WORKSTATION ENVIRONMENT FOR WASTEWATER TREATMENT DESIGN USING AI AND MATHEMATICAL MODELS

by

Jehng-Jung Kao
John T. Pfeffer
E. Downey Brill, Jr.
James J. Geselbracht

Department of Civil Engineering
University of Illinois at Urbana-Champaign

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University of Illinois
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ABSTRACT

This research explores the use of computer-based environments to facilitate environmental engineering decision making. A prototype system is developed for wastewater treatment plant design as an exploration tool to demonstrate the techniques and principles proposed. Several mathematical techniques, interactive graphic displays, and friendly user interfaces are used. The mathematical techniques are: (1) mass and water balances for an analysis program for wastewater treatment plant design, (2) a rule-based system for sludge bulking judgment, and (3) a standard processor for checking a design against existing design standards. The interactive graphic displays provide visual data for effective data manipulation, and the friendly user interfaces are designed for engineers who are not necessarily computer experts.

by Jehng-Jung Kao, John T. Pfeffer, E. Downey Brill, Jr., and James J. Geselbracht

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Keywords: Wastewater Treatment Plant Design, Computer Aided Design, Decision Making
CHAPTER 1
INTRODUCTION

In analyzing environmental engineering decision making problems, such as the wastewater treatment plant design (WTPD) problems described herein, cost is not the only important issue, and other modeled as well as unmodeled issues must usually be considered, e.g. uncertainty, reliability, equity, etc. Since such problems are complex, exact mathematical methods to solve them are not available. Furthermore, presentation of models or alternatives is usually difficult, and the computer interfaces needed to modify or rebuild a model are cumbersome. This research explores approaches for dealing with these issues by means of a prototype computer aided system using several mathematical techniques, graphic displays, and a user–friendly interface to deal with these issues for the WTPD problems.

The base WTPD model and analysis program adopted in this research were modified from those developed by Tang et al. [1987]. The base model is for a complete secondary wastewater treatment plant, including sludge processing and disposal. In addition to individual unit process performance, the model considers the interactions among various unit processes.

Figure 1.1 provides a typical process flow sheet showing the individual unit process and various connecting flows. Several important unit processes can be included in the model, such as primary clarification, activated sludge with final clarification, gravity thickening of mixed primary and waste activated sludge, primary and secondary anaerobic digestion, vacuum filtration, and final sludge disposal via a sanitary landfill. Since a plant scheme can be dynamically changed based on design needs, the designed combination of unit processes may be different from the one shown in Figure 1.1.

The prototype computer aided system is being developed for the design of wastewater treatment plants. Such a system should contain the tools for analysis and preliminary design of environmental engineering processing plants. The concept of “design” implies selection of process chain, determination of mass and water, and facility cost estimation. One procedure for designing a wastewater treatment plant involves establishing influent and effluent conditions, selecting unit processes for an appropriate treatment train, applying appropriate performance models for unit processes selected, setting up a mathematical model, solving the mathematical model to find a feasible design, estimating the total cost, generating and comparing alternatives, and checking the design against standards. Such a procedure is complex, time-consuming, and sometimes tedious. The computer aided system presented in this research is intended to facilitate the procedure by eliminating the burden on a designer for formulating a model, solving the model, generating alternatives, etc. Moreover, the computer aided system increases the power of the traditional trial–and–error procedure. A trial–and–error procedure is usually tedious if each trial takes a long time to set up and finish. However, the trial–and–error procedure would be powerful if only pressing several buttons were needed to finish a trial with the results presented immediately to the designer. The computer aided system provides almost real–time responses to the designer; this advantage lets the designer easily generate alternatives, compare alternatives under different design conditions, and significantly shorten the time required to analyze the design of a wastewater treatment plant.

Several techniques were used to develop the computer aided system. The techniques include mass and water balances, a rule–based technique, an interactive
graphical display, and a user interface. For data manipulations, it is better to provide graphical displays. Additionally, graphic displays usually can be used to provide a comfortable interface. Interactive graphical displays with a pointing device, a computer mouse, was used for this research. The designs of the user interface of the current prototypes are based on experience in developing software for engineers who are not necessarily computer experts.

By combining the mathematical techniques and using the developed user-friendly graphical interfaces, a prototype computer aided system has been developed for wastewater treatment plant design. The prototype has been implemented on the Apollo workstations. Although the discussions above and in Chapters 3 to 5 focus on the design of a computer aided system for WTPD, the issues raised in developing the system also apply to many other engineering models.

1.1. Report Outline

Chapter 2 reviews literature from a variety of disciplines on issues and techniques for developing computer aided systems. Chapter 3 discusses the characteristics of computer aided systems in general. Techniques and their contributions to decision making processes are described. Chapter 4 presents the mathematical techniques: mass and water balances, a rule-based technique, and a standard processor. Chapter 5 presents the prototype for WTPD. A discussion of design approaches and a demonstration of the prototype are detailed. Discussions and research conclusions are given in Chapter 6. Finally, the program structure of the computer aided system is provided in Appendix A.
CHAPTER 2
LITERATURE REVIEW

Decision making is an iterative process of examining, modifying, comparing, and selecting a preferred solution(s) among many feasible alternatives. This process is not a single step optimization analysis. Numerous attributes or criteria may be employed in evaluating the alternatives. The criteria, however, may be conflicting, and the best solution may not be obvious. To generate alternatives, to do analysis tasks, and to present the solution(s) to a decision maker may be difficult. Also, there may exist unmodeled issues or uncertainties, and thus a mathematically optimal solution(s) may not imply the best solution. There is no single method available to deal with these issues. However, by drawing on the literature on wastewater treatment plant design and computer aided systems, a variety of applications and results are discussed.

Wastewater Treatment Plants Design

Wastewater treatment plant design (WTPD) is an important environmental engineering decision making problem. Many unit processes and characteristics of chemical, physical, or biological reactions are not well understood. Usually, a designer must use his experiences and a trial and error procedure to deal with these uncertainties for developing a sound design.

Geselbracht et al. [1988] used a rule-based technique to develop an approximate reasoning model for sludge bulking judgment. Two sets of 15 plant designs evaluated by an experienced engineer were used in calibrating the model. The model is designed not only for evaluating the bulking potential of an existing design but also for incorporation directly into an optimization model to determine the increased cost of reducing the likelihood of bulking.

Since a WTPD model is highly nonlinear, mathematical difficulty generally exists. Although several models have been developed for optimizing an activated sludge plant (see Tang et al.[1987], Uber[1988], and Kao[1987]), the modification of the models for different plant schemes is difficult and sometimes the modified models can not be solved by currently available mathematical software. Tang [1984] formulated a comprehensive WTPD model. The model is used as a base design for the prototype computer aided system developed in this research. However, since a variety of plant configurations can be used, Tang's optimization model is not used in the prototype because of mathematical difficulty.

Computer Aided Systems

A decision-making process may consist of two stages: exploration of possible good alternatives by analyst(s), and then examination of those alternatives by decision maker(s). The two stages may be iterative since no compromise solution may be selected initially, and the analyst(s) may be required to explore more alternatives. For both stages, there is complexity in modeling, modifying, and presenting the problem, especially if an interactive decision-making process is necessary. To reduce the working complexity, several ideas for developing computer aided systems have been proposed and demonstrated in the literature.

Johnson and Loucks [1980] incorporated computer graphics in an interactive multiobjective decision-making process for water supply planning. The computer
graphics provided not only a rapid means of information transfer, but also an effective interface for better understanding and evaluation.

Sagie [1985] developed a computer aided modeling and planning system for general linear problems. Several languages were provided for data definition, model definition, picture definition, and text definition. A multilingual capacity was made available by translating a key word dictionary from English to other national languages. The system was controlled by command languages which require knowledge of computer programming and linear programming.


Cohen et al. [1987] presented the application of an intelligent workstation for electrocenter design. The enhancement of an engineer's productivity and improvement in the creative processes for engineering design were discussed.

Brill et al. [1989] implemented an experiment for evaluating modeling-to-generate-alternatives (MGA) approaches by using a design system for airline network. The system, called interactive design environment for airline systems (IDEAS), used features of a workstation environment to aid in the design of airline networks. A graphical tutorial was provided for subjects to learn the system in less than thirty minutes. IDEAS is a typical computer aided system developed, and several ideas used for the computer aided system described in this report are from the experience of developing IDEAS.

In view of the current literature in the field of environmental engineering there are few satisfactory computer aided systems for decision-making problems. Possible reasons are the complexity of a decision-making process and the difficulty of integrating decision support tools into a friendly working environment. Currently, tools and environments which exploit the high-resolution graphics capabilities of independent workstations are being developed. In this research the workstation environment is used to implement graphics and mathematical tools to reduce the working complexity encountered in a decision-making process.
CHAPTER 3
COMPUTER AIDED SYSTEMS

For a complex decision-making problem, such as the WTPD problems described, it is usually difficult to set up or modify a model, to generate potential alternatives, and to present the model or alternative solutions. This chapter first describes, in general, how to use computer aided systems to reduce the complexity of these tasks based on an assumed working process. The techniques used in developing two prototype computer aided systems are then discussed.

3.1. General Issues Related to Computer Aided Systems

Figure 3.1 shows a general process for decision making using mathematical models. Before a compromise solution is selected by a decision maker(s), the working process is expected to be implemented iteratively. This research has focused on six of the stages (A through F in Figure 3.1). Figure 3.2 shows where to incorporate new features of computer aided systems into the working process for decision making. Several techniques are discussed in Chapter 4: a solution procedure for developing the analysis program, a rule-based system for sludge bulking judgment, and a standard processor for checking a design against standards. The following sections provide general discussions of the contributions of the other two techniques, graphical displays and a user interface, to the process.

3.2. Graphic Interface

The purpose of the graphic displays designed in the prototype is mainly for visual presentation of data (stage E) and to provide an interface to a decision maker (stage F).

Attributes such as cost are usually important for a decision-making problem. The display of attributes, however, may be difficult. For example, the display of cost curves may be difficult because the curves are exponential and might cover a wide range of design parameter values. Although semi-log plots can be used to represent cost curves, to perceive the approximate value of cost from the plot is difficult. A semi-log curve gives only the shape of curve and does not provide much help for examining a cost region. In this research, the cost curves are presented in normal scale so that the approximate cost associated with a design parameter value can be easily seen (see Chapter 5). Similarly, the presentation of a problem configuration, such as a wastewater process scheme, and results, such as a set of numerical output data, also require appropriate presentations. The goal of using graphic displays for attributes, configurations, and results is to present them in a manageable manner for instant evaluations.

3.3. User Interface

The designs of the user interfaces of the current prototypes are intended to make data entry and function choices as simple as possible. It is assumed that the users would be engineers but not necessarily computer experts.

Characteristics

The user interface is a key component in a good computer aided system. An analyst, modeler, or designer may be reluctant to use a system that is
Figure 3.1. A Working Process For A Decision-making Problem
1. Identify problem(s) and collect data and issues

2. Build (or modify) model

3. User interface

4. User interface

5. Mathematical tool(s)

6. Obtain the mathematical solution

7. Mathematical tool(s)

8. User interface and Mathematical tool(s)

9. Generate alternatives

10. Graphic interface

11. Present alternatives to decision maker(s)

12. Graphic interface

13. Is the decision maker(s) confident for the compromise solution?

14. No

15. Yes

Implement the final solution

Figure 3.2. Incorporating New Features of Computer Aided Systems into the Working Process for Decision Making
computationally efficient but that has a poor user interface. Some characteristics of a good user interface are: (1) simplicity of learning; (2) minimal possibility of making mistakes; (3) flexibility in modification of models and data; (4) efficiency of data organization or solution management; and (5) clarity of instructive feedback (stage A & D).

Menu Selections

Requiring the user to type the number or letter of an entry directly in a list requires that the user is familiar with the keyboard layout and generally takes longer. A menu-driven interface with a pointing device (mouse) to make selections is developed. Such an interface is expected to require less learning time.

Modification

For an analyst to construct good alternatives for a complex problem, it is often desirable to use a variety of mathematical tools and to examine a significant amount of data. For obtaining a good solution, it is necessary to examine a significant number of alternatives and to choose appropriate issues to be modeled. How to select and model these issues is an important issue. The model may be frequently changed before a decision is made. Furthermore, several known but unmodeled attributes may be significant when alternative solutions are examined, and new attributes may be discovered during the analysis. Modification is a task which may occupy most of the time of an analyst or designer for building good alternatives or solutions. To simplify the modification process and to increase the productivity of an analyst or designer, several functions requiring no more than pressing a mouse button were developed to make this task as simple as possible.

Graphic Oriented Object In Exploratory Design

Another significant part of this research is to explore and compare several different ways to help the designer in doing exploratory design by using graphic oriented objects. In this research, several graphic objects are used to represent physical objects, e.g., unit processes. By manipulating these objects by simply moving a mouse and pushing a button, an analyst can easily explore a good design.

Feedback (checking, warning, and message)

An important component of a user-friendly system is an intelligent feedback system that can respond to all possible actions (valid or invalid) selected by a user. For example, if the user makes a valid action, then a message should appear to explain what has been accomplished or changed as a result of the action. If an invalid action is made, then a message should appear to explain why it is invalid and suggest one or several valid actions which might be appropriate substitutes. The responses need not be in text, but they should be unambiguous. In this research, a feedback system which includes error messages, warning messages, help messages, a beeper, valid action response messages, and graphical displays was developed. However, since the computer aided system is a prototype, some inappropriate feedbacks likely still exist in the system and will be identified only through additional testing and development of the system.
3.4. Summary

With the graphic display and user interface, the working complexities of presentation, modification, and working with software packages can be significantly reduced. By combining these techniques and mathematical techniques described in Chapter 4, a prototype interactive computer aided system was developed for the WTPD problems. The system is demonstrated in Chapter 5. The system not only provides an analyst or decision maker with information, but also provides good interfaces for analyzing and modifying a model. Although the developed system is a prototype and for a specific problem, it should illustrate concepts of developing computer aided systems and provide a way to identify and address some of the issues which are important for other engineering decision making problems.
CHAPTER 4
MATHEMATICAL TECHNIQUES

Mathematical techniques were used for doing simulation analysis, obtaining mathematical solutions (stage C in Figure 3.1), generating alternatives (stage D), and checking the feasibility of a design. The solution procedure for developing the analysis program, a rule-based system for sludge bulking judgment, and a standard processor for checking a design against standards are described respectively in the following sections.

4.1. Solution Procedure

This section presents the technique for solving the mass balance, including recycle streams contained in the processing system. A set of equations may be used to describe the activated sludge process. The number of equations will depend on the detail to which the process is described. For example, 16 equations and 19 unknowns are used to describe the activated sludge process in this model. It requires the specification of 3 variables to fix the unit process. Tang [1984] used 6 state variables to describe each stream in the process, but reduced the system to 1 equation and 4 unknowns.

It seems that the solution technique’s robustness depends on which 3 variables are chosen to specify the design. Tang originally chose the recycle rate, the sludge age, and the hydraulic retention time to fix the design. In later, unpublished work, he rederived his equations so that the design variables were the sludge age, aeration tank volume, and final clarifier area. In the model developed here, the design variables are the mixed liquor volatile suspended solids (MLVSS), aeration tank volume, and the final clarifier area.

A new approach to solving the activated sludge equations was taken for several reasons. First, Tang’s solution technique involved reducing the system of equations to a single, complex equation and finding its root using the Newton-Raphson technique. Because the current program allows the user to choose one of several models for final clarifier thickening and clarification performance, that approach could not be used. Second, Tang’s solution technique has proven to be unstable. Many designs, determined to be feasible by the optimization model (the same set of equations but solved in a different manner) can not be solved with his analysis program. A thorough investigation into the problem has not been undertaken and the cause of the instability is not known. But this instability was an additional reason to try another approach.

The approach used herein seems to perform well. Situations in which the equations have failed to be solved generally have been those with infeasible designs.

Four state variables are tracked through this program to monitor the characteristics of each stream: flow, soluble BODs, total suspended solids, and biodegradable suspended solids. The only process currently included in this program which distinguishes between solid types is the activated sludge process.
The notation and units of the state variables used in the following description are listed below:

- \( Q_i \): flowrate at control point \( i \), m\(^3\)/hr;
- \( X_{iA} \): active biomass concentration at control point \( i \) in kg/m\(^3\);
- \( X_{iT} \): total suspended solids concentration at control point \( i \) in kg/m\(^3\);
- \( S_i \): soluble BODs concentration at control point \( i \), g/m\(^3\);
- \( i \): index of a control point;
- \( V \): volume of aeration tank, m\(^3\);
- \( k \): the maximum specific utilization coefficient, 1/day;
- \( K_s \): the half-velocity constant, g BODs/m\(^3\);
- \( b \): the endogeneous decay coefficient, 1/day;
- \( y \): the growth yield coefficient, g cell/g BODs;
- \( A_f \): surface area of secondary clarifier (m\(^2\));
- \( f_d \): fraction of total solids which are biodegradable.

**Loading vs. Unit Sizes.**

The program allows the user to specify a design based on loading rates or unit process sizes. The choice is made in the problem formulation section after choosing the Design Parameters option. A good approach to design might be to use loading rates to design the plant for average conditions and then to take the resulting sizes and determine the performance for varied temperature and inflow (peak) conditions.

**Primary Clarifier**

![Diagram of Primary Clarifier](image)

For the primary clarifier as shown in Figure 4.1, an initial guess as to the underflow (\( Q_8 = 5\% \) of feed) and overflow (\( Q_2 \)) is made. The surface area is determined as the smallest area which satisfies the maximum average overflow rate, maximum peak overflow rate, and minimum detention time criteria. Overflow and underflow TSS are determined from the user-chosen process models. The solids mass balance is then used to calculate a new estimate for the underflow. The flow balance is next used to calculate a new estimate for the overflow. The resulting value for \( Q_u \) is compared to the previous guess and if it is within the tolerance (0.1%), continue. If not, iterate. Soluble BOD is assumed to be unchanged in the clarifier. Total BOD is determined as the sum of the soluble BOD and the biodegradable solids fraction. (The constants for converting from mg/L VSS to mg/L BODs are currently specified as activated sludge modeling constants).

**Activated Sludge.**

The activated sludge system as shown in Figure 4.2 may be defined by the following system of 16 equations:

1. Definition of Sludge Age or Solids Retention Time (srt)
   \[
   \text{srt} = \frac{X_{3A} \times V}{(Q_4 X_{4A} + Q_7 X_{7A} - Q_2 X_{2A})}
   \]
2. Flow Balance around Aeration System
   \[ Q_2 = Q_4 + Q_7 \]
3. Substrate Utilized
   \[ \text{FOOD} = \text{BODFEED} - S_3 \]
4. Monod Kinetics
   \[ \text{FOOD} = \text{hrt} \times k \times S_3 \times X_{3A} / (K_s + S_3) \]
5. Mass Balance on Active Biomass around full system
   \[ X_{3A} \times (1 + b \times \text{srt}) \times \text{hrt} = y \times \text{srt} \times \text{FOOD} \]
6. Definition of Hydraulic Retention Time (hrt)
   \[ \text{hrt} = \frac{V}{Q_2} \]
7. Underflow Balance
   \[ Q_5 = Q_7 + Q_6 \]
8. Thickening Equation
   \[ X_{7T} = f(Q_5, Af) \]
9. Clarification Equation
   \[ X_{4T} = f(Q_3, X_{3T}, Af) \]
10. Continuity through underflow
    \[ X_{5T} = X_{7T} \]
11. Continuity through underflow
    \[ X_{6T} = X_{7T} \]
12. Mass Balance on Total Solids around Clarifier
    \[ X_{5T} \times Q_5 = X_{3T} \times Q_3 - X_{4T} \times Q_4 \]
13. Flow Balance around Final Clarifier
    \[ Q_3 = Q_4 + Q_5 \]
14. Constant Solids Mix
    \[ X_{3A} / X_{3T} = X_{4A} / X_{4T} \]
15. Constant Solids Mix
    \[ X_{3A} / X_{3T} = X_{7A} / X_{7T} \]
    \[ X_{3T} - X_{3A} = (1-f_d) \times X_{2T} \times \text{srt} / \text{hrt} \times 24 \]

Assumes that the feed active biomass is zero \((X_{2A} = 0)\). The unknowns in these 16 equations are: hrt, srt, Q3, S3, X3T, X4A, X4T, Q4, X5T, Q5, X6T, Q6, X7A, X7T, Q7, and FOOD. The design parameters are: V, Af, X3A. Equations 4, 8, and 9 represent performance models for the unit processes and are subject to modification by the user. The other equations, for the baseline activated sludge processing...
scheme, are based simply on mass and flow balances and are not subject to revision. The solution is found by the following approach:

1. Determine the total BOD of the process feed.

2. Determine the smallest aeration tank volume which satisfies the volumetric and sludge loading and retention time criteria.

3. Assume a recycle rate of 50%. This gives an estimate of Q3. Assume a sludge age of 5 days.

4. Determine the hydraulic retention time based on the current aeration tank volume. Determine the total solids in the mixed liquor from eqn. (15).

5. Determine the smallest final clarifier area which satisfies the hydraulic and solids loading criteria.

6. Determine the effluent solids concentration based on eqn. (9). If this violates the effluent standard, increase the area by 1% until the standard is met.

7. Check the aeration tank design to see if it violates the maximum loading or detention time requirements. If so, set the warning flag. Determine the actual sludge and volumetric loadings.

8. Find the effluent soluble BOD (S3) by finding the root of the quadratic equation which results from the combination of eqns. (3) and (4). Find the substrate utilized from eqn. (3).

9. Determine the effluent total BOD. If it exceeds the standard, then check to see if the solids contribution alone exceeds the total BOD standard. If so, increase the final clarifier size by 1% and go back to step 6. If not, determine the aeration tank volume which will reduce the soluble BOD to a level necessary to meet the standard given the current clarifier size and go back to step 7.

10. Determine the sludge age from eqn. (5).

11. Find Q4 as the result of combining eqns. (1), (2), (10), (12), and (13).

-- Q5 = Q3 - Q4
-- Solve for X5T with thickening and continuity eqns. (8) and (10).
-- Solve for Q3 from eqn. (12).
-- Compare Q3 to original estimate, if within tolerance (0.01%), continue, or else modify estimate and iterate back to step 5.

12. Determine the remaining unknowns

-- X7T = X5T
-- Q7 = Q2 - Q4
-- X6T = X7T
-- Q6 = Q5 - Q7

13. Determine air flow and power requirements according to two methods. Based on the peak BOD loading, and the design standard, determine the required oxygen supply. Next, determine the oxygen demand based on the mass balance performed and the following equation:

\[ \text{Ox. Req'd (kg/day)} = 24/100 \times Q2 \times \text{FOOD} \times (1.5 - 1.42y/(1+b\times\text{srt})) \]

Finally, calculate the power and air flows required for both oxygen demands. The air flow calculation is:

\[ \text{Air Req'd = Calc. Ox. Req'd} \times \text{S.F.} / \text{O.T.E.} \times (\%) / 0.232 \text{ lb O2/lb air} / 0.0748 \text{ lb air/SCF air} \]
hp reqd = S.F. * Calc. Ox. Req'd (lb/hr) / O.T.E (lb/hp hr)
Only one of the air flow and hp requirements will be used in calculating costs.
Capital and O&M costs are determined based on the air flow. Power cost is
determined based on the hp required. The user chooses which of the two sizing
methods to use in the aeration parameters edit section.

14. Determine the likelihood of bulking for the design.
The approach utilized in this research for examining the likelihood of bulking is
developed by Geselbracht et al. [1988]. The approach is discussed in the next
section.

Note that the maximum specific growth rate and the endogenous decay
coefficient are adjusted when the temperature is different than 20 °C.
Those rate constants are adjusted as:
\[
\frac{k_T}{k_{20}} = 1.072 (T - 20)
\]
with the default values. The reference temperature and the base of the exponent
may be changed in the program. No adjustment is made to the half-saturation
constant.

Gravity Thickener

\[Q_{11} = Q_9 \times \frac{(X_9T - X_{11}T)}{(X_{10}T - X_{11}T)}\]
The underflow solids flux is then calculated, and checked against the previous
estimate. If it is within tolerance then continue. If not, then iterate.
Once within tolerance (0.01%), determine the overflow from a flow balance. The
soluble BOD is assumed to be unchanged through the process. Under the condition
where the feed solids concentration exceeds the predicted underflow concentration, the underflow concentration is set equal to the feed and a supernatant flow of zero results. Thus, the thickener is shown to have no effect on the stream.

**Primary Digester**

![Diagram of Primary Digester]

For the primary digester as shown in Figure 4.4, solids destruction is modeled as a 1st-order reaction in a CSTR. The user defines the kinetic rate constant and detention time. Note that the kinetic rate constant is not tied to the reactor temperature. The reactor temperature is used only for the heat balance. The volume is determined according to inflow and detention time or volumetric loading (lb solids/1000 cu ft day), whichever is greater. Effluent soluble BOD is fixed by the user. Total heat requirement is the sum of reactor heat losses, heat needed to raise the temperature of the feed solids and water, and the heat lost with the water vapor in the biogas. Net energy is the difference between biogas energy and reactor heat requirements. Heat loss is determined for the reactors according to the coefficients which are defined as parameters. The tank sizes are determined according to the height (a parameter) and the following schedule:

<table>
<thead>
<tr>
<th>Volume (1000 cu.ft)</th>
<th>Number of tanks</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>2</td>
</tr>
<tr>
<td>500</td>
<td>3</td>
</tr>
<tr>
<td>1,250</td>
<td>4</td>
</tr>
<tr>
<td>1,700</td>
<td>5</td>
</tr>
<tr>
<td>2,000</td>
<td>6</td>
</tr>
<tr>
<td>&gt; 2,000</td>
<td>7</td>
</tr>
</tbody>
</table>

**Secondary Digester**

For the secondary digester as shown in Figure 4.5, size is fixed by the feed solids loading criterion. Use the feed solids flux as the initial estimate of the underflow solids flux \((Q14 \times X14T)\). Use one of the underflow solids models (a function of underflow solids flux) to determine underflow solids concentration. Combining mass and flow balances on the process yields:

\[
Q14 = Q12 \times (X12T - X13T)/(X14T - X13T)
\]

Calculate the underflow solids flux, and check against the previous estimate. If within tolerance then continue. If not, then iterate.
Once within tolerance, determine the overflow from a flow balance. The soluble BOD is assumed unaffected by the process.

**Vacuum Filter**

The user specifies the filter yield (lb solids/sq ft–hr) and the supernatant solids concentration. A specific weight of the cake of 1.05 is assumed. Filter area is determined based on the feed and filter yield. Cake and filtrate flows are based on a mass balance on solids and a flow balance. Soluble BOD is unaffected by the process.

**Recycle Approach**

Recycle streams are differentiated from other streams as providing additional loading on the process which they feed, but not being the major contributor. They are specified in a matrix, PS, by placing an 8 in the tens position. So, for example, if a stream is to be recycled to the primary clarifier, the entry in the PS matrix would be 82 (as opposed to 2 for a non-recycle stream feeding the primary clarifier).

Recycle streams are assumed initially to have flows and concentrations of zero. A pass is made through the unit processes (according to the ORDR vector in the analysis program) to determine flow and concentration values for the recycle streams. Those values are compared to the initial estimate and, if not within the tolerance, new estimates are made (and placed into the RECYCLE matrix), and another pass through the plant is taken. This continues until tolerances are met (1% for flow, BOD, and TSS; 0.01 MGD for flow).

**Process Models**

The design environment allows the user to model the performance of the unit processes in many different ways. The overflow and underflow solids and BOD concentrations may either be directly specified or one of several models developed for that process may be chosen. Those options are presented to the user in a graphical form. The options available to date are summarized below:

**Primary Clarifier**

- **Overflow Solids**
  - Constant Removal Efficiency
  - Smith (1968)
  - Voshel and Sak (1968)
A rule-based modeling technique is used for evaluating the likelihood of the design resulting in sludge bulking in this design environment. The technique was developed by Geselbracht [1988]. Sludge bulking is a poorly understood problem in activated sludge wastewater treatment plants. An engineer must use judgment gained from experience when he designs an activated sludge plant to prevent bulking, which can cause the plant to fail.

An attempt was made to use fuzzy logic in order to model sludge bulking probability. Research results were taken from the literature and formulated as rules in a rule-based system which relates design variable values to the likelihood of a design experiencing bulking problems. The weights of association of those rules to the conclusion that a given design would experience bulking problems and the logical interaction of those rules were calibrated using an experienced engineer's evaluation of a set of 15 plant designs. The consistency of the engineer's evaluations and those of judgment model had been checked with a second set of 15 designs. The approach was detailed by Geselbracht [1988].

4.3. Standard Processor

Another area of expert systems which could prove useful in the design environment is a routine which checks a design against the relevant standards. Little has been done along these lines in the environmental engineering field. Jennings [1986] developed a prototype expert system (DIKE) for hazardous waste facility review. Many other instances can be found of computerized design standards summary in the structural engineering field.
One reason for the lack of standards processing in the environmental field is the limited standards for treatment facility design (as compared to the voluminous steel, concrete, etc., standards in the structural field). The fewer number of standards simplifies the problem. However, more detailed design and performance standards are currently being proposed both at the state and federal level for hazardous and domestic solid waste disposal facilities (which could eventually become a part of the design environment).

A standards processor could fit nicely into the design environment. In its current form, the user specifies a facility design according to size or loading criteria. A mass balance is then run. While the default loading criteria can be made to reflect a given set of standards, as the engineer iterates through the design process, those loading criteria may be changed to reflect unmodeled concerns. A better approach would be to have a routine with which, once a mass balance is complete, the engineer can quickly check his design against the relevant standards. Such a routine should report to the user violations of and recommendations given by the standards.

Several sets of standards exist for the design of wastewater treatment facilities. In many cases individual states have adopted a set of standards. One common set (in the Midwest, anyway) is Ten State Standards [1978]. The following are rules taken from the Standard.

55. Equalization

55.1 IF Diurnal variations in flow are expected THEN install flow equalization.

55.52 Aeration equipment SHALL BE sufficient to maintain 1.0 mg/L DO in the mixed basin at all times. Air supply rates SHOULD BE a minimum of 1.25 cfm/1000 gallons of storage capacity.

60. Settling

61.1 Multiple units SHALL BE provided in all plants where design flows exceed 100,000 gpd.

62.1 The minimum length of flow from inlet to outlet SHOULD BE 10 feet. IF violation THEN special provisions must be made to prevent short circuiting. Primary clarifiers SHALL BE as shallow as practicable. Primary clarifier depth shall be greater than 7 feet. Activated Sludge clarifiers SHALL HAVE sidewater depths of at least 12 feet. Clarifiers following fixed film reactors SHALL HAVE sidewater depth of at least 7 feet.

62.21 Surface settling rates for primary tanks SHOULD NOT exceed 1000 gpd/sq ft at design average flows OR 1500 gpd/sq ft for peak hourly flows. Primary settling of normal domestic sewage CAN BE expected to remove 30% to 35% of the influent BOD.

62.22 Surface settling rates for intermediate tanks following series units of fixed film reactor processes SHALL NOT exceed 1500 gpd/sq ft based on peak hourly flow.

62.23 Surface settling rates following trickling filters or rotating biological contactors SHALL NOT exceed 1200 gpd/sq ft based on peak hourly flow. The hydraulic loading SHALL be based upon peak hourly rate. IF settler follows (conventional OR step aeration OR contact stabilization OR the carbonaceous stage of separate-stage nitrification) THEN maximum hydraulic loading is 1200 gpd/sq ft.
IF settler follows extended aeration THEN max. hydraulic loading is 1000 gpd/sq ft.
IF settler follows a separate nitrification stage THEN maximum loading is 800 gpd/sq ft.
The solids loading for all activated sludge processes SHALL NOT exceed 50 lbs/day/sq ft at the peak rate.

62.43 IF avg. flow \(\leq\) 1.0 MGD THEN weir loadings SHOULD NOT exceed 10,000 gpd/LF.
IF avg. flow > 1.0 MGD THEN weir loadings SHOULD NOT exceed 15,000 gpd/LF.

62.7 Walls of settling tanks SHALL extend at least 6 inches above the surrounding ground surface AND SHALL provide not less than 12 inches freeboard.

73.11 Multiple anaerobic digester tanks ARE RECOMMENDED.
If a single digestion tank THEN alternate method OR emergency storage SHALL BE provided.

73.12 A minimum sidewater depth of 20 feet IS RECOMMENDED. The depth SHOULD BE sufficient to allow for the formation of a reasonable depth of supernatant liquor.

73.3 Design calculations SHOULD BE submitted to justify design.
IF no design calculations THEN ...
IF completely mixed THEN maximum loading is 80 lbs VS/1000 cu ft day.
IF moderately mixed THEN maximum loading is 40 lbs VS/1000 cu ft day.

76.2 The number of vacuum filters SHOULD BE sufficient to dewater the sludge produced WHEN one largest unit is out of service.
The storage capacity SHOULD BE sufficient to handle at least a 3-month sludge production.

82.111 The activated sludge process MAY BE used where sewage is amenable to biological treatment.

82.12 IF flow > 1 MGD THEN plant SHALL BE designed to facilitate easy conversion to various operation modes.

82.31 Calculations SHOULD BE submitted to justify the basis for design of aeration tank capacity.
Calculations using values differing substantially from those recommended SHOULD reference actual operational plants.
IF process design calculations are not submitted THEN ...
IF Conventional OR Step Aeration OR Complete Mix THEN Maximum Volumetric loading = 40 lb BOD5/day 1000 cu ft AND F/M \(>\) 0.2 lb BOD5/lb MLVSS day AND F/M \(<\) 0.5 lb BOD5/day lb MLVSS AND MLSS > 1000 mg/L and MLSS \(<\) 3000 mg/L.
IF Contact Stabilization THEN Max Vol Load = 50 AND F/M \(>\) 0.2 AND F/M \(<\) 0.6 AND MLSS > 1000 mg/L AND MLSS \(<\) 3000 mg/L.
IF Extended aeration OR Oxidation ditch THEN Max Vol Load = 15 AND F/M \(>\) 0.05 AND F/M \(<\) 0.1 and MLSS \(>\) 3000 and MLSS \(<\) 5000.
Liquid depths SHOULD NOT BE less than 10 feet OR more than 30 feet.

82.322 IF reliability guidelines must be met THEN total aeration volume SHALL BE divided among two or more units.
82.33 Aeration Equipment
Aeration equipment SHALL BE capable of maintaining a minimum of 2.0 mg/L of dissolved oxygen in the mixed liquor at all times.
IF values are not determined experimentally AND IF not extended aeration THEN design oxygen requirements SHALL BE 1.1 lbs O2/lb peak BOD applied.
IF values are not determined experimentally AND IF extended aeration THEN design oxygen requirement SHALL BE 1.8 lbs O2/lb peak BOD applied.
IF nitrification THEN the nitrogen oxygen demand SHALL BE 4.6 times the diurnal peak TKN content of the influent.

82.332
IF alpha and beta are not determined experimentally AND IF primarily treating domestic wastewater THEN wastewater transfer efficiency SHALL BE 50% of clean water efficiency.
IF NOT extended air process THEN normal air requirements SHALL BE 1500 cu ft/lb BOD5 peak aeration tank loading.
IF extend air process THEN normal air requirements SHALL BE 2000 cu ft/lb BOD5 peak aeration tank loading.

Rules such as those presented above should be constructed into a routine which may be called from the analysis program.
CHAPTER 5
COMPUTER AIDED SYSTEM FOR
WASTEWATER TREATMENT PLANT DESIGN

5.1. Design Approach

A major design question is how does (or should) an engineer design (determine the sizes of the units in) a wastewater treatment process. It is desirable to design a processing scheme and to size units so that the complete system works, is efficient, and performs reliably.

Conventional Approach

A conventional approach is described in the wastewater engineering text by Metcalf & Eddy (M & E) [1979] for designing an activated sludge process. The design is initiated by giving the influent conditions as well as two process design variables (sludge age and mixed liquor volatile suspended solids, MLVSS) and the return sludge concentration. Thus, from a “design analysis” point of view, the problem is already solved; all that remains is to use these variables to calculate the resulting state variables. Aeration volume is conservatively determined based on the soluble BOD removal required under the condition of high effluent suspended solids (probably the effluent standard). Checks are then conducted on the resulting hydraulic retention time and the volumetric loading rate. The text guides the user in selecting those design variables by providing recommended ranges. It also warns of other factors which must be considered during the design, including cost. Unfortunately, the nature of the interactions between the design variables and the resulting cost and reliability of the design is not explicit.

Computer Aided System Approach

The preliminary design of an activated sludge plant includes sizing the aeration basin and final clarifiers. Feasible sizes for those units are constrained to a large degree by allowable loading rates specified by State or Public Health standards. For example, Table 5.1 presents some typical recommended loading rates for these units.

Table 5.1. Recommended Activated Sludge Loadings

<table>
<thead>
<tr>
<th>Criterion</th>
<th>10 State</th>
<th>V &amp; H</th>
<th>M &amp; E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum HRT (hr)</td>
<td>7.5</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Minimum HRT (hr)</td>
<td>6.0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Min Sludge Loading (1/day)</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Max Sludge Loading (1/day)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Max Vol. Loading (lb/1000 cu ft day)</td>
<td>40</td>
<td>40</td>
<td>37.5</td>
</tr>
<tr>
<td>Min Vol. Loading (lb/1000 cu ft day)</td>
<td>--</td>
<td>30</td>
<td>18.7</td>
</tr>
<tr>
<td>Maximum MLSS (mg/L)</td>
<td>3000</td>
<td>--</td>
<td>3000</td>
</tr>
<tr>
<td>Minimum MLSS (mg/L)</td>
<td>1000</td>
<td>--</td>
<td>1500</td>
</tr>
<tr>
<td>FST Max Hyd. Loading (gpd/sq.ft)</td>
<td>1200</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>FST Max Solids Loading (lb/day sq.ft)</td>
<td>50</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

HRT: hydraulic retention time;
10 State: Ten State Standards [1978];
V & H: Viessman and Hammer [1985], page 498.
Other constraints on the design are the performance criteria which are specified by the effluent standards. The loading rates probably have no intrinsic meaning by themselves but have been used as rules of thumb by engineers. The volumetric loading generally recognizes that oxygen transfer in the aeration basin becomes limiting when the aeration density becomes high. Sludge loading appears to influence the dominant organism type (filamentous vs. floc-forming) in the basin.

To illustrate the decision making flexibility which remains for the engineer, the Ten-State Standards recommended loading rates were used with design conditions as shown below.

Flow = 10 MGD
Influent Soluble BOD5 = 150 mg/L
Influent TSS = 150 mg/L

The design variables used are the mixed liquor volatile suspended solids (MLVSS), aeration tank volume, and the final clarifier area. For a MLVSS of 1250 mg/L there is an acceptable aeration tank volume range of 2.9 to 7.3 million gallons with an associated annualized cost range of $950,000/yr to $1,100,000/yr (15% difference). Design considerations such as cost, performance, and reliability can be used to narrow this range.

The analysis program can be used to solve the mass balances rapidly and to determine the cost for a given design. The first step to the problem is to formulate the influent conditions and effluent requirements for which the plant must be designed. Next, the average influent conditions are used with acceptable average loading criteria to determine unit process sizes. Those loading criteria may come from applicable State or regional design standards or from the consulting firm's company policy. Next the performance of the resulting design (specific unit sizes) should be checked under peak loading and adverse temperature conditions. From this point on, the user can iteratively delete processes or change unit process sizes to see the effect on cost and performance by the computer aided system.

5.2. Computer Aided System

5.2.1. General

The prototype computer aided system is an interactive system. Although the following demonstration illustrates how the system works, it is much easier to understand from a videotape or a live demonstration. The general characteristics of the prototype have been discussed in Chapter 3. The following discussions focus on the characteristics specific for a WTPD model and a demonstration of the general and specific characteristics.

As mentioned in Chapter 1, a wastewater treatment plant design problem is usually complex. The complexity is caused not only by the mathematical difficulty of obtaining a numerical solution, but also by the presentation of the design data, manipulation under different design conditions, generation of potential alternatives, and interaction in a trial-and-error or solution selection procedure. The goal of the prototype is to provide an efficient, accurate, creative, user-friendly, and easy-to-use system for use in the design of wastewater treatment plants.

The prototype was first developed on an IBM PC AT. Since the IBM PC AT has limited capacity and screen resolution, the PC version was complex to use. The PC version was thus converted to an Apollo workstation environment. The user
interface of the prototype on the Apollo workstation is much simpler and easier to use.

For data entry, data must be manipulated in the prototype to define the problem which is to be solved and to describe performance and constraints for the unit processes. The approach taken here is to allow the user "form fill-in" of the table displayed on the screen. Such a format allows the user to quickly make changes to a data set. When the user is confronted with a table of data, the entries may be changed by directly typing in the new value on the corresponding input field.

A variety of process performance models are available in the prototype. This flexibility is considered important for allowing the engineer to explore the impact of research results or specific plant operating data on the design and performance of a plant. Those performance models are presented to the user by way of a two-dimensional plot of the performance parameter (solids concentration, fractional removal, etc.) vs. a significant design parameter (overflow rate, underflow rate, etc.). All of the available models are plotted on the same scale. The user selects one of the models, that curve is highlighted, and an abstract of information (under what conditions it was developed, the equation form of the model, etc.) is presented. Whichever model is selected when the user leaves the selection menu is chosen for the analysis. This presentation approach works well, and the presentation of the available models together on the same plot provides interesting comparisons. However, many of the models have more than one dependent variable and thus the plot does not tell the whole story. For example, the overflow solids concentration model for the final clarifier may depend on overflow rate, unit feed rate, and/or feed solids concentration. A two-dimensional plot requires one of these variables to be fixed.

Model selection screens will display the curves of the models available to specify process performance and a menu of model authors. The model currently chosen will be highlighted on the graph. A short description of each performance model is presented when that model is highlighted on the screen. The description includes the model's equation and the position of the equation parameters (indicated as $c_1$, $c_2$, $c_3$, ...).

A number of checks are made while the problem is being solved. For example, the aeration tank volume is determined as the minimum volume that satisfies the maximum loading and minimum detention time values. If the volume violates the minimum loading rate or maximum detention time, there is no solution for those design conditions. In instances where the design proves infeasible, or a violation of a design condition or standard has occurred, a warning message will be shown on the screen.

The data that are used to formulate a problem, processing scheme, performance models, etc. may be stored and recalled as designs. The number of designs that can be stored is limited only by the memory capacity on the workstation used.

The cost equations have been modified to utilize a generic function. Generally, the cost equations are piecewise non-linear curves of the form:

$$\text{COST} = a \cdot (X)^b$$

where $a$ and $b$ are modeling parameters and $X$ is the relevant sizing variable. The program allows up to five curve segments for each cost function. Each curve segment is defined by specifying its upper bound (the lower bound is the previous segment's upper bound or zero), $a$ and $b$. The cost parameters are loaded into the
program from a data file and they may be modified without changing the source code.

The display of cost curves is very important for a designer to size a process or determine capacity of a facility unit. However, as mentioned in Chapter 3, the display of cost curves is not easy. For the PC version, the cost curves are displayed by semi-log plots. Although a semi-log plot can cover the whole range of parameter values, it is hard to see the approximate value of cost. A semi-log curve gives only the shape of curve and is not much help for a designer in evaluating the cost region of interest. For the Apollo version, a normal scale plot is used to show the cost curve. By using the normal scale, the cost curve can be more easily understood and used by the designer. The range of parameter values to be displayed can be provided as input by the designer in two data fields, one for a reference point and the other for a spanning range. The designer can select a desired range by entering values into the two fields, and a cost curve, centered at the reference point and span backward and forward by the span range specified, would then be shown with the cost associated with the reference point. The flexibility of showing different ranges of the cost curve and the cost for a particular parameter value is very useful for the designer to select an appropriate design under a cost constraint.

The program’s interface is written with DIALOG. The user controls program flow using the computer's mouse. Menu options are presented as a set of boxes on the screen. The user moves the mouse cursor into the box of the option desired and clicks the left button. This will activate that capability. When popup windows appear, they can be deactivated (popped down) by clicking the middle mouse button. A general description of the program structure is provided in Appendix A.

Capabilities

The following capabilities are currently functional on the Apollo workstations:

- construct interactively activated sludge models of any combination of a given set of unit processes and solve the mass balances and find the cost and the likelihood of bulking for that treatment scheme;
- specify a processing scheme graphically;
- specify unit process sizes;
- change interactively baseline model parameters and plant design conditions (flow, waste strength, etc.);
- view details of mass balances throughout plant and details of system capital and O&M costs with data presented in either a tabular or graphical format;
- display output data graphically;
- save and load an unlimited number of design cases;
- receive further explanation regarding the values of model parameters and the conditions under which they were developed.

These capabilities are demonstrated in the next subsection.

5.2.2. Demonstration

The following description presents features of the prototype by graphical demonstrations. The demonstrations simulate the interactive environment. However, as mentioned above, the system is easier to understand from a videotape or live demonstration.
Introduction

Upon initiation of the prototype, an introduction is displayed as shown in Figure 5.1. After any mouse button is pressed, the program options which are present in that full environment are briefly explained below. In the initial screen shown in Figure 5.2, a default set of unit processes is shown. The unit processes shown on the screen provide an interface for various manipulations, e.g. configuration, editing parameters, and examining results. The designer can simply click the mouse button on the desired unit process to make a selection and then manipulate any necessary action. Although the prototype so far does not allow the designer to add interactively an arbitrary number of unit processes, this default group can be reset to any set of unit processes presented. The default set gives most unit processes used for an activated sludge system; it should be suitable for most cases.

The top row of menu options is for editing design parameters, selecting flow models and design approach, solving a design, reporting likelihood of bulking, showing cost figures and related information, and quitting the program, respectively. These options and those which are going to be presented can be easily selected by clicking the mouse button on the desired menu item. The ability to make selections without typing from the keyboard is one of the major characteristics of the friendly interface. This row of options controls the major activities in the design session and are demonstrated in more detail after Figure 5.7.

The second row is a message area which is used to report a short response, warning, or error messages. If the message is long and/or important, a popup window will be shown to bring it to the designer’s attention instead of showing it on the message area. The messages, message area, popup window, and beeper establish the feedback system to avoid mistakes made by the designer and guide the designer to explore good alternatives.

The third row of options is for configuration of the process schematic. The first option is a name field where the designer can type a name. If the design name exists in the database, then the design will be opened. Otherwise, a default set of unit processes without any linkages will be shown. An exception is that the activated sludge and final clarifier are treated as an individual process, and the recycle flow linkage can not be changed. The name provides an identification for a design. The next options in the third row are used to show a list of names of created designs, re-configure a design, fix a configuration, and select flow types (under or over flow), respectively. Below the three rows of options is the working area to configure a process schematic. After a schematic is configured, it serves as an interface for manipulating related information of the schematic.

The design procedure used in this prototype has two steps. In the first step the configuration is “free” to have changes or modifications in its linkages. In the second step the configuration (or process schematic) is “fixed.” There are two reasons for using the “fix” and “free” options: (1) to avoid confusion in using the configuration because the configuration is also used as an interface for other tasks; and (2) to avoid inadvertently changing a configuration in editing or doing other tasks because any configuration change would change the set of parameters and model equations. Options are also grouped based on the condition (free or fixed) of the current configuration. The free group of options includes Re-Configure, Fix Configuration, and Under- and Over- flow, and the fixed group of options includes the top row of options except Quit. If working on a free configuration, the fixed groups of options will be deactivated and will not respond to the designer’s selection,
and vice versa. This limitation reduces the chance of that the designer will inadvertently select an undesired option. In Figure 5.3, the configuration named New is free and the fixed group of menu options is deactivated. The texts associated with deactivated options are turned gray, so the designer can distinguish them from active techniques.

Create, Configure, and Open a Design

Creating a new design is easily done by typing a new design name in the name field. After typing a name, the default set of unit processes would be shown. On the screen with the default set shown, by interactively clicking the mouse button on a process and drawing the flow lines to another process, a process schematic can be configured. Although a designer can create a process schematic of any combination of unit processes, the schematic may be infeasible based on design constraints or mass and flow balance conditions. In Figure 5.3, a process schematic would be set up after drawing, by moving the mouse, the underflow line from the final clarifier to the gravity thickener.

After creating a design, the designer should fix the configuration by selecting the “Fix Configuration” option. A fixed configuration is not allowed to change. In Figure 5.4, the design New is fixed. The fixed group of options is then activated and the free group is deactivated.

The designer can open an existing design by typing a name such as “test” in Figure 5.5 into the name field. The desired design is then opened. Note that the free group of options is deactivated because the “test” design is an existing design and therefore fixed.

The designer can construct a different design by typing a new name into the name field and by using the procedure described (see design “partial” in Figure 5.6). A list of design names can be shown by selecting the option “Configuration List” for review (see Figure 5.7).

The interactive approach of using the mouse to specify flow linkages is very convenient for setting up a process schematic. Each time the designer types a new name, a new design is created. After the option “Fix Configuration” is selected, the design will be stored in the computer memory. Those unit processes which do not have any linkage to or from any other process(es) will be automatically deleted. Thus, no options are needed to SAVE and DELETE individual processes.

View and Edit the Design Parameters

The characteristics of design parameters and results obtained from solving a design are shown in the forms shown in the next figures. A form can be selected for viewing and editing by clicking the mouse cursor on the desired position in the process schematic. For example, by clicking the “influent,” the form for the feed characteristics will be displayed as shown in Figure 5.8. The editable fields are highlighted by using bold character display (see the number on the right of the form shown in Figure 5.8). To edit, the designer can click the mouse on a desired field. Then, a small triangular cursor will be shown to indicate the typing position (see the second number, 100.00, in the form shown in Figure 5.8), and the designer can then enter a new number. Since each field is self-explained, no more explanation for each field is provided in the following descriptions. Figures 5.9, 5.10 and 5.11, 5.12 and 5.13, 5.14 and 5.15, 5.16, and 5.17 show the input and output forms for the primary clarifier, activated sludge system, gravity thickener and secondary digester,
primary digester, vacuum filter, and effluent conditions, respectively. The input (editable) fields are highlighted by bold character display. The output fields are those numbers which are not highlighted; it shows the information which is not editable and only for reference purpose. The output fields are discussed again later after the option “Solve” is introduced.

Since the information for some unit processes exceeds the display capacity of the screen, it is divided into two separate windows, one containing output and frequently used input fields and the other containing the less frequently modified parameters (see Figure 5.10 and 5.11, 5.12 and 5.13, and 5.14 and 5.15). The second window can be shown by selecting a menu option on the first window. By the “form-in” approach demonstrated above, the design parameters related to a specific unit process can be easily examined and modified.

Flow Models

A variety of process performance models from the literature is available in the prototype. The performance models can be displayed by first selecting the option “Flow Model” and the desired flow type (under- or over-flow), and then clicking the mouse on the desired unit process. For example, Figure 5.18 shows a pop-up window in which two available underflow models for the primary clarifier are displayed and the Dick model is selected with the description and the associated curve highlighted. The selection can be made by clicking the mouse on the check boxes provided on the right of the pop-up window. Various performance models for different unit processes are shown in Figures 5.19, 5.20, 5.21, 5.22, 5.23, and 5.24.

Solving and Results

After the values of all design parameters are determined and all performance models are selected, the designer can solve the design model by selecting the option “Solve” on either the top row or the top right corner of an editing window. Although the Solve option is duplicated, the one in the editing window makes it easy to see the changes immediate after some modifications are made to the design parameters; this interactive ability has been found to be very useful for exploring alternative designs. For example, Figure 5.25 shows a solution with the cost of $2,190,266, shown at the bottom of the output form. The designer may want to change the value of a design parameter. For instance, the maximum of sludge loading may be changed from 0.5 to 0.45 lb BOD/ lb MLVSS day. A new solution can be obtained by re-solving the design (see Figure 5.26). The new solution has the cost of $2,191,346.

After creating a feasible design, the designer may want to examine the likelihood of experiencing sludge bulking. By selecting the Bulking option on the top row, a pop-up window for the probability of bulking based on the design conditions will be shown (see Figure 5.27).

One of two options can be selected to specify the method used for solve the design model: fixed process sizes or specified loadings. The two options are shown on the top row. Each option has a group of editable fields. If the fixed sizes option is selected, all editable fields related to the fixed loadings method will not be highlighted; and vice versa (See Figure 5.28).

Cost Information

Cost is usually an important issue for a design. It is very desirable to have good representation for cost related information. The cost function, however, is generally
exponential and covers a wide range which cannot fit a general computer screen. A semi-log plot may cover whole cost range, but, as mentioned, the plot may not be useful. The following figures demonstrate how to improve the presentation of the cost related information.

The cost related information includes a cost summary table, cost parameters, cost curves, and cost coefficients. First, the “Cost” option in the top row should be selected for showing the cost related information. Upon selecting the Cost option, a list of sub-options is shown as in Figure 5.29. The cost summary table can be displayed by selecting the sub-option “Cost Summary” (see Figure 5.30). Cost parameters, average wage rate, electricity cost, capital recovery factor, methane value, and sludge disposal cost, can be modified from a pop-up window shown after selecting the sub-option “Cost Parameters” (see Figure 5.31).

Five types of cost information are provided in this prototype: capital, operations, maintenance, supplies, and power. Other than specific unit processes, there are several other components in a design (e.g., return sludge pumping) that impact the cost. Instead of using the configuration as the interface for displaying cost curves, a list is provided and selections are implemented by the checkbox approach. Figures 5.32, 5.33, 5.34, and 5.35 show the capital, operations, maintenance, and supplies cost curves for primary clarifier, and Figure 5.36 shows the power cost for return sludge pumping.

On the curves, the cost associated with the value of a design parameter in the current solution is indicated by a circle and the parameter value is shown in the field “Ref. Point=>” and the cost is shown in the message area. The field “Span” indicates the range around the current value to be shown. And the fields “Coeff a” and “Coeff b” are the cost coefficients for the cost function associated with the displayed range. For example, Figure 5.37 shows the capital cost curve of return sludge pumping with pumping capacity = 72.39 cu m/hr indicated and the cost shown in the message area. The value of pumping capacity can be changed and the new cost is indicated and shown. (see the field “Ref. Point=>”, the circle on the cost curve, and message area in Figure 5.38). The span range and cost coefficients can also be changed as shown in Figures 5.39, 5.40, and 5.41, respectively.

Design Violation and Standard Processing Report

After a design is solved and the solution has been checked against the design conditions or standards to determine if any violation occurs, a pop-up window with a warning message would be shown to tell the designer of violation(s). Although only one figure, Figure 5.42, is used to illustrate this ability, this kind of warning message may frequently appear in a real design session by checking feasibility and using the standard processor described in Chapter 4. This feedback capacity is very important for guiding the designer to the design of a sound plant.

Comparison

In Figure 5.43, the design “partial,” in which no primary and secondary digesters are used, is solved and the cost summary is shown. By comparing the cost table with the one shown in Figure 5.30, the effect of deleting secondary and primary digesters on the cost can be observed. Also, the duplicate “Solve” option can be used to compare the results obtained from using different values of a design parameter.
5.3. Summary

This chapter presents the features of the prototype developed for a WTPD problem. The prototype monitors actions that the designer selects and performs the action selected. The menu options are designed to be as simple as possible. Most options are shown in one window and are laid out to avoid complexity in selecting menu options. The deactivation of unnecessary options reduces the chance of inadvertently choosing undesired options. For the PC version of the prototype, more levels of pop-up windows are needed and thus complexity increases. To avoid confusion, at most two levels of pop-up windows are shown on the screen for the Apollo prototype. The second level of pop-up windows shows parameters which are infrequently modified.

The “Solve” option is provided in each editing screen, and the designer can see a new solution immediately after changes are made. Since the interactive response time is quick, the conventional trial-and-error procedure can be used efficiently. The ability of the prototype to solve a mass balance on virtually any unit process combination is a great aid to the designer when searching for a good system design or when he wishes to put together a model of a processing scheme quickly.

The feedback system provided in the prototype is intended to guide the designer in a design session. This prototype is expected to aid a process designer in shortening the time for producing a feasible design and to provide functions to assist the exploration of better designs. The designer can take into account other issues and modify the design by trial and error.
Welcome to the Computer Aided System for Water Treatment Plant Design.

Press any mouse button to continue.
Figure 5.2
Figure 5.3
Current Configuration:

Effluent:

Primary Clarifier

Gravity Thickener

Primary Digester

Secondary Digester

Vacuum Filter

Land Fill

Activated Sludge

Figure 5.5
The current configuration is fixed.

Current Configuration: partial

Influent

Primary Clarifier

Activated Sludge

Final Clarifier

Gravity Thickener

Vacuum Filter

Effluent

Land Fill

Figure 5.6
Figure 5.7
Figure 5.8
Figure 5.9

Flow Model

Activated Sludge
Gravly Thickener
Total Solids (mg/l) 150.000 60.035 70000.000 7.398 262500.000

Vacuum Filter

Primary Clarifier

Primary Digester

Secondary Digester

Effluent

Influent
Kinetik Model Parameters

Maximum Utilization Coefficient (monod, 1/day) 5.00
Half-saturation constant (monod, mg/L) 60.00
Yield coefficient (g solids/g BOD removed) 0.60
Endogenous decay rate @ 20 °C 0.06
Design MLVSS concentration (mg/L) 1250.00
Temperature (°C) 25.00
Temperature coefficient 1.07

Aeration Parameters

Aeration Supply Safety Factor 2.00
Oxygen Transfer Efficiency (%) 8.00
Design Oxygen requirement (lb O2/lb BOD applied) 1.10
Oxygen Transfer Efficiency (lbs O2/hp-hr) 1.80

Other Constants

Conversion Factor (lb BOD/lb VSS) 1.42
Conversion Factor (lb BOD/1000 cu.ft day) 0.67

Figure 5.10
Influent

Primary Clarifier

Activated Sludge

Final Clarifier

Effluent

Kinetics Model Parameters

- Maximum Utilization Coefficient (monod, 1/day): 5.00
- Half-saturation constant (monod, mg/l): 60.00
- Yield coefficient (lb solids/lb BOD5 removed): 0.60
- Endogenous decay rate @ 20 oC: 0.06
- Design MLVSS concentration (mg/l): 1250.00
- Temperature (oC): 25.00
- Temperature coefficient: 1.07

Aeration Parameters

- Aeration Supply Safety Factor: 2.00
- Oxygen Transfer Efficiency (%): 8.00
- Design Oxygen requirement (lb O2/lb BOD applied): 1.10
- Oxygen Transfer Efficiency (lbs O2/hp hr): 1.80

Other Constants

- Conversion Factor (lb BOD/L/lb VSS): 1.42
- Conversion Factor (lb BOD/L/lb BODL): 0.67

Activated Sludge

- S = 4.812
- MLVSS (mg/L) = 1250.00
- MLSS (mg/L) = 1642.252

- Endogen decay rate @ 20 oC: 0.06
- Design MLVSS concentration (mg/l): 1250.00
- Temperature (oC): 25.00
- Temperature coefficient: 1.07

Aeration Parameters

- Aeration Supply Safety Factor: 2.00
- Oxygen Transfer Efficiency (%): 8.00
- Design Oxygen requirement (lb O2/lb BOD applied): 1.10
- Oxygen Transfer Efficiency (lbs O2/hp hr): 1.80

Other Constants

- Conversion Factor (lb BOD/L/lb VSS): 1.42
- Conversion Factor (lb BOD/L/lb BODL): 0.67

Vacuum Filter

Figure 5.11
Figure 5.12
Figure 5.13
Figure 5.14
### Heat Balance Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Temperature (C)</td>
<td>35.00</td>
</tr>
<tr>
<td>Ambient Temperature (C)</td>
<td>15.00</td>
</tr>
<tr>
<td>Tank Height (ft)</td>
<td>30.00</td>
</tr>
<tr>
<td>Inside Transmittance Coefficient</td>
<td>2.00</td>
</tr>
<tr>
<td>Outside Transmittance Coefficient (TOP)</td>
<td>1.30</td>
</tr>
<tr>
<td>Outside Transmittance Coefficient (SIDE)</td>
<td>1.30</td>
</tr>
<tr>
<td>Outside Transmittance Coefficient (BOTTOM)</td>
<td>2.00</td>
</tr>
<tr>
<td>Wall Conductance Coefficient</td>
<td>8.30</td>
</tr>
<tr>
<td>Top Thickness (inch)</td>
<td>8.00</td>
</tr>
<tr>
<td>Sidewall Thickness (inch)</td>
<td>18.00</td>
</tr>
<tr>
<td>Bottom Thickness (inch)</td>
<td>12.00</td>
</tr>
<tr>
<td>Heat Exchanger Efficiency (fraction)</td>
<td>0.90</td>
</tr>
</tbody>
</table>

### Performance Parameters

- **Biological Rate Constant (91/day)**: 0.15
- **Effluent Soluble BOD5**: 500.00
- **Gas production (SCF gas/lb VS destroyed)**: 13.50
- **Biogas energy value (BTU/SCF)**: 650.00

### Performance Parameters

- **Biological Rate Constant (91/day)**: 0.15
- **Effluent Soluble BOD5**: 500.00
- **Gas production (SCF gas/lb VS destroyed)**: 13.50
- **Biogas energy value (BTU/SCF)**: 650.00

### Primary Digester

- **HRT (days)**: 36.819
- **Loading (lb/1000 cu.ft day)**: 80.000
- **Global Eff.**
  - **Sludge Cake**
  - **Heating Requirements**
  - **Total (BTU/hr)**: 959082.000
  - **Conduc.Heat Losses**: 350071.000
  - **Heat Energy (mmBTU/yr)**: 33018.400
  - **Water vapor losses**: 22344.200

### Design Parameters

- **Digester Volume (cu. ft)**: 190882.05
- **Maximum Loading Rate (lbs VS/1000 cu.ft day)**: 80.00
- **Solids Detention Time (days)**: 15.00

---

**Figure 5.15**
Figure 5.16
This approach uses the differential thickening technique which is based on the limiting flux theory. The parameters for the resulting equation come from the batch settling equation of the form:

\[ V = c_1 \times X - c_2 \]

Figure 5.18
Constant underflow solids assumes constant thickening regardless of the clarifier size. This could be true because of controlling hydraulic limitations of the sludge withdrawal mechanism.

The model is: \( X(z) = c_1 \)
This approach uses the differential thickening technique which is based on the limiting flux theory. The parameters for the resulting equation come from the batch settling equation of the form:  

\[ V = c_1 \times X - c_2 \]
This approach uses the differential thickening technique which is based on the limiting flux theory. The settling parameters for a mixture of primary and waste activated sludge come from the settling parameters for each sludge and the model developed by Suidan: 

\[ ac = aw + (ap - au)f_{p} - c \]
Figure 5.22

- Influent
- Secondary Digester
- Activated Sludge
- Gravity Thickener
- Primary Digester
- Secondary Digester
- Vacuum Filter
- Effluent

Constant underflow solids assumes constant thickening regardless of the clarifier size. This could be true because of controlling hydraulic limitations of the sludge withdrawal mechanism.

The model: Xander (C2) = C1
Voshel and Sak developed two models relating the solids removal efficiency to both the influent solids concentration and the overflow rate based on their plant-scale study performed in Michigan. The model shown here assumes no polymer addition.

The model is

\[ \text{EFF} = c_1 \times (x_1 - c_2) \times (L_p - c_3) \]

Figure 5.23
Figure 5.24

This model is based on studies performed on a pilot-scale clarifier at a full-scale plant. His model is: $X_{eff} = c_1 + c_2 \times Q_{miss} + c_3 \times (Q_{miss}/AF)$.
Figure 5.25
Figure 5.26
AN EXPERIENCED ENGINEER'S JUDGEMENT REGARDING THE LIKELIHOOD OF EXPERIENCING BULKING PROBLEMS BASED ON THE PLANT DESIGN

Plant Design Information:
- BOD REMOVAL RATE (kg BOD5/kg MLVSS day) = 0.44
- SLUDGE LOADING 1 (kg BOD5/kg MLSS day) = 0.34
- SLUDGE LOADING 2 (kg BOD5/kg MLVSS day) = 0.45
- VOLUMETRIC LOADING (kg BOD5/cu.m day) = 0.56
- MASS LOADING, PST (kg/cu.m hr) = 2.26
- DISSOLVED OXYGEN CONC (mg/L) = 1.50

LIKELIHOOD OF EXPERIENCING A BULKING PROBLEM: 0.77

THE FOLLOWING CONDITIONS CONTROL THE LIKELIHOOD OF BULKING:
- Volumetric Loading > 0.56 kg BOD/cu.m day
- Sludge Loading 1 > 0.3 kg BOD applied/kg MLSS day
- Sludge Loading 2 > 0.3 kg BOD applied/kg MLVSS day

Figure 5.27
Figure 5.28
Figure 5.29
Influent

SUMMARY OF ANNUAL PLANT COSTS ($/YR)

<table>
<thead>
<tr>
<th>UNIT</th>
<th>CAPITAL</th>
<th>OPERATION</th>
<th>MAINTENANCE</th>
<th>SUPPLY</th>
<th>POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Settling Tank</td>
<td>$34,980</td>
<td>$24,417</td>
<td>$7,962</td>
<td>$3,383</td>
<td>$56</td>
</tr>
<tr>
<td>Primary Sludge Pumping</td>
<td>$2,334</td>
<td>$12,496</td>
<td>$5,625</td>
<td>$605</td>
<td>$56</td>
</tr>
<tr>
<td>Aeration Tank</td>
<td>$37,100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diffused Air Aeration</td>
<td>$119,711</td>
<td>$170,317</td>
<td>$114,474</td>
<td>$1,339,045</td>
<td></td>
</tr>
<tr>
<td>Secondary Settling Tank</td>
<td>$39,528</td>
<td>$25,603</td>
<td>$8,141</td>
<td>$3,817</td>
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</tr>
<tr>
<td>Recycle Sludge Pumping</td>
<td>$2,689</td>
<td>$603</td>
<td>$430</td>
<td>$300</td>
<td>$2,014</td>
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<tr>
<td>Gravity Thickener</td>
<td>$5,777</td>
<td>$11,311</td>
<td>$5,560</td>
<td>$462</td>
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<tr>
<td>Primary Anaerobic Digester</td>
<td>$36,622</td>
<td>$39,153</td>
<td>$23,771</td>
<td>$4,138</td>
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</tr>
<tr>
<td>Secondary Anaerobic Digester</td>
<td>$2,128</td>
<td>$10,169</td>
<td>$5,214</td>
<td>$563</td>
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<tr>
<td>Vacuum Filter</td>
<td>$3,673</td>
<td>$96,324</td>
<td>$12,671</td>
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<tr>
<td>Recycle Stream Pumping</td>
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<tr>
<td></td>
<td>$284,040</td>
<td>$400,659</td>
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<td>Sub-Total =&gt;</td>
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<tr>
<td>Energy Credit:</td>
<td>$37,253</td>
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<tr>
<td>Sludge Disposal:</td>
<td>$31,594</td>
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<tr>
<td>Total Annual Cost:</td>
<td>$2,191,346</td>
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<td></td>
</tr>
</tbody>
</table>

Figure 5.30
Influent

Primary Clarifier

Activated Sludge

Final Clarifier

Gravity Thickener

Primary Digester

Secondary Digester

Vacuum Filter

Cost Summary

Cost Parameters

Cost Type:
- Capital Cost
- Operations Cost
- Maintenance Cost
- Supplies
- Power

Primary Settling Tank

- Primary Sludge Pumping
- Aeration Tank
- Diffused Air Aeration
- Final Settling Tank
- Return Sludge Pumping
- Recycle Pumping
- Gravity Thickener
- Primary Digester
- Secondary Digester
- Vacuum Filter

Ref. Point = 2587.29
Span = 500.00
Coeff a = 824.00
Coeff b = 0.77

Figure 5.32
Influent

Primary Clarifier

Activated Sludge

Final Clarifier

Gravity Thickener

Primary Digester

Secondary Digester

Vacuum Filter

Figure 5.33
IF  View/edit 17

Flow Model
- Fixed Process Flow
- Cost Summary
- Specified Loading
- Solve

Building

Cost

Quitting

Influent

The y-axis value of Ref. Pt. - $318

Cost Parameters

Supplies

Cost Type

Capital Cost

Operations Cost

Maintenance Cost

Power

Cost

Bulkin on Cost

(Cont.)

Quit

Figure 5.34
Influent

Primary Clarifier

Activated Sludge

Final Clarifier

Gravity Thickener

Primary Digester

Secondary Digester

Vacuum Filter

Figure 5.35
Influent

Primary Clarifier

Activated Sludge

Final Clarifier

Gravity Thickener

Primary Digester

Secondary Digester

Vacuum Filter

Figure 5.37
**Figure 5.40**

<table>
<thead>
<tr>
<th>Current Configuration</th>
<th>Cost Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Configuration</td>
<td></td>
</tr>
</tbody>
</table>

Cost Parameters:
- Capital Cost
- Operations Cost
- Maintenance Cost
- Supplies
- Power

Cost Types:
- Primary Settling Tank
- Primary Sludge Pumping
- Aeration Tank
- Diffused Air Aeration
- Final Settling Tank
- Return Sludge Pumping
- Recycle Pumping
- Gravity Thickener
- Primary Digester
- Secondary Digester
- Vacuum Filter

Ref. Point = 300.00
Span = 500.00
Coeff a = 1000.00
Coeff b = 0.53
Influent

Primary Clarifier

Gravity Thickener

Primary Digester

Vacuum Filter

Effluent

Land Fill

Figure 5.42
Figure 5.43
CHAPTER 6
DISCUSSION AND CONCLUSION

A prototype computer aided system has been developed for a WTPD model. The prototype is intended to improve the effectiveness of implementing decision making analysis tasks (see Chapter 3). An analyst or decision maker does not have to be a computer expert to use the prototypes, and the user-friendly interfaces require a minimal time for learning. The interactive response time is quick and editing is easy. The prototype also takes care of many time-consuming tasks: bookkeeping, tabular data preparation, data management, etc. These tasks usually occupy a significant amount of an analyst's time. With the prototype, these tasks can be done as simply as pushing a button. Thus, the analyst's time can be spent more efficiently in examining issues for generating good alternatives. The productivity of the analyst is then enhanced.

Although the system is for a specific problem, it illustrates concepts of developing computer aided systems for engineering design. The discussions in the next section focus on general issues in the design of a computer aided system for engineering decision making problems. The discussions are based on the general components of such a system discussed in Chapter 3 and use examples from the prototype.

6.1. Issues In Developing Computer Aided Systems

Mathematical Techniques and Tools

An engineering decision-making problem usually requires the use (or development) of several mathematical techniques or tools. In addition to general characteristics such as accuracy and efficiency, the linkages among the users, techniques, tools, and other components in the computer aided system should be effectively built for incorporation of mathematical techniques and tools into a computer aided system.

Setting up an input format, for a software package is generally time-consuming for somebody who is not familiar with the package, and it may be difficult to transfer an output from a package to become an input to another package. An interface is therefore suggested as a bridge among mathematical packages.

The interface can be presented graphically as in the graphic object oriented approach. The graphical objects, of course, cannot fully replace a mathematical model because of completeness and accuracy, but they provide a good overview of a model. The perception of graphical objects as a model can be improved if a more precise presentation can be provided. For example, the size of any closed box in Chapter 5 to express a unit process can be used to represent the physical size, and the size can be understood if a scaling aid is provided. Even though such an improvement may be possible, there is always a tradeoff between capability and simplicity. Providing a scaling aid may complicate the working screen, and it may take more time to see the exact value from the size than from the mathematical model.

Making decisions about tradeoffs between capability and simplicity is a very important activity in this area of research. Different decisions may change the final product significantly. The main factors considered in this research for the decisions
are: user's preference, available software and hardware facilities and their limitations, implementation time, frequency of usage, and contribution. In other words, a function should not be designed if it is hard for the user to understand or learn, difficult to implement on current facilities, forms a bottleneck and slows down the system, or only useful for a specific situation or purpose.

**Graphical Interface**

As mentioned and demonstrated, the graphical interface is mainly used for presentation. Presentation is important in doing design tasks and making good decisions. However, presentation of an attribute (e.g., cost), model (e.g., wastewater treatment plant model), or solution (e.g., noninferior set) sometimes is difficult.

Clarity and simplicity are characteristics of a good presentation, but they are usually in conflict with each other. For example, in the WTPD case a lot of information can be shown for a design. In the PC version, a menu system with up to four levels of pop-up windows was used. Although each screen provides clear information for an individual piece of the design, the user may not easily recall the entire system. One way to overcome this complexity is not to use pop-up windows. The screen size of an Apollo workstation monitor is suitable to hold most of the desirable information, but there are several complexities for this way of presentation: 1) too much information shown at the same time may be difficult to handle; 2) display of detailed information about a component, such as a unit process, would reduce room for other information, e.g., about the plant scheme; 3) the designer usually does not need most of the information simultaneously; 4) the design screen may become complicated and the response time will be increased. Thus, a decision was made as a compromise between the clarity and simplicity: a menu system with up to two levels of pop-up windows was used for the final WTPD prototype. The second level of pop-up windows shows infrequently examined or less important attributes of a design, and these attributes are expected to be examined only about once for a design. When a second level pop-up window is needed, it is displayed beside the first level pop-up window instead of erasing the first one (Figures 5.12, 5.14 and 5.16). The designer, therefore, still has a chance to examine all related information at the same time, while the simplicity of usage, display, and response is maintained.

Judgments on the tradeoff between clarity and simplicity in presentations occur in many situations, e.g., use of hidden screen(s), places to show pop-up windows, layout of presented information, etc. There are no explicit rules for making the judgments because they are problem dependent, but the general concept for making the judgments is to make modifications to increase both clarity and simplicity while maintaining an acceptable level of each. This in itself is a multiobjective decision-making problem with unquantifiable issues. Using the MGA conceptual approach, having typical users examine several different alternative presentations may be the best way to make the decisions.

Although the graphical interface is used mainly for presentation, it should not be restricted to that purpose. For example, the plant scheme and graphic objects demonstrated in Chapter 5 can also be used as an interface to retrieve information related to a physical component expressed as a graphic object. A graphic interface may reduce the complexity of a user interface significantly.
User Interface

A computer aided system requires a good user interface. The characteristics of a good user interface are, as described in Chapter 3, ease of learning, minimization of mistakes, flexibility in modification, efficiency of data and solution organization, and clarity of instructive feedback.

A pointing device, mouse, is used to make most option selections in the prototype. By moving a mouse and clicking a button on a desired menu item or graphic object, a function can be easily selected with the response displayed immediately after the selection. In case the user makes a logical mistake, feedback (e.g., beeper or error message) will explain the mistake and give some suggestions. For example, if an attempt is made to solve an infeasible design, then a pop-up window will be shown with a message for violations and possible modifications to the design. Mistakes such as the infeasibility example are hard to prevent in advance of a design session, but many general mistakes are preventable. For example, in developing the two prototypes, the layout of all menu items was carefully arranged to avoid inadvertently selecting wrong menu items. In the prototype, there are free and fixed groups of menu items. The two groups are put in different areas on the screen, and the menu texts of the inactive items are turned gray and cannot be selected. The chance of inadvertently selecting wrong items is thus significantly reduced.

Another important aspect of a user interface is data and/or solution management. Tedious tasks, such as bookkeeping, data storage, classification, etc., usually take a significant amount of an analyst's time. The computer aided systems should be responsible for implementation of these tasks so that an analyst can spend time more efficiently. Although the details of the design of data and solution management are not described, the general concept used was to keep most data during a working session in a hardware memory which has fast accessibility but is of limited capacity. Data are saved permanently in an alternative memory when the user is not actively engaging the system, e.g., he is thinking or reading. This concept is to try to make the best use of the capabilities of a computer. The storage and retrieval of data in the two prototypes are generally not necessarily explicit to a user except when the user interface is used. The file in storage, however, should be opened to a designer if needed. For example, the mathematical models for the prototype were stored by the designer's name and can be used separately without the prototype. The files for models can be used for other purposes, e.g., presentation or input to a software package.

This section discusses general issues with examples from the demonstrated prototype. While the prototype is for a specific problem, the general issues such as those described above and in Chapters 1, 3, and 5, are applicable to many other problems. Currently, few systems have been developed for environmental decision-making problems. This research is intended to demonstrate the capability of a computer aided system to improve an environmental decision-making analysis. To summarize this research, the use of a computer aided system in a decision-making process is discussed further in the next section.

6.2. Decision Maker(s), Analyst(s), Computer Aided System(s) and Decision-making Process(es)

Without computer aided systems, the decision-making processes presented in Chapter 3 (Figure 3.1 and 3.2) would be implemented step by step and iteratively until a good decision is reached. However, with computer aided systems on a multi-tasking workstation, the analysis and decision-making process can become
more dynamic. The analyst can jump from one task to another more easily. Both analyst and decision maker can use the same systems to examine the issues of concern, and thus it is possible to have greater interactions between them. Also a new task(s) which is significant for a particular decision-making problem may be needed in a given case. For example, the decision maker may want to identify a utility function to generate a compromise solution. Computer aided systems allow the extension of tasks, e.g., a utility function can be easily added to a model by the modeling language. The decision making process shown in Figure 3.1 is therefore not enough to explain these dynamic manipulations. A new dynamic decision-making process is thus proposed as in Figure 6.1. The process is less sequential. Instead, interaction, interruption, and detour may occur more readily at any stage of the process.

As shown in Figure 6.1, the analyst, decision maker, and friendly interface provided by computer aided systems form an efficient dynamic decision making process. By using computer aided systems like the prototypes, it is expected that decisions can be made in a more efficient and effective manner.

The prototypes can also serve as an interface between an analyst and a decision maker. The prototypes can be used to present the alternatives to the decision maker, and the decision maker can examine the alternatives directly on the graphical interface provided. Interactions between the analyst and decision maker should be made easier. Better solutions could result and the time required for a decision-making process could then be significantly reduced.

6.3. Future Research

Since the computer aided system is a research prototype, a number of changes or extensions are needed to make it more complete, more robust, and more efficient. For example, other user friendly features such as "cut and paste" may be used. Of course, there is always a trade-off between capability and simplicity. How to provide the maximum capability while maintaining simplicity is a key research issue in developing a computer aided system. Several suggestions for improvements or potential extensions of the prototype or new techniques are listed below:

- explore ways to present attributes of the WTPD model for comparison;
- overcome the numerical difficulties that occurred in solving a highly nonlinear WTPD model and improve the computation efficiency in optimizing the model;
- extend the WTPD model to include any process system;
- provide flexibility in: selecting a graphic object to express an attribute or real object, adding attributes to the prototypes, modifying the way to create an optimization model, and arranging the display and layout of menu items or models; and
- provide easy-to-learn tutorials (as the one developed for IDEAS [Brill, et al., 1989]).

Certainly, there are many other useful options to extend the prototype. To provide an additional capability might, however, increase the complexity of using the prototype. Before an extension is made, it should be evaluated carefully to ensure that the benefit justifies the complexity. An improved computer aided system should also be easy to learn and use.
implement a task(s) using a computer aided system
possible sequence for implementing tasks

Figure 6.1 A Working Process For A Decision-making Problem
APPENDIX A

PROGRAM STRUCTURE

The overall design and characteristics of the programs of the prototype computer aided system are described in this appendix. The designs of programs for mathematical techniques are not described. The codes are not listed, but an overview and the structure of the programs are provided. The length of the programs is about 9000 lines in total. Several languages and software packages were used to develop the programs on an Apollo workstation, a Unix based computer equipped with a 1024x1280 monochrome screen monitor, a three-button mouse, and a QWERTY keyboard.

The two major software packages that were used in the development of the programs are briefly discussed, with several examples, in the following section. The programming structure of the programs is then described for several major tasks.

A.1. Software Packages

Two major packages, DOMAIN/DIALOGUE [1987] and DOMAIN/2D Metafile [1985], were used to develop the programs. Each package is briefly discussed below with some examples from the programs.

DIALOGUE (Purpose: Interface Design for Menu Items)

DIALOGUE, an Apollo DOMAIN interface language, was mainly used to design the user-interface of the programs. A detailed description of DIALOGUE can be found in the DOMAIN/DIALOGUE User's Guide. Only a brief discussion based on the programs is presented here.

The interface between the users and application programs (developed by the software designer for special tasks) was established by means of a DIALOGUE descriptive file. The descriptive file contains two major sections: Application Interface (see the left column in Table A.1) and User Interfaces (see the right column in Table A.1).

The Application Interface consists of programmer defined selections which are linked to application programs. Each selection could be associated with a predefined DIALOGUE task (e.g., task MSG will display a message, and task STRING will wait for input of string data—see DOMAIN/DIALOGUE User's Guide for a complete list). For example (see the left column in Table B.1), the selection “ViewEditModel” is linked to the application program “pSwitchWork” and associated with the DIALOGUE task MENU. This means when one of the options, ViewEdit or ModelOpt, in “ViewEditModel” is selected by the user, DIALOGUE will pass control to the application program “pSwitchWork” to switch working status.

The User Interface is used to construct the menu items to be displayed on the screen of the interface. Several characteristics of the menu items can be defined separately: characteristics such as the orientation, the shape and color of the menu item, the character string that appears on the menu item, the help message associated with the menu item, and the font and size of characters. For example (see the right column Table A.1), the selection “SwitchWorki” will display a checkbox type menu with two selections of “View/Edit” and “Flow Model” and the help message will be displayed on the screen when requested by the user. The overall
Table A.1: Sample DIALOGUE Descriptive File: Application and User Interfaces

APPLICATION_INTERFACE wwtpface
{--------MainMenus--------}
ViewEditModel:= ENUM:
    COMP => <call pSwitchWork>;
    CHOICES = (ViewEdit ModelOpt);
    VALUE = ViewEdit;
END

MethodList:= ENUM:
    COMP => <call pMethod>;
    CHOICES = (Fixed Process sizes Specified Loadings);
    VALUE = FixLoading;
END

Solve := NULL:
    COMP => <call Solving>;
END

Bulking := NULL:
    COMP => <call pBulking>;
END

CostShow := NULL:
    COMP => <call pCostUnits>;
END

Quit:= Null:
    COMP => <RETURN>;
END

USER_INTERFACE wwtpface
{--------Top Row--------}
MainMenus := ROW:
    ORIENTATION = horizontal;
    CONTENTS = (SwitchWork MethodSwitch Solve Bulking Cost Quit);
END

SwitchWorkl := MENU:
    ORIENTATION = horizontal;
    MARKSTYLE = checkbox;
    FONT = */sys/dm/fonts/times-bold14*;
    Task = ViewEditModel;
    ENTRIES = {
        "Switch the working status"
    };
    HELP-TEXT = "Switch the working status";
End

MethodSwitch := MENU:
    ORIENTATION = horizontal;
    MARKSTYLE = checkbox;
    FONT = */sys/dm/fonts/times-bold14*;
    Task = MethodList;
    Color_set = off;
    ENTRIES = {
        "Fixed Process sizes"
    };
    HELP-TEXT = "Selection solution method."
End

Solve := ICON:
    TASK = Solve;
    STRING = "Solve";
    FONT = */sys/dm/fonts/times-bold14*;
END

Bulking := ICON:
    TASK = Bulking;
    STRING = "Bulking";
    FONT = */sys/dm/fonts/times-bold14*;
END

Costl:= ICON:
    TASK = CostShow;
    select =>
        <CostTypesPop show; + take_locator>;
    FONT = */sys/dm/fonts/times-bold14*;
    String = "Cost";
END

Quit := ICON:
    FONT = */sys/dm/fonts/times-bold14*;
    TASK = Quit;
    STRING = "Quit";
END
layout of the menu items on the screen is then defined. For example (see the right column in Table A.1), the menu items defined by "SwitchWorki," "MethodSwitch," "Solvei," "Bulkingi," "Costi," and "Quit" are grouped next to each other by "MainMenus" as the top row options described in Chapter 5.

The use of DIALOGUE greatly expedites the user interface design of the programs to provide a user-friendly working environment.

2D Metafile (Purpose: Graphic Display)

The other major package used for developing the programs is Domain/Graphics 2D Metafile. It was mainly used to display the process scheme, performance model curves, cost curves, and other graphical output. This graphics package provides not only some primitive options, such as line, circle, and box, but also some useful operations on graphics statements. The programs exploited two useful operations (segment and pick-and-identify operations) to display figures and also provide interactive ability.

The 2D Metafile provides the facility to define a group of graphic objects as a segment, and to perform actions on each segment. For example, a process scheme consists of boxes and polygons (unit processes), shaded or unshaded diamonds (inflow, underflow, and outflow indications), lines (flows or links), and text (process names), one or several of which can be grouped as an individual graphics segment. This facility allowed the programs to be designed to be interactive.

The 2D Metafile also provides the facility to pick and identify graphic objects on the screen. This allows the programs to locate the position of the mouse cursor on the screen and the graphic object to which the mouse points. This facility immensely contributed to the interactive ability of the programs.

A.2. Program Structure

The programs were mainly written in PASCAL. Figure A.1 shows the logical sequence for one operation of the programs in the working session. The User Interface portion was designed using DIALOGUE.

Since the prototype is interactive, the program structure does not follow a fixed flow or a hierarchical pattern. The programs can be interrupted or redirected based on user responses, so a traditional program flow chart or a hierarchical tree is not sufficient to explain the whole program structure. Instead, the programs are described by groups of program modules used to implement specific tasks. However, these groups are related to each other, and should not be considered as independent.

Program modules are grouped in the following categories: initialization, graphic display, action response, checking and warning, interactive ability, numerical model, message, and data management. The concept and/or program logic for each group is described below.

Initialization

Modules in this group are used to initialize data, parameters, graphical screen area, interface layout, and message entries. Initialization is done at the initial use of a program or a function. For example, the initialization of the graphical area will not be done until a graphical display is needed.
Figure A.1 Logical Sequence For One Operation
Graphic Display

The modules in this group do not function independently. They are usually called by other modules to display or modify graphic objects on the screen.

Message

This group is used to provide messages in response to user actions. These messages report the current status of an operation and provide further instructions pertaining to the operation. Modules related to the display of messages cannot be separated into individual modules as they appear in many places in the programs.

Action Response

This group forms the main body of the programs. The responses to a selected operation can be textual (e.g., messages described earlier), graphic (e.g., curves), or tabular (e.g., list of cost summary).

Checks and Warnings

Many error checks are performed after each action selected by the user. If an error check fails, generally a beep will be sounded with the display of an error message. The error checks include: wrong keystroke, infeasible design, wrong cursor position, change of working design without saving current modified working network, recycle flows, etc. Although most checks do not form an individual module, they do operate independently to help users avoid making mistakes.

Interactive Ability

The interactive ability of the programs was accomplished using two major features: 1) menu items of the user interface, built using DIALOGUE, to detect operation selections, and 2) the two modules written using 2D Metafile, to take control from DIALOGUE to continue the execution of the selected operation. As mentioned in Section A.1., the facility to pick and identify graphic objects makes possible the interactive capability of the programs. Although checks and displays are not included in this group, they are part of the interactive operations.

Numerical Model

Program modules for information and for implementing the mathematical techniques. They are independent and can be isolated from the prototypes if desired.

Data Management and Operation

The various categories of data (e.g., list of design parameters, plant scheme) for each user were stored in different files or data structures, which were uniquely named based on the user’s name.

Operations in the programs may jump from group to group or module to module without following a fixed sequence. The descriptions listed above provide an overview of the design of the programs.

The programs have been demonstrated to several professional environmental engineers. Its user-friendly fashion lets a designer or an analyst easily implement
decision-making analysis tasks without reading any user manual in advance. The learning time for using the computer aided system is short. Although the problem is complex, the interface guides the user in developing good alternatives. Also, the high resolution Apollo Domain 1280x1024 monitor has provided a good working environment for both the programmer and users.
REFERENCES


