Title: Expert System for Troubleshooting the Activated Sludge Wastewater Treatment Process

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Abstract: This report deals with development of a knowledge based system for use in troubleshooting the activated sludge wastewater treatment process. It discusses the anticipated hurdles to be overcome and benefits to be realized. It provides an outline of the proposed system and an example of its use. The report also addresses the organization, stages, and expected resources for the development of such a system.

DEVELOPMENT OF AN EXPERT SYSTEM FOR TROUBLESHOOTING THE ACTIVIATED SLUDGE WASTEWATER TREATMENT PROCESS

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and R. Wagner

EMP - P9003

EXECUTIVE SUMMARY

The activated sludge process is used in wastewater treatment to remove suspended and dissolved organic matter from municipal waste streams. A biological mass (biomass), which feeds on the organic material present in the wastewater, is grown and provided with oxygen via aeration.

This process is perceived as a black box by the operations staff of a typical plant. These personnel do not clearly understand the principles on which the process operates. Although this minimal level of understanding is sufficient for day-to-day processing, any serious problems currently require the services of a consultant or domain expert.

The quantity of heuristic knowledge involved in troubleshooting the activated sludge process, and the relatively small number of people possessing this knowledge, make it an excellent candidate for incorporation into an expert system. The expert system software may be marketed either independently or as part of larger contract packages.

The primary benefits to be realized by system users are that (a) human consultants will no longer be needed, except in unusually severe cases, and (b) plants whose processes have gone awry can be corrected more quickly, thus reducing the chance for release of undesirable substances into the environment.

The proposed expert system is to be developed at a nationally recognized consulting firm, using the knowledge of in-house and leading industry domain experts. The knowledge can be best represented in a structured production system format, which readily enables the knowledge utilization methods of forward and backward reasoning.

Input from potential system users will be extensively garnered during the full scale system development stage to maximize user friendliness and resultant system utilization in the field.

Financial resources for system development will be derived primarily from capital in the consulting firm's research and development budget. This may be augmented by grants from government sponsored research organizations such as the National Science Foundation.

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INTRODUCTION

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BACKGROUND

The activated sludge process is used in wastewater treatment to remove suspended and dissolved organic matter from the wastestream. A biological mass (biomass) is developed which feeds on the organics and solids present in the wastewater. Dissolved oxygen is provided by mechanical aeration or diffused aeration in the aeration basin to maintain the biomass in an aerobic state. The biomass settles out of the wastestream in the secondary clarifier producing a clear effluent. The biomass which settles out is returned to the aeration basin to again feed on the wastestream. The effluent that leaves the clarifier is discharged to the receiving water body, a river or lake. The effluent must be treated to the level required to meet the current secondary treatment standards defined by the EPA. Figure 1 shows a diagram of the activated sludge process.

An upset in the process due to a biomass that becomes inactive or one that does not settle properly in the secondary clarifier will allow organics and/or solids to enter the receiving water body. An effluent that exceeds the standard defined by the EPA will result in a violation. Violations may result in fines to the owner of the treatment facility and repeated violations could result in building restrictions being imposed on a municipality.

SYSTEM PURPOSE

This section discusses the principal problems associated with the activated sludge wastewater treatment knowledge domain, the reasons why this expertise lends itself to incorporation into a knowledge-based system, and the benefits that can be realized from such a system.

DOMAIN PROBLEMS

The activated sludge process is understood by most operations staff as a black box. The principles by which the process operates are, for the most part, not clearly understood by plant operators. This is not a problem during normal day-to-day process operations. However, when a process problem occurs, operations staff typically do not possess the education and research skills necessary for effective troubleshooting.

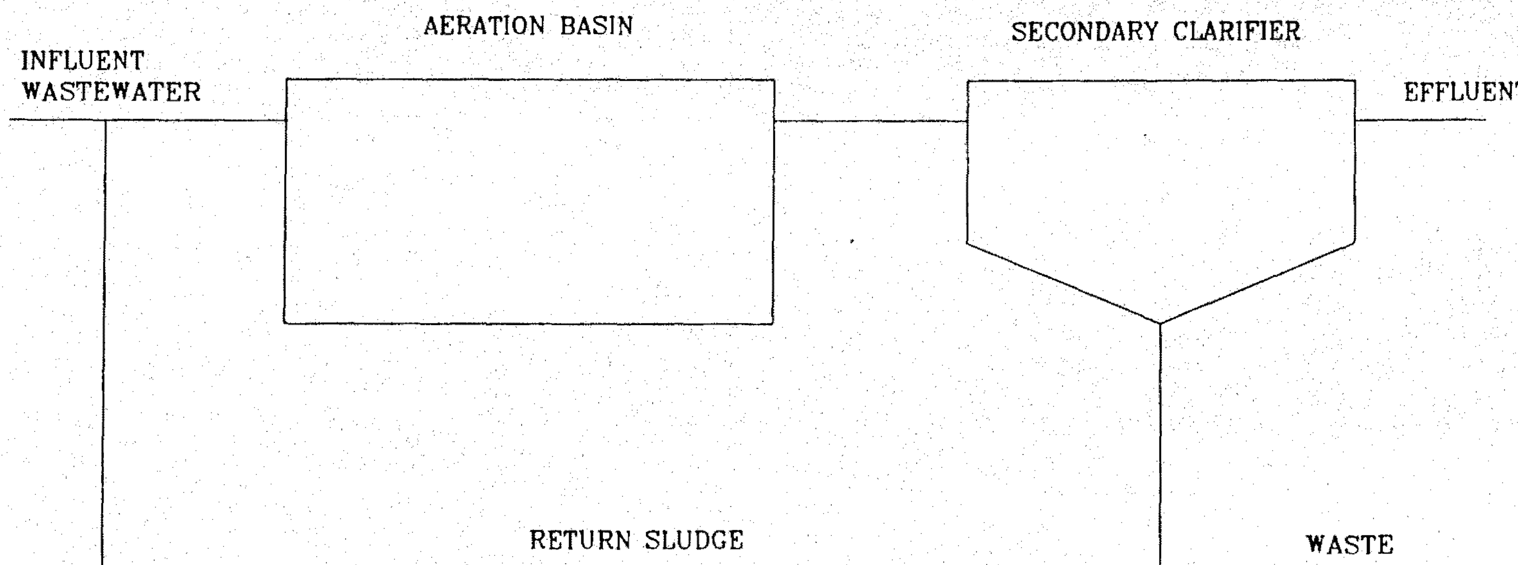

FIGURE 1
ACTIVATED SLUDGE PROCESS

Thus, the services of a consultant or domain expert are currently needed when problems arise. This usually entails a special trip to the problem plant by the consultant for problem diagnosis and rectification.

Unfortunately, the total number of domain experts in this country is relatively limited with respect to the number of wastewater treatment facilities. Further, many of these consultants are approaching retirement age and their accumulated knowledge will be lost to the industry.

Two main problems arise from the cumulative situation described above: (a) process difficulties at a particular plant may not be diagnosed and corrected as quickly as they should be, and (b) the troubleshooting is costly to the plant operating organization because of the human consulting services that are required.

REASON FOR SELECTING KNOWLEDGE BASED SYSTEM

The type of knowledge used for wastewater treatment process troubleshooting is largely heuristic in nature and is not easily represented in a simple decision tree format. Furthermore, the troubleshooting expertise draws on several related scientific and engineering fields, thus covering a significant amount of technical ground. When combined, these two factors strongly suggest the use of a knowledge-based system for harnessing this diverse and sometimes fuzzy knowledge.

A knowledge-based troubleshooting program will provide the expertise and background knowledge in the fields of microbiology, chemistry, physical science, hydraulics, and sanitary engineering which is necessary to thoroughly understand and effectively troubleshoot the process. The application of knowledge-based engineering tools during system development will result in an improved user interface by providing a new and significantly better method for handling the large amount of interdisciplinary information.

EXPECTED BENEFITS

A knowledge-based computer program which addresses troubleshooting of the activated sludge wastewater treatment process will essentially put expert knowledge tools into the hands of the day-to-day wastewater plant operations staff. The domain expertise will no longer need to be provided on a consulting contract basis. Instead, it will be readily available for immediate application when and where needed.

The troubleshooting guide will be marketed as a software package to accompany existing software tools currently marketed by a nationally recognized consulting firm. A further advantage is that marketing the system will provide additional income to this firm.

SYSTEM FUNCTION

The use of the activated sludge expert system in the treatment plant is dependent on the methodology used for making process decisions. An understanding of this methodology is required to understand how the expert system will be used. This section discusses this decision methodology.

Process decisions are made in the wastewater treatment plant by the operator in responsible charge of the specific unit process. Process adjustments are typically made on a daily basis. Figure 2 Activated Sludge Process Control Decision Model, graphically shows a model of the sequence of events that occur in the decision making process for activated sludge process control.

PLANT OPERATING CONDITION

The central feature of the process control model is the plant operating condition. This is the present state at which the treatment plant is operating. This operating condition is not one of steady state. The operating condition is one that is continually changed due to two influences: Influent waste and equipment operation.

The characteristics of the influent wastewater are highly variable. These characteristics are typically quantified as flowrate, biochemical oxygen demand (BOD), total suspended solids TSS), and pH. These variables change throughout the day as the habits of the contributors, local population, change. For instance, the flowrate is highest in the midmorning hours and the evening hours and lowest in the middle of the night. This corresponds to the residents of the local area contributing to the treatment plant in the morning when they get up and in the evening when they return from work and get ready for bed. Obviously, the treatment plant operator has no control over these variables although the operating condition of the process will change with changes in the influent waste.

The variables that the operator has còntrol of are through the operation of the equipment in the treatment plant. Careful consideration must be given to the changes in the operation of the equipment to insure that the appropriate action is taken to counteract the effect of the changing influent wastewater.

COLLECT INFORMATION

The operator must collect information about the process before he can determine the appropriate control action to be taken. The operator can collect information in three forms. These are visual observations, plant instrumentation, and laboratory analysis.

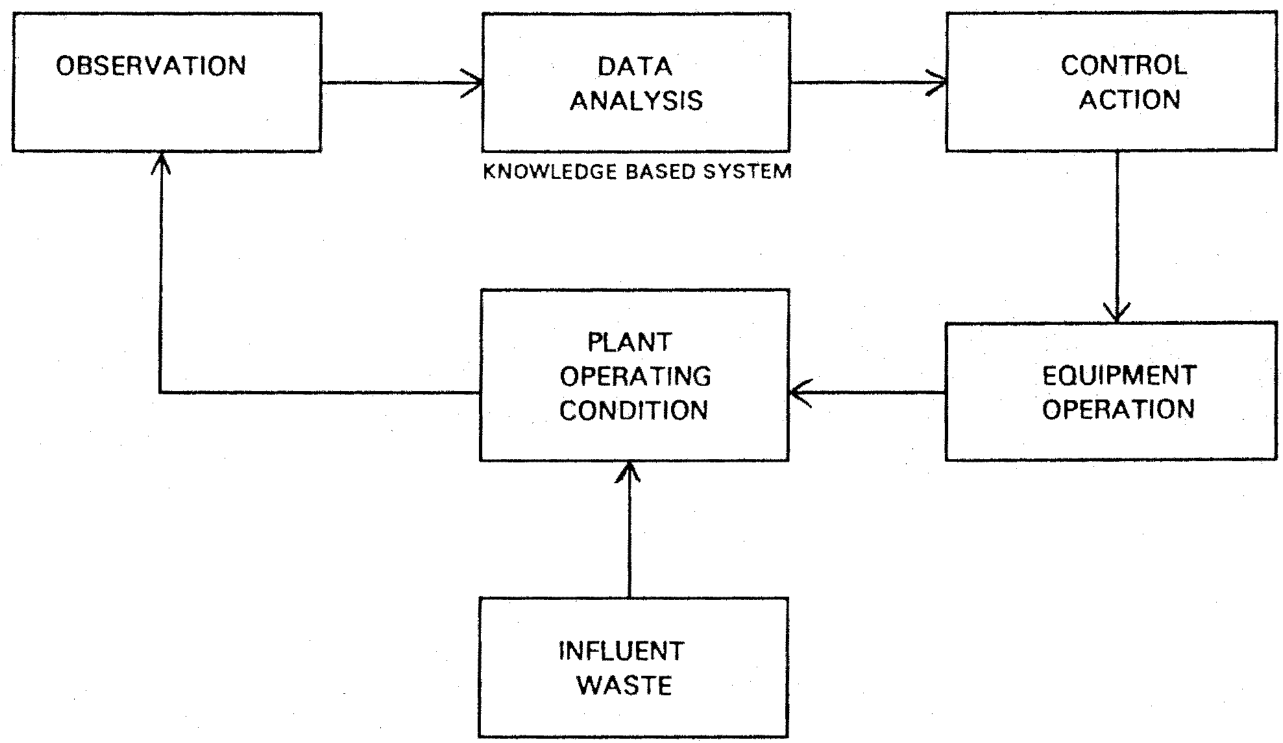

FIGURE 2
ACTIVATED SLUDGE
PROCESS CONTROL DECISION MODEL

Process information based on visual observations is extremely important. This is because instrumentation is not available to gather much of the information necessary to make control decisions. Visual observations include foam color and characteristics, effluent clarity, effluent color, and sludge color. Use of this information is highly dependent on the experience and judgement of the operator and may be interpreted differently by various experts. The rules-of-thumb that relate to process changes due to these visual observations are not always technically proven and may not be accurate as they tend to be judgmental.

The capability of on-line instrumentation in the wastewater treatment field is extremely limited. Wastewater is not an homogenous liquid which makes it extremely difficult to obtain representative readings from primary elements. Properties of wastewater such as grease content and biogrowth causes fowling of the primary elements which makes them difficult and labor intensive to maintain.

Proven primary elements successfully used in the wastewater field are level probes and flow meters. Primary such as density meters, suspended solids probes, blanket detectors, and pH meters have not proven dependable. Current research in this area is showing promising developments, but the technology cannot be depended on in the immediate future.

Due to the current problems with the use of dependable primary elements, on-line instrumentation to monitor process variables is limited. Values such as flow and volume can be measured and are typically recorded on a daily basis by operations staff.

Laboratory analysis of the wastewater is performed on a daily basis. The results are used by the operations staff to determine the current operating condition of the process. These samples are either a composite or grab sample depending on the test that is to be performed.
A grab sample is a single sample of the flowstream taken at a specific time. This sample represents a snapshot of the process at that specific time. This sample type is use for analysis of pH, dissolved oxygen, and settling characteristics (SVI). The results of this type of sample are useful to the operator, but must always be used with the knowledge that it is only a single data point for a process that changes with time.

The composite sample is a collection of samples taken from the flowstream and mixed. These samples are typically composited by time or by flowrate. This sample is analyzed in the laboratory for wastewater characteristics such as biochemical oxygen demand (BOD), suspended solids (TSS), and total solids (TS).

PROCESS INFORMATION ANALYSIS

The operational data that is collected in each of the three forms is analyzed by the operator to determine the proper control strategy that will be implemented. This analysis is usually done by performing standardized calculations and comparing the raw data and calculated data with the same data previously calculated. The data obtained on the previous day and in many cases during the previous week is analyzed with the current information in the form of trend charts. Interpretation of trends which may be occurring in the process is a necessary skill of the operator. The identification of a change in a process variable that will show a possible future upset to the process necessary to maintain a high quality plant effluent.

After observing a change in the process variable, the operator must determine the proper changes to the process that will correct the current problem or redirect the potential problem. The operator uses judgement gained from training and experience in the operation of the process to determine the proper control action that should be implemented.

CONTROL ACTIONS

Control actions are typically made once per day to the process. The control action stays in effect for that day. The operator then makes another control action the following day using the information that was collected on the process under the control scheme that was implemented the previous day.

EQUIPMENT OPERATIONAL MODES

The control actions are implemented through changing the operation of the process equipment. Most of the process equipment used in the activated sludge treatment process are pumps, aerators, and blowers. Changes in the operational modes of this equipment is usually done by changing the speed or pumping rate or by changing the duration by which the equipment item operates, which also affects the volume pumped.

Modifications to the equipment's operational mode will change the distribution of active biomass in the activated sludge process or change the level of oxygen in the aeration basin. These changes will solve a majority of the operational problems.

USE OF THE EXPERT SYSTEM

The major element which will determine the success of this system is the manner in which the system interacts with the user. This system must interact with the user to provide "expert" information when and in the format that the user needs the information in the data analysis step of the process decision model. The design of the knowledge user interface will provide the capability for this base of knowledge to be used in a variety of different ways making it a very useful tool to all professionals working in the treatment profession. Potential uses of this expert system will be:

- o Operator Training Programs
- o Plant Operators
- o On Line Troubleshooting Assistance (Remote trouble shooting)
- o Plant Design Analysis

The common base of "expert" knowledge will serve several purposes. The expert system user interface must be designed so each of these users can work with the database. Examples on the use of the system for these functions are described below.

OPERATOR TRAINING PROGRAMS

Operators can use this system to develop the knowledge of wastewater plan operation and trouble shooting. This can be done by simulating real problem situations. This will allow the operator to get familiar with the human computer interaction/cooperation.

PLANT OPERATORS

This system will be used as an intelligent operation and troubleshooting assistant. When a symptom is found that can lead to a problem, the user can key in the symptom and follow the guideline question and answer to come up with the potential problem. Then they might want to get the action procedure or check/evaluate some particular problem prior to seeing the action procedure.

Another task can be to keep records of new problems which have not been incorporated into or anticipated by the system. The users need to record failures of this system to give a correct guideline to a certain symptom or problem. This information will be helpful for the expert to review/evaluate the knowledge base system and to update it.

TROUBLESHOOTING ASSISTANCE

This system can be used remotely as a telephone service to provide quick assistance and problem troubleshooting. This task would also include the record keeping of new problems and feedback on the performance of the knowledge system.

PLANT DESIGN ANALYSIS

The task of the design engineer is to update and review the validity of their designs. Critical requirements of a treatment plant design is the capability of the design to consistently produce and acceptable plant effluent. This knowledge base can be used by the designer to perform a vulnerability analysis on the treatment plant design by suggesting potential problems in the process and having the expert system determine what may happen. The design engineer would use this information to check the plant design to see if the capability to overcome this problem is included in the design.

KNOWLEDGE REPRESENTATION

The knowledge used here is based on the actual experience gathered in the operation of wastewater plants. The initial knowledge was collected and is organized in the format that outlines the thought process of the troubleshooter. An outline of this information is shown in Appendix A. This information shows the thought process that the troubleshooter uses, but does not provide the knowledge in the necessary format to incorporate into the expert system. This knowledge did provide the basic information needed to organize the knowledge into a useful structure.

Using an approach similar to the work package approach developed by Niwa, the information was organized as an Activated Sludge Process Knowledge Package. To organize the knowledge into this package, the activated sludge process was divided into process activities and equipment.

The first step was to determine all of the equipment that makes up the activated sludge process. A sample listing of this equipment is shown in Table 1. The activated sludge process was then divided into the activities which work within each stage of the process. A sample of these activities is shown in Table 2. The process activities and process equipment was then placed on a common matrix with the Activated Sludge Process Knowledge Package was developed. This is shown on Table 3.

This package allows for the identification of the specific relationships between process activity and equipment items. The relationships are shown by a shaded box in the matrix. This follows the decision model that was developed earlier in this paper. The process activity is the operating conditions of the process that the operator is monitoring. The equipment items are the control variables that the operator has to work with to make process changes. This matrix links these two variables.

The next step was to determine the types of problems that could occur with a failure of a process activity or an equipment item. These are the problems that the user will need help from the expert system to solve. These problems are linked to the specific cause of the problem through problem factors. A problem factor then relates directly to a specific knowledge package, which would be problem with an equipment item or process activity. A sample of this concept is shown on Table 4.

The goal of knowledge organization is to develop condition-action pairs such as IF A THEN B, which are called production rules. Some example of production rules are:

1. If low dissolved oxygen then brown foam
2. If effluent not clear and SVI over 150 then low MLSS
3. If low MLSS and high F/M then white foam
4. If high DO then low MLSS

CODE	PROCESS EQUIPMENT
A1	Aeration Basin Diffusers
A2	Aeration Basin Air Piping
A3	Aeration Basin Mixers
A4	Aeration Basin Air Flow Meters
A5	Aeration Basin Effluent Weirs
B1	Process Blowers
B2	Blower Speed Controls
B3	Blower Air Control Valves
B4	Channel Blower
B5	Channel Air Distribution System
C1	Clarifier Stilling Well
C2	Clarifier Baffle
C3	Clarifier Sludge Collector
C4	Clarifier Scum Collector
C5	Clarifier Drive Motor
C6	Clarifier Overflow Weirs

TABLE 1 PROCESS EQUIPMENT IN ACTIVATED SLUDGE

CODE	ACTIVITY
A1	Oxygen Dissolution
A2	Bacterial Oxygen Uptake
A3	Basin Mixing
A4	Flow Splitting
A5	Dissolved Oxygen Control
C1	Sludge Sedimentation
C2	Sludge Recycle
C3	Scum Collection and Removal
C4	Effluent Collection and Disposal

TABLE 2: ACTIVITIES IN THE ACTIVATED SLUDGE PROCESS

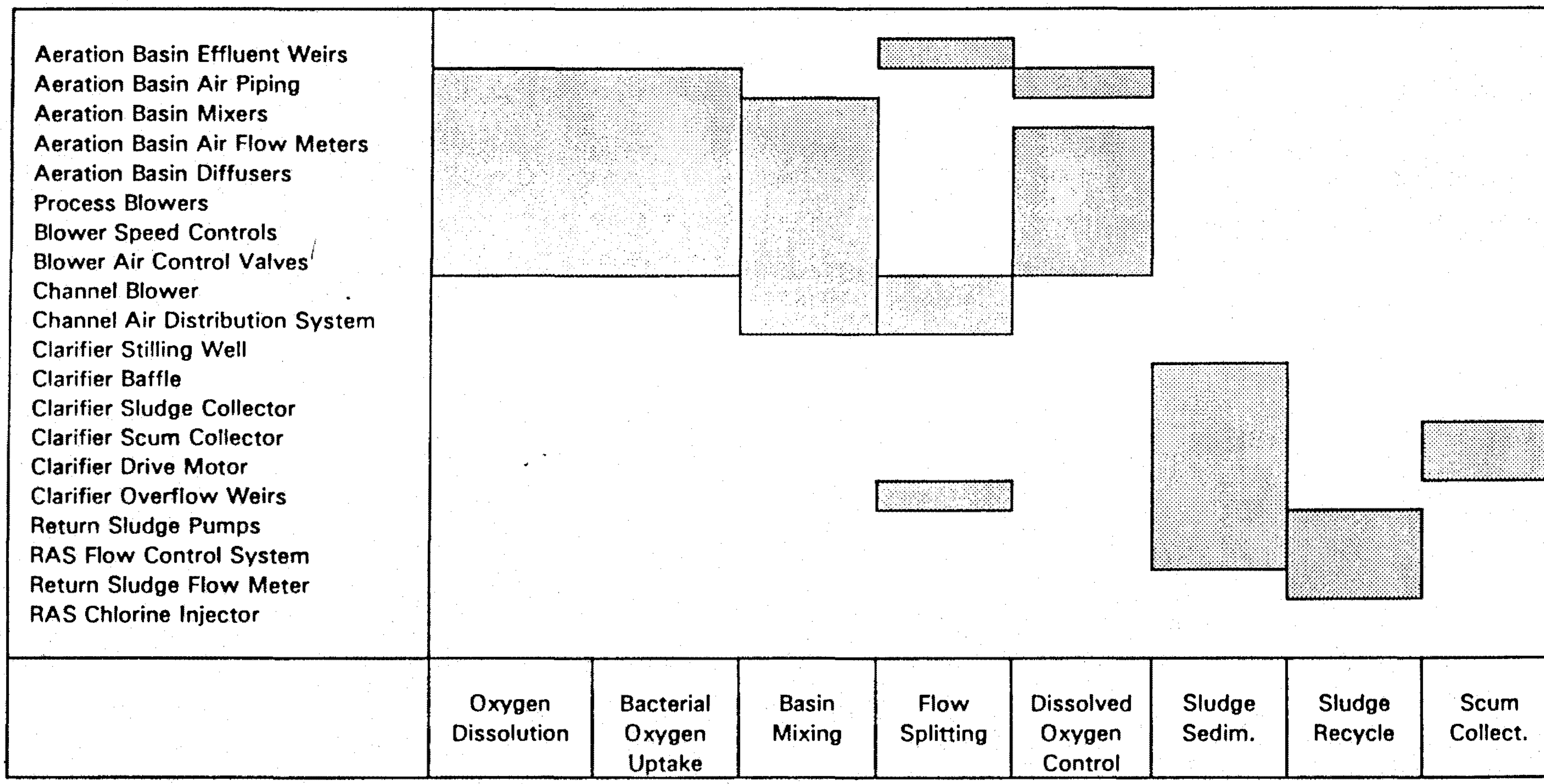

TABLE 3: ACTIVATED SLUDGE PROCESS KNOWLEDGE PACKAGE

CODE	OBSERVATON OF PROBLEM	PROBLEM FACTOR		
		CHANGING INFLUENT WASTE PARAMETER	CHANGING PROCESS PARAMETER	EQUIPMENT FAILURE
A3	HIGH EFFLUENT TSS	C1f	C1a C1b C1c C1d C1e	C1g
A4	HIGH EFFLUENT BOD	C2b	C2a C2c C2d c3g c4c	
A5	HIGH EFFLUENT AMMONIA	C4b C4c	C1a C1b C1d2	C1g C2g
A6	HIGH EFFLUENT TURBIDITY	C2a	C1b C1f C1d3 C3c C4f1	C3b C3c C4d

TABLE 4: PROBLEM KNOWLEDGE

EXAMPLE USAGE

The communications between the operator and the knowledge based system is through questions and answers. These are guided by symptoms or problems given to the expert system. The inference engine and the knowledge base in this system then guide the operator with the "intelligent" question and answer to help the operator locate the problem. This will help the operator locate a problem quicker and prevent possible incorrect control actions which would create larger problems.

There will be three main parts to the system. These are the problem identifier, the problem occurrence evaluation and verifier, and the action procedure guidance. These options are best explained by example. Following is an example of the communications between a system user and the software for each option.

1. The problem identifier

   Input : Symptom(s) that happen in the plant

   Output : Possible problem(s) associated with the symptom(s) given to the system.

   Method : The forward reasoning method will be used to determine the suggested problem(s)

2. The problem occurrence evaluation and verifier.

   Input : Problem to be evaluated or verified with a series of questions provided by the system requiring a response by the operator.

   Output : Series of "intelligent" questions guided by the knowledge base and the inference engine.
   An explanation of the reasoning the system used to make the judgement/decision.

   Method : The backward reasoning method will be used to determine the evaluation and verification of the occurrence of a certain problem.

3. The action procedure guidance based on specific problem identified by the system.

   Input : After the problem(s) have been identified the next step will be the action procedure guidelines by the system. It can be a followed up from the previous session or input directly by operator.

   Output : The output sill be a series of action procedures to overcome certain problems which have occurred in the process.

   Method : A database method will be used which will associate certain problems with certain procedures of action.

EXPECTED BENEFIT OF THE SAMPLE USAGE

Forward reasoning part can identify certain potential problems based on the symptoms given as input. This will help the operator recognize the possible problems which can occur. The operator can then further select the most serious problem to check further. The expert system then uses backward reasoning to verify the possibilities of occurrence of the problem by using guided questions on other symptoms which usually accompany the problem in question.

After possibilities of the certain problems have been identified and verified, the expert system will then give the description of necessary actions to perform in order to overcome the problems.

The expert system will give the benefit of quicker analysis of problems. It will give guidelines of several symptoms to be checked for a certain problem and give guidelines for the actions necessary to overcome the problems. This quick response may minimize the adverse affect of problem on the process and may save time and energy, saving the expert only for the serious and difficult problems.

SYSTEM DEVELOPMENT

This section discusses the details of system development as envisioned by the authors of this proposal.

SYSTEM DEVELOPMENT PROJECT TEAM

The ability to develop a successful expert system will depend on the support and commitment of upper management and the technical experts involved in the knowledge extraction. A development team will be form consisting of both in-house experts and outside expert consultants. In-house members will consist of a representative from Upper Management, a Project Manager, technical leaders from both the engineering design and operational support areas, knowledge engineers and computer programmers. Outside members will be a potential user of the system providing financial, expert knowledge, and a facility for testing the system. Each project team member will have a specific responsibility in the development of the system. An organizational chart for the project team is shown in Figure 3.

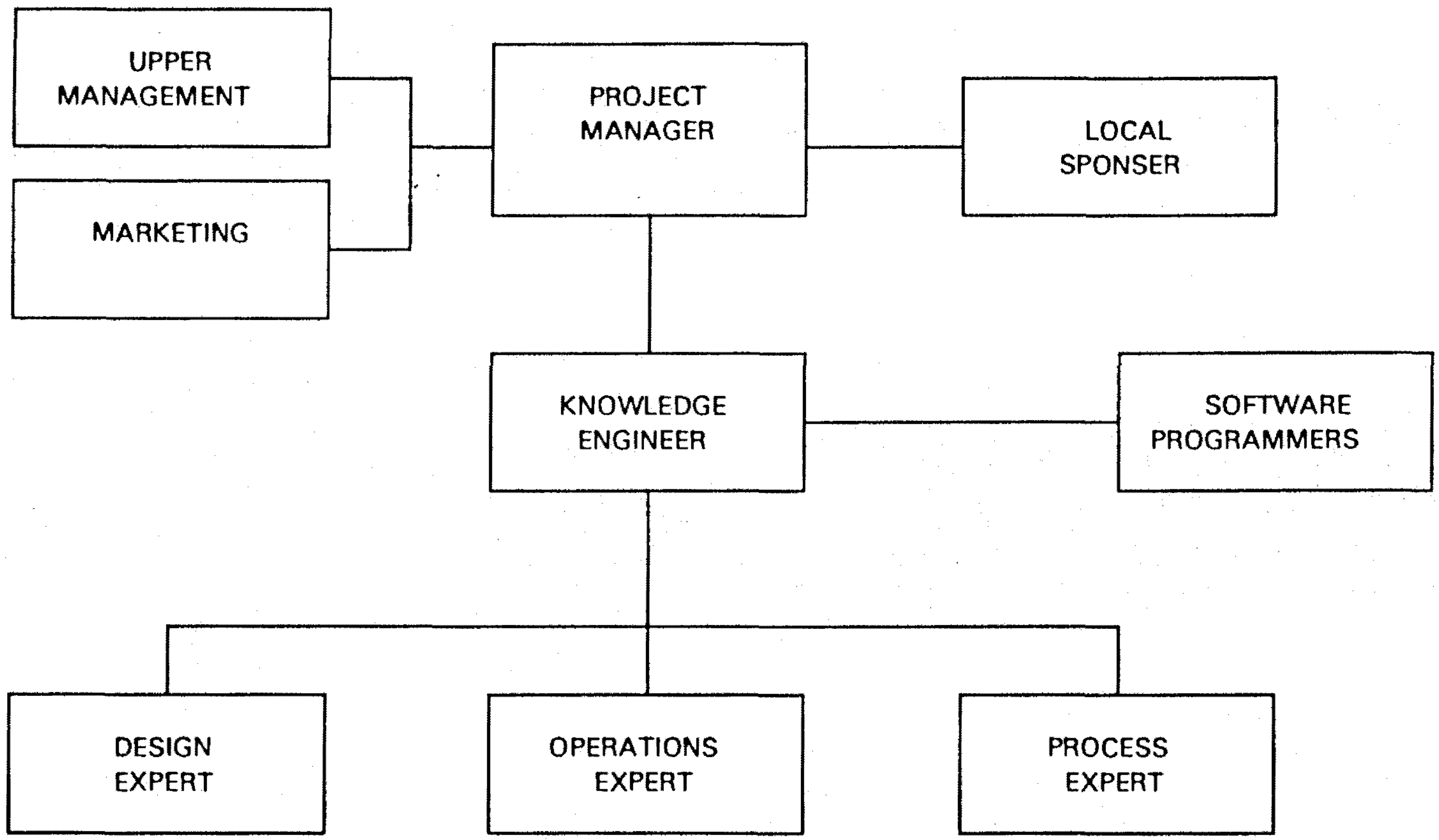

FIGURE 3

ACTIVATED SLUDGE TROUBLESHOOTING EXPERT SYSTEM DEVELOPMENTAL PROJECT TEAM

Project Staff

Upper Management: Represent the organization in providing direction throughout the development of the system focusing on overall issues such as applications and implementation of the system. Provides the resources to develop the system such as the experts time.

Project Manager: Provides the day to day leadership and acts as a facilitator to resolve problem that occur in the development of the system. The Project manager will be responsible for developing and maintaining the project schedule and budget.

Technical Leaders: Responsible to supply information and developing the technical portion of the rule system. provide the knowledge and skills of their experiences in the design and operation of the activated sludge wastewater treatment process. Reviews and authenticates the knowledge formation utilized by the system. Works closely with the knowledge engineers in the extraction of information. These are experts in the areas of design, plant operations, and the activated sludge process.

Knowledge Engineers: Gather the information and builds the system using the knowledge generated by the technical leaders or his support staff. The knowledge Engineer will outline the knowledge extraction procedure and over see the development of the system.

Local Sponsor: The local sponsor will eventually be the end user of the system, the local sponsor will provide his and his staffs expert knowledge in the day to day operation of the facility. The Local Sponsor will provide a facilitate for prototype testing in exchange for full implementation of the system..

Software Programmers: Provided by the computer support organization, will work directly with the Knowledge Engineer in establishing a recommendation for selection of the inference engine and programming the knowledge base information.

Marketing: Establish a mass marketing program and provides input into the useability of the system.

Resources

This project will require considerable resources from staff within the firm. Special expertise in knowledge engineering which in not available within the firm will need to be contracted. These staff needs were discussed in the section above.

Funding for this project will be established in two ways. The first will be to establish an agreement with a local sewerage agency. This agency will act as a local sponsor of the project. This project will be of benefit to them by providing them with a useful tool and establish them as a leader in the wastewater field. The second method of funding will be through an in-house recovery number. Project cost will be charged to a specific project number where they will accumulate throughout the project. After the system is developed, the fees generated from the sale of the expert system will be returned to this project number. Profits for the sale of the package will be shown after the development costs are recovered.

A project budget for the development of this system has been developed and is shown on Table 5.

TABLE 5
ACTIVATED SLUDGE TROUBLESHOOTING GUIDE
PROJECT COSTS

Position	Labor Hours	Labor Cost	Expenses	Overhead	Total
Project Manager	2080	$ 60,000	$ 5,000	$ 97,800	$ 162,800
Experts	400	12,000	1,000	19,560	32,560
Programmers	4160	50,000	12,000	81,500	143,500
Knowledge Engineer	2080	-	100,000	-	100,000
Other	400	15,000	1,000	24,450	40,450
Total Project Cost		$ 137,000	$ 119,000	$ 223,310	$479,310

Preliminary marketing inquires have indicate that through a mass marketing program over a three year period, approximately 300 clients would purchase the system. An acceptable charge for a system such as this would be $7,500.

The software would require on-site training to insure that it would be used properly. The cost of one weeks training by an operations specialist including expenses is $5,000. This would result in a recovery of $2,500 for each system that is sold. Using these assumptions, the total projected recovery would be $750,000. Providing a marketing budget of $20,000 and a maintenance cost of $50,000 per year, the system will show a profit of $100,000.

DEVELOPMENT STAGES

Research into the strategies for development of and expert system shows that each project must go through a specific sequence of steps. The developmental stages for implementation of this project are as follows:

- Preliminary planning phase
- Initial knowledge acquisition
- Pilot system development

- Full scale system development and knowledge acquisition
- Full scale system implementation and personnel training
- System maintenance

Each of these development stages will be discussed.

Preliminary Planning Phase

In this phase, the core project development support organization will be formed. A detailed schedule will be drawn up, requests for total project resources will be presented, and the scope of the pilot and full scale systems will be finalized.

This phase will end when these tasks are complete and upper management has approved the project resource requests. Expected duration is three months.

Initial Knowledge Acquisition

This initial stage will include the selection of a knowledge representation system. It is appropriate to make this selection during this phase because the type of system best fitted for the knowledge will become apparent as the knowledge itself is gathered.

This stage will concern itself primarily with acquisition of knowledge for the pilot system. To this end, the project development support organization will be extended to include several wastewater treatment experts whose primary function will be to provide the necessary domain knowledge. The time these domain experts devote to the project will have been previously authorized by management.

This stage should require eight months and will be considered complete when it is deemed that sufficient knowledge has been gathered in order to develop the pilot system.

Pilot System Development

The goal of this stage will be to develop a working pilot knowledge based expert system for the troubleshooting of wastewater treatment processes. This system will focus on only one facet of the total wastewater treatment knowledge domain in order to keep its scope reasonably limited and be able to thoroughly address the selected facet.

Completion of this stage will coincide with the demonstration of the pilot system to management. This stage will require about seven months.

Full Scale System Development and Knowledge Acquisition

Upon successful demonstration of the pilot program, this phase will be concerned with developing the full scale system as envisioned during the preliminary planning phase. Any lessons learned during the pilot system development stage will be incorporated into the full scale system. This will include an evaluation of the knowledge representation and inference engine schemes that were used for the pilot system, as it may be desirable to alter these for optimum performance of the full scale system.

Further knowledge acquisition will be necessary since the knowledge domain scope for the full scale system will be larger than that of the pilot system. It may be necessary to modify the scope that was envisioned in the preliminary planning phase, depending on the level of difficulty that was encountered during pilot system development.

Also during this stage, a significant amount of time will be spent obtaining input from the potential end users of the system. Emphasis will be placed on tailoring the system into one which will be deemed truly useful by the targeted users.

This stage is expected to require the greatest concentration of resources. It will be complete when the full scale system is working adequately for implementation. Estimated time for full scale system development is six months.

Full Scale System Implementation and Personnel Training

This stage will be devoted to installing the full scale system on the end users' hardware and providing any necessary training for its use. The training may be offered in formal classes if this seems most appropriate. A user's manual will be prepared for those unable to attend training or who have had prior computer experience.

The implementation stage will be complete when the full scale system software is successfully running on all the targeted hardware, and the core group of end users has become acquainted with its use. Six months should be required for this stage.

System Maintenance

System maintenance is often neglected once a knowledge based system has been implemented. However, this ongoing effort is necessary to keep the system viable and useful. Therefore, system maintenance is considered here as a separate stage for success of the project.

Once in this stage, the project development support organization will no longer be needed in its full force. Some subset of that group should be formally designated as the "guardians" of the system, with their task being that of permanent system custodians. This smaller group should only need to consist of about two or three people, with approximately 25 to 40 percent of their time devoted to system maintenance. This percentage may be higher at first, but may be expected to level off with time as system growth stabilizes.

Those responsible for system maintenance should be experts in the domain of wastewater treatment so that they can evaluate new information for incorporation into the knowledge base. A permanent knowledge engineer will probably not be needed in this group as long as one is available on a consulting basis. For the reasons stated above, this stage will not have an anticipated end point.

PROJECT SCHEDULE

This expert system will require extensive resources and capital as outlined above. Good engineering practice mandates that planning of these resources is performed to insure that the activities occur in the proper sequence and that the resources are optimally used. A preliminary schedule of the activities that will occur in this project is shown in Figure 4. This schedule is acceptable at this stage of the project, but will required greater detail when assigned to a project manager and the key staff are assigned to the project.

FIGURE 4

ACTIVATED SLUDGE TROUBLESHOOTING GU
IMPLEMENTATION PLAN

	TASK	MONTH 1	ONTH 15	MONTH 16	MONTH 17	MONTH 18	MONTH 19	MONTH 20
PRELIMINARY PLANNING								
1.A	Project Management Plan							
1.B	Local Sponsor Agreement							
1.C	Contract Knowledge Engineer							
1.C.1	Scope of Work							
1.C.2	Interview/Select							
1.C.3	Negotiate/Award							
INITIAL KNOWLEDGE ACQUISTION								
2.A	Formulate Program							
2.B	Knowledge Aquisition							
2.B.1	Design Experts							
2.B.2	Process Experts							
2.B.3	Operations Experts							
2.C	Establish Rules/Problem							
2.D	Expert Review Rules							
PILOT SYSTEM								
3.A	Develop Pilot System							
3.B	Review Pilot System							
FULL SCALE SYSTEM								
4.A	Develop Expert System							
SYSTEM IMPLEMENTATION								
5.A	Aquisition of Hardware							
5.B	Installation of Hardware/Network							
5.C	Installation of Software							
5.D	Personnel Training							
SYSTEM MAINTENANCE								
6.A	Perform Maintennace of System							