Evaluation of case-based design principles and the decision tree selection process in the design of Soche wastewater treatment plant, Blantyre, Malawi

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ABSTRACT
This paper evaluates case-based design principles and the decision tree selection process in the design of Soche wastewater treatment works (WWTW) in the city of Blantyre, Malawi. According to the Case Study Manager in the ED-WAVE tool, a similar case to both dry season and wet season conditions of Soche plant is Municipal Case 6 in Greece. The raw material at Municipal Case 6 in Greece is raw municipal sewage. The typical wastewater parameters are BOD_5, COD and TSS. The treatment target is BOD_5, COD and TSS reduction. A decision tree selection process for aerobic biological treatment also matched the treatment processes at Soche WWTW where the raw material is raw municipal sewage and the treatment target is BOD_5, COD and TSS reduction. The study confirmed the complementarity of case-based design principles and the decision tree selection process in the design of wastewater treatment systems. After encountering a new situation, already collected decision scenarios (cases) are invoked and modified in order to arrive at a particular design alternative. The study also confirmed the practical use of the decision tree selection process in the design of wastewater treatment systems. What is necessary, however, is to appropriately modify the case arrived at through the Case Study Manager and the system gotten from the decision tree selection process in order to come up with a design appropriate to the local situation taking into account technical, socio-economic and environmental aspects.

Keywords: case-based design, Case Study Manager, decision tree selection process, ED-WAVE tool, wastewater treatment

1.0 INTRODUCTION

The design of efficient wastewater treatment systems is a complicated task which requires significant engineering experience as well as deep theoretical knowledge by the designers. Usually the task facing engineers is two fold: (1) to determine the levels of treatment that must be achieved and (2) to determine a sequence of methods that can be used to remove or to modify the components found in the wastewater in order to reduce the environmental impact and to meet ecological requirements. Therefore, an information reference system accumulating knowledge in the field of wastewater treatment and water reuse in an easily accessible way would be of great interest to the engineers. This is accomplished in the case-based design principles contained in the ED-WAVE tool (Balakrishnana et al., 2007). This is an educational tool for training on technologies for efficient water reuse using virtual application sites.

1.1 Decision support methods

Decision support techniques are rational processes/synthetic procedures for applying critical thinking to information, data, and experience in order to make a balanced decision when the choice between alternatives is unclear. They provide organised ways of applying critical thinking skills developed around accumulating answers to questions about the problem. Steps include clarifying purpose, evaluating alternatives, assessing risks and benefits, and making a decision.

Depending on the type of information used and way of achieving result (decision-making), the design supporting methods can be distinguished on three major approaches: algorithmic, knowledge-based inductive reasoning, and case-based reasoning (Negnevitsky, 2002; Avramenko and Kraslawski, 2008).

1.2 Algorithmic approach

The algorithmic design approach views the design process as the execution of an effective domain-specific procedure that yields a satisfying design solution in a finite number of steps. The main premise of this approach is that the initial requirements are well defined and there are precisely defined criteria for determining whether or not an algorithm meets the requirements.

Algorithmic approach is the reasoning strategy which is guaranteed to find the solution to whatever the problem is, if there is such a solution (Negnevitsky, 2002; Avramenko and Kraslawski, 2008).

1.3 Knowledge-based inductive reasoning approach

This approach to decision support is based on capturing knowledge of a certain domain and using it to solve problems. The design is considered as a problem-solving process of searching through a state-space, from initial problem state to the goal state (Althoff, et al., 1995; Avramenko and Kraslawski, 2008).

1.4 Case-based reasoning approach

Case-based problem solving is based on the premise that a design problem solver makes use of experiences (cases) in dealing with resolving new problems instead of resolving every new problem from scratch (Kolonder, 1993). Coyne et al. (1990) classify the case-based approach into three activities: creation, modification, and adaptation. Creation is concerned with incorporating requirements to create a new prototype. Modification is concerned with developing a working design from a particular category of cases. Adaptation is concerned with extending the boundaries of the class of the cases.

Case-based reasoning (CBR) solves new problems by adapting previously successful solutions to similar problems. A CBR approach can handle incomplete data: it is robust with respect to unknown values because it does not generalize the data. Instead, the approach supports decision making relying on particular experience (Avramenko & Kraslawski, 2008).

1.5 Treatment Adviser and Decision Tree making process

The Treatment Adviser in the ED-WAVE tool generates a simple sequence of treatment technologies for given water characteristics. It analyses the influent water characteristics and supplemented information of other factors (economical, technical or ecological) to select a suitable treatment technology; alternatively the user can use the Process Builder to construct a valid treatment sequence (Balakrishnan, et al., 2005). This is based on the algorithm of selection of the proper wastewater treatment method based on previously constructed rules represented as a decision tree.

A decision tree (or tree diagram) is a map of the reasoning process (Negnevitsky, 2002). The tree is a graph or model of decisions and their possible consequences. It includes chance event outcomes, resource costs, and utility. It is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences www.mindtools.com/dectree.html (16.7.2009). A decision tree provides a highly effective structure within which to explore options, and investigate the possible outcomes of changing those options. The results of outcomes are retrieved from expert opinion and experience.

2.0 METHODOLOGY

2.1 Study site

The case studied in this paper was the Soche WWTW located at the south-western end of Blantyre city. Soche works serves a physical catchment area of some 24km^2 comprising the south-west residential area of the city, including Queen Elizabeth Central Hospital (QECH). 30% of the influent to the works is from the light industrial areas of Ginnery Corner and Maselema. The average dry weather flow rate for the plant is 5,573 m^3/day. The works is a principal tanker reception centre for latrine and septic tank faecal sludge. On average, about six tankers are received per day, totaling approximately 36 m^3/day.

The influent at Soche WWTW is municipal sewage. The typical wastewater parameters monitored at the plant are Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). The treatment target is BOD_5, COD and TSS reduction. A reduction of BOD_5 to below 20 mg/l, COD to below 60 mg/l and TSS to below 30 mg/l is not achieved as required by the regulatory standards.

2.2 Data collection and analysis

Physicochemical data was collected through a desk study which was based on the work by Kuyeli, (2007). Sampling of physicochemical parameters was done between the months of October to November, 2005 for the dry season, and February, 2006 for the wet season using the grab sampling method. Samples were collected using one-liter plastic bottles that had been cleaned by soaking in 10% nitric acid, and rinsed several times with distilled water. Three one-liter samples were collected at each point. BOD_5 was determined by the Winkler method of oxygen measurement in the samples before and after incubating for five days at 20^{0}C (APHA, 1985). TSS were determined by filtering the samples through pre-weighed glass fibre filters as described in APHA (1985). COD was determined according to the method illustrated by Kuyeli (2007).

A mean concentration was calculated along with a standard deviation on the results obtained for three samples collected from each point.

2.3 Case-based design

Case-based design (CBD) is one of the commonly used mechanisms of approximate reasoning in intelligent systems and decision support systems. These mechanisms offer a powerful and general environment in which is generalized a basis of already accumulated experience being represented in the form of a finite and relatively small collection of cases. Those cases constitute the essence of the existing domain knowledge. When encountering a new situation, already collected decision scenarios (cases) are invoked and eventually modified to arrive at a particular design alternative. Case storage is an important aspect in designing efficient CBD systems. Case storage should reflect the conceptual view of what is represented in the case and take into account the indices that characterise the case. The case-base should be organised into a manageable structure that supports the efficient search and retrieval methods. This is accomplished in the ED-WAVE tool (Avramenko & Kraslawski, 2008).

2.4 Decision tree selection process

According to Singhrunnusorn and Stenstrom (2009), there are seven elements that are critical for the technical selection of a wastewater treatment system in developing countries. These are reliability, simplicity, efficiency, land requirement, affordability, social acceptability and sustainability. These elements integrate social, economic, and environmental concerns necessary to be addressed in evaluating appropriate system alternatives. These are some of the values that have to be questioned in the decision tree making process.

According to results of a survey conducted in Thailand by Singhrunnusorn and Stenstrom (2009), reliability, affordability and efficiency are amongst the most important elements, followed by sustainability and social acceptability. Land requirement and simplicity are low in priority with relatively inferior weighting. A decision tree would be constructed after an analysis of the above factors.

3.0 RESULTS

3.1 Comparative sequencing of treatment units

According to the Case Study Manager in the ED-WAVE tool, a similar case to both the dry season and wet season conditions of Soche WWTW has similarities to Municipal Case 6 in Greece (2003), with a flow rate of 6,600 m^3/day. The treatment sequence for this plant and the comparative sequencing of the treatment units at the Soche plant, dry and wet season, and the actual sequencing of treatment units at Soche works are illustrated in Table 1.

Table 1: Comparative sequencing of treatment units for Municipal Case 6 and Soche WWTW

Plant/ Step No.	Municipal Case 6, Greece	Suggested sequencing of dry season conditions by Treatment Adviser	Suggested sequencing of wet season conditions by Treatment Adviser	Actual sequencing for Soche plant
1	Screening	Grit chamber	Neutralisation	Screening
2	Grit chamber	Neutralisation	Chemical precipitation	Grit channels
3	Oxidation ditch	Chemical precipitation	Activated sludge	Primary sedimentation
4	Sedimentation	Activated sludge process	Activated carbon adsorption	Trickling filters
5	Chlorination	Activated carbon adsorption	Ion exchange	Humus tanks
6	-	Ion exchange	-	Sand filters (disused)

3.2 Decision tree making process

A decision tree (or tree diagram) is a map of the reasoning process (Negnevitsky, 2002). The tree is a graph or model of decisions and their possible consequences. It includes chance event outcomes, resource costs, and utility. It is a decision support tool that uses a tree-like graph or model of decisions and their possible consequences www.mindtools.com/dectree.html (16.7.2009). A decision tree provides a highly effective structure within which to explore options, and investigate the possible outcomes of changing those options. The results of outcomes are retrieved from expert opinion and experience. The process of selection of a treatment method from a decision tree is illustrated in Figures 1 and 2 where parts of a decision tree for selection of primary treatment and aerobic treatment type, respectively, is presented. In the tree diagram, each treatment level or option is considered, and after successfully passing all decision trees, the final treatment sequence is considered. Other examples of wastewater treatment plants determined in this manner in Blantyre, Malawi, are illustrated in Figure 2.

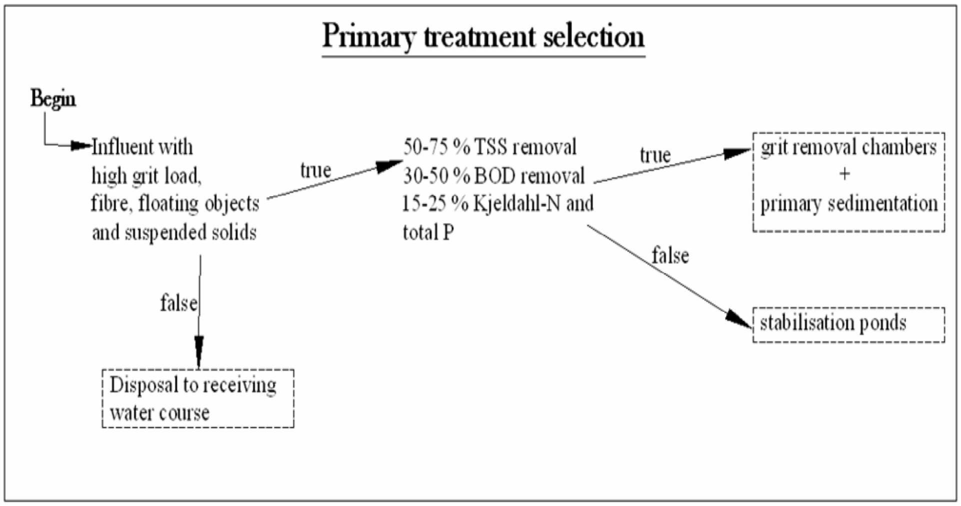

Figure 1: Decision tree for primary treatment selection; Source: Chipofya (in press)

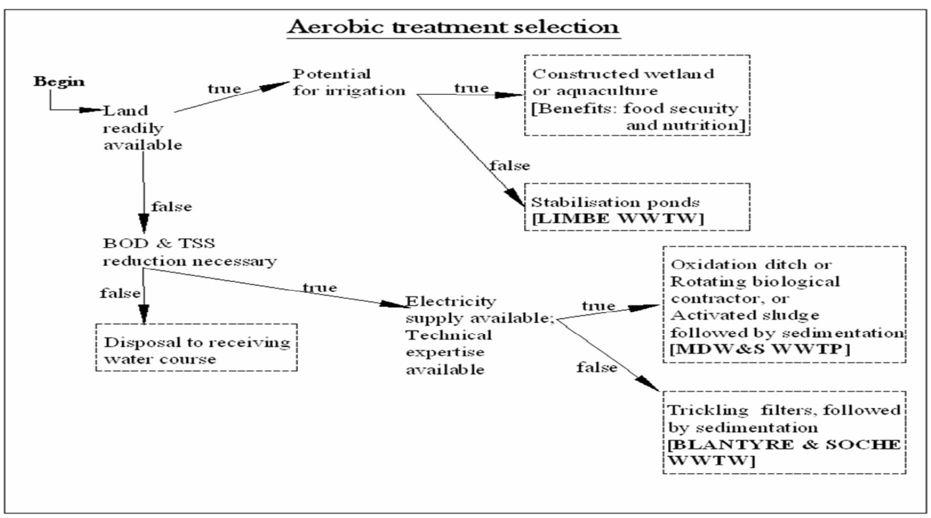

Figure 2: Decision tree for selection of types of aerobic biological treatment at Soche WWTW; Source: Chipofya (in press)

4.0 DISCUSSION

The plant under review uses physical, biological, and chemical processes as outlined by Banda (2007) to reduce the concentration of pollutants in the wastewater. Screening is only included at Municipal Case 6 in Greece and in the actual sequencing for Soche plant. Grit removal is incorporated at Municipal Case 6 in Greece, the suggested sequencing of dry season conditions at Soche and the actual set up at Soche.

Grit removal is necessary for the removal of inorganic grit which may cause abrasion of comminutors and impellers of sludge pumps. The grit may also set hard in sludge hoppers, transmission pipes and in the bottom of digesters. This may call for more frequent maintenance than normal (Barnes, 1981).

Municipal Case 6 and Soche WWTW both have a sedimentation process. This is necessary for the removal of readily settleable matter from the wastewater. Through this process, a BOD_5 reduction of 25-40%, and a TSS reduction of 50-70% is achieved (Barnes, 1981; Metcalf & Eddy, 2004).

Finally, both plants under review have an aerobic biological treatment stage. This is necessary to ensure that a substantial quantity of organic matter in liquid state is oxidized prior to the effluent being discharged into public water courses where it would otherwise exert an oxygen demand (Barnes, 1981). However, Municipal Case 6 uses oxidation ditches while Soche WWTW uses trickling filters. Trickling filters are a preferred technology for Malawi because they do not involve electrical/mechanical equipment. In addition trickling filters require little maintenance.

In the decision tree making process (Figure 2), each treatment level is considered, and after successfully passing all decision trees, the final treatment sequence is considered. A decision tree provides a highly effective structure within which to explore options, and investigate the possible outcomes of changing those options. The results of outcomes are retrieved from expert opinion and experience.

5.0 CONCLUSION

The study confirmed the complementarity of case-based design principles and the decision tree selection process in the design of wastewater treatment systems. After encountering a new situation, already collected decision scenarios (cases) are invoked and modified in order to arrive at a particular design alternative. The study also confirmed the practical use of the decision tree selection process in the design of wastewater treatment systems. What is necessary, however, is to appropriately modify the case arrived at through the Case Study Manager and the system gotten from the decision tree selection process in order to come up with a design appropriate to the local situation taking into account technical, socio-economic and environmental aspects (Singhrunnosorn and Stenstorm, 2009).

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