. Keeping track of any choices made in the process train design or during simulation. In the course of an economic study, it must be possible to go back to any previously made choice, in order to investigate different alternatives, starting from any point in the decision process.

MoSS-CC characteristics

In Figure 1, the procedure underlying MoSS-CC and its software implementation are depicted.

The procedure is named the Virtual Product Life-cycle (VPL) (Vangheluwe et al., 1994) as it describes (and partially prescribes) the evolution of the system-to-be-designed ("virtual", as all experiments are conducted through simulation). It consists of two major phases:
1. the design phase, during which structural decisions are made (i.e., the different process units are chosen). Mostly, given an average input and desired output for the system to be built, steady-state models are used to determine structural parameters (such as volume, surface of the tanks,...).
2. the dynamic analysis phase, where behavioural choices are made (optimal parameter choice, controller tuning, ...).
The rationale behind MoSS-CC is that at each phase in the process, system and cost models are linked. In the first phase (design), only investment costs are considered. In the second phase (dynamic analysis), operating costs are added. When comparing the overall cost of different alternatives (obtained after dynamic analysis), it may be necessary to revise structural decisions made in the first phase. 

At the core of MoSS-CC is the realisation that both system behaviour and cost are explicitly represented in the form of models which are subsequently used for simulation. The cycle in both phases, design and operation (see Figure 1), denotes an iterative process for which simulation support is given by the WEST++ interactive environment developed at the BIOMATH department (Vangheluwe et al., 1998).

The process iterates over:
1. interactively building a model by connecting basic building blocks representing the WWTP’s units ("AND" choice);
2. answering questions about the model thus obtained through experimentation (simulation, model calibration, optimisation);
3. either the process stops here or further refinement is needed. In case of refinement, the model, augmented with the results of the experimentation, allows one to choose from a number of alternatives for each of the sub-models ("OR" choice).

In the design phase, a choice has to be made between alternative structural choices. In the dynamic analysis phase, one chooses typically from different levels of process detail (e.g., IAWQ ASM1 or ASM2, point settler or Takacs model). A System Entity Structure (SES) (Zeigler, 1984), a tree-shaped knowledge structure in which AND and OR alternatives are listed, provides the choice space for the user. In essence, the SES encodes design and modelling knowledge. In MoSS-CC, the rules of Biotim have been implemented as design models and the WEST++ modelbase is used for dynamic simulation. Finally, in the VPL tree, the MoSS-CC environment keeps track of all choices made during the evolution of the process described above. This allows the user, by means of a VPL browser, to trace back to any previous choice and to try other alternatives. Thus, arbitrary feedback is added to the process and scenario analysis, whereby it becomes possible to compare consequences (A1, A2, A3 in Figure 1) of different choices made during the process.

EXAMPLE

In the design phase of an industrial WWTP receiving an influent flow rate of 1400 m³/d with a COD of 2000 g/m³ (five days a week), the addition of an equalisation tank to the conventional activated sludge process has been proposed to reduce load variations occurring during week ends. Table 1 depicts the plant design parameters for the two scenarios considered:
1. conventional activated sludge process with a control of the oxygen transfer efficiency (PI controller) to keep the oxygen concentration near a value of 2 mg/L;
2. equalisation tank followed by a conventional activated sludge process.

In scenario 1, the variable aeration costs have been assessed through dynamic simulation and a Biotim cost function. The evolution of the oxygen transfer coefficient and of the cumulative aeration and operating cost are shown as a function of time in Figure 2. Cost values are divided by the total operating cost over the simulation time to give normalised costs.
When only considering investment costs, the two scenarios give similar results (see Table 1). Without dynamic simulation, the first alternative would have been chosen, as the easiest one to operate. Simulation results show that the operating costs - including variable aeration costs - and the net present values are only slightly more important in scenario 2 (5 % and 4 %, respectively). An objective decision could thus be made on the basis of considerations other than economics, as it has been shown that the two alternatives will have a similar total cost over the life span of the plant.

CONCLUSION

The above has introduced the concept of software supported “total” cost analysis. The procedure used as well as the MoSS-CC software tool were briefly presented. The integration of operating costs in the overall assessment of scenarios allows refinement of cost analyses and the impact on cost of real time control can thus be quantified. Current efforts aim at implementing the investment and (variable) operating costs directly in the software tool. Further research will also introduce non-monetary optimisation objectives, such as plant flexibility or the risk of failure, in the performance index.

REFERENCES


