DEVELOPMENT OF A REAL-TIME ADVISORY EXPERT SYSTEM AS A TRAINING TOOL FOR COPPER FLOTATION OPERATORS.

by

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ABSTRACT

An Expert System has been implemented to assist operators in applying knowledge about froth conditions in the control of the flotation circuit at Highland Valley Copper. For some time, the personnel at Highland Valley Copper have recognized that froth type is a useful indicator of good operating conditions. However, the operating strategy based on froth type recognition is an ad-hoc skill in which different operators use a variety of terms, features and procedures to identify and solve problems. This knowledge was brought into a real-time environment to advise the operators on the floor in identifying froth types and troubleshooting corrective action.
This thesis describes the steps taken to acquire the knowledge, to design the required system, to implement the real-time advisory expert system and the trend analysis module and to evaluate its efficiency as a training tool.
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INTRODUCTION

One of the most dominant forces driving change in the industrial sector is the rapid development and growing sophistication of technology. The effect of technological advancement in the workplace results in the generation of more information and an experienced, highly-skilled workforce is in demand. Human consultants are a valuable resource for expertise and communication when problems arise that an individual has not previously encountered. Unfortunately, such domain experts are only available for limited time durations.

For the past 10 years, there has been a great deal of interest in an area of Artificial Intelligence commonly called Expert Systems. These are problem-solving programs that model the reasoning and decision-making of experts in a particular field. Expert system technology is gaining widespread recognition as as a useful method to apply in supervisory process control, on-line process troubleshooting and consulting. By combining the expertise of experienced operators with real-time plant data, expert systems can provide advice and assistance to novice operators.

This research project is aimed at developing an on-line advisory expert system to assist novice operators of a flotation circuit and at evaluating the benefits gained from this technology. The thesis will focus on answering the following question:

"How can an on-line advisory expert system be used to train and assist flotation operators in their function?"

This thesis is arranged into six chapters. Chapter one introduces the fields of Intelligent Computer-Aided Instruction and Advisory Expert Systems. Chapter two and three detail the knowledge domain and the knowledge engineering of the advisory expert system developed for a copper flotation circuit. Chapter four describes how an intelligent alarm system can assist flotation operators in the task of real-time trending analysis. Chapter five presents an evaluation of the expert system developed to assist flotation operators and chapter six provides a discussion on selected issues.
Expert System Technology in Training

1.1 On How Expert System Technology is Used in Training

Expert systems (ES) developed as a subfield of Artificial Intelligence in the mid 1960's. They have become the most commercially successful progeny of AI in general. ES are defined as "computer systems that apply reasoning methodologies on knowledge in a specific domain in order to render advice or recommendation much like a human expert" [Turban, 1990]. Expert systems differ from conventional programming in that they use symbolic processing, are very easy to modify and can explain their actions when the user queries how a particular decision was made.

Primarily, expert systems mimic human reasoning by applying knowledge on different sources of information in order to make a decision. Figure 1.1 shows a decision pyramid with an example of a decision strategy for a SAG mill overload condition.

![Decision Pyramid](image)

Cut down the mill feedrate by 20%

The mill is overloaded.

Mill power draw is going down and mill hydrostatic pressure and feed rate are high

Mill Amps Draw = 6000 Amps
Mill Hydrostatic Pressure = 200 psi
Mill Feed Rate = 1200 t/h

Figure 1.1-Decision pyramid (modified from Touchstone et. al., 1990)

In this example, signals are drawn from the SAG mill sensors or from operator inputs. Expert systems transform this raw data into meaningful information using fuzzy sets. Fuzzy sets translate the numerical values into qualitative statements such as "high" or "trending down fast". Then knowledge is applied to this information to characterize the state of the process. Knowledge is expressed in the form of "IF-AND/OR-THEN-ELSE"
rules. Depending on the process state, the expert system makes a recommendation to the user or, in the case of a closed-loop system used for process control, implements a series of setpoint changes.

To educate people, expert systems can be used as training tools, tutors, or "tutees". As training tools, expert system are used to assist the novice in reasoning and to give advice much like a human expert would do. They are stand alone programs that interface with the trainee or acquire data directly from the plant. As tutors, expert systems are components of complex Intelligent Computer-Assisted Instruction systems. These systems are composed of several modules using different knowledge bases to simulate a learning relationship between a student and teacher. As "tutees", the process of building an expert system is used as a means of knowledge acquisition. The following sections of this chapter will describe how expert system technology is used in intelligent tutoring systems (also called intelligent computer-assisted instruction) and advisory expert systems.

1.2 Intelligent Computer-Assisted Instruction

Intelligent computer-assisted instruction (ICAI) is a type of computer-based instruction that incorporates artificial intelligence methods and techniques. Overlap exists between the development of expert systems and ICAI systems in that expert systems serve as modules for ICAI systems. ICAI uses a component or modular approach which provides both the student and the program flexibility in the learning environment. The goal of ICAI is to mimic individualized tutoring, resembling what actually occurs when student and teacher sit down one-on-one and attempt to teach and learn together. Training and educational devices incorporating expert systems understand what, whom and how they are teaching and can accommodate content and methods to meet the needs of an individual.
1.2.1 Components of ICAI Systems

An ICAI is generally composed of a student module, a teaching module, and an expertise module. In certain applications, a simulation module is added to the system to allow the trainee to explore real world applications. Figure 1.2 shows a schematic of the structure of an ICAI (adapted from Ok-choon Park, 1991).

The student module is a method of representing the student's understanding of the material being taught. As the student interacts with the program, the student module assesses the student's knowledge and hypothesize about the student's conceptions and reasoning. The monitoring strategy consists of pattern matching and recognition that "flags" the subject-matter, facts or rules that the student has mastered. Student problem-solving behaviour, direct questions asked of the student and assumptions based on the student's experience are the principal sources of information used to model the student's knowledge. The student's misconceptions and deficiencies are forwarded to the tutorial module to select the best instructional treatment.

The tutoring module contains the expertise of a model trainer and uses it to determine how the system should present material to the student. The tutorial module also
provides feedback to the student by helping him to recognize his errors and change to the correct response. The instructional knowledge base generally includes various types of instructional strategies, rules for making inference about the student's misconceptions and learning needs and prescriptive rules for selecting the best instructional treatment. The tutorial module communicates with the expertise module to compare the student's performance with the computer-based expert's solution and adapts the student's learning needs on the basis of the information from the student module.

The expertise module contains the declarative, procedural and heuristic knowledge of the domain expert. It includes both the content to be taught and how to use that knowledge to solve related problems. The expertise module is generally developed independently of the ICAI system as an articulate and separate module. It is used by the teaching and the student module to provide information for computer-based teaching.

1.2.2 Tutoring Strategies

Different instructional approaches can be taken when designing an ICAI system. The tutoring strategies used in ICAI systems have evolved from the instructor-centered expository form that was applied in the development of computer-assisted instruction. With the addition of expert and student modules, ICAI researchers have adopted a learning-by-doing approach where the trainee is required to engage actively in the training process by testing his own ideas or practicing skills in a realistic context. The Socratic and the coaching method are the most popular approaches of designing ICAI [ Dede, 1986].

Many ICAI systems are developed to follow the Socratic model. This method consists of asking questions to draw out of the trainee the understanding of the phenomena discussed. From the answers given, the system assesses the knowledge level of the trainee and determines the instructional process to be followed. In contrast, the coaching method guides the student during a game or simulation while monitoring the student's performance. The coach monitors the user on multiple dimensions of performance, evaluates the user's proficiency at problem solving in comparison to the
expert module and interrupts the user to give advice or a compliment. The coaching method is designed to develop process skills in learning-by-doing situations while the Socratic method provides a more instructor-centered approach geared to building a foundation of descriptive knowledge [Dede, 1986]

1.2.3 Applications and Limitations of ICAI

Several ICAI were developed in the beginning of the 1980's mainly as teaching programs for students. SCHOLAR was the first attempt to use AI as the basis of a tutoring program. It uses semantic networks to teach geography. More recent systems are based on the coaching strategy and use rules for stating teaching principles. A large variety of systems were developed to teach mathematics and LOGO programming [Papert, 1980] to young children. SOPHIE [Brown et. al., 1975] and STEAMER [McFarland and Parker, 1990] are probably among the most complex ICAI programs. SOPHIE stands for "SOPHisticated Instructor for Electronics". SOPHIE does not teach anything systematically but rather presents the student with a circuit that contains a fault. The student attempts to find the bug by taking measurements while SOPHIE supervises his learning and comments on his actions. STEAMER teaches how to operate a steam plant on a military ship. A prototype was installed in the field within a few years and is still being used today to train new recruits. STEAMER is characterized by explanations on the reasoning strategy and high quality graphics.

So far, apart from STEAMER, very few ICAI systems have been used for industrial training. The main limitations to the expansion of ICAI technology are their high development cost, their complexity and their lack of flexibility. Experience in ICAI has revealed a rule of thumb that each hour of instruction requires 1500 hours of professional development [Lippert, 1989]. The high sophistication of ICAI systems have confined them to laboratories and class rooms. System validation in ICAI has not yet met the research and evaluation criteria established for instructional design. Rosenberg (1987) comments on ICAI testing as "... poorly controlled, incompletely reported, inconclusive, and in some
cases totally lacking". While analyzing the progress made by ICAI systems over the past 15 years, McFarland and Parker (1990) could not evaluate the benefits of these systems: "Will this intelligence promised by AI significantly improve computer-based education and training? Present research and development studies have yet to provide an answer". Lippert (1989) mentions that most of the ICAI work has been done by AI scientists with little involvement of educational technologists and field experts: "It is thus small wonder that the work has seemed esoteric and of little practical use so far, or that the results are rarely followed up with a view toward production". The future of ICAI probably lies in areas where traditional forms of instruction work poorly.

1.3 **Advisory Expert Systems**

Advisory expert systems are designed to assist an operator in his functions by suggesting operating strategies, troubleshooting process upsets and offering explanations on the reasons why and how a recommendation was reached. This training technology has invaded most of the areas of human thought and activity, with applications in different fields ranging from medical diagnosis, financial planning, production scheduling and strategic military planning.

1.3.1 **Types of Advisory Expert Systems**

Advisory expert systems can be divided into two major categories: off-line and on-line expert systems.

1.3.1.1 **Off-line Consultant-Type Expert Systems**

Most systems reported in the literature fall into this category. Such systems are usually developed to make expertise in trouble-shooting and diagnosis available to less experienced personnel. They are user-driven and get their information by asking questions of the user or by referring to databases. A number of expert system-based tutoring tools have been developed over the past 20 years in several different fields of industrial training and education.
MYCIN, as the pioneer of expert systems, is probably the most referred to knowledge-based consultation program. MYCIN was developed in the 1970's at Stanford Medical School by Dr. E.H. Shortliffe. The expert system was designed to aid physicians in diagnosing meningitis and other bacterial infections of the blood and to prescribe treatment. It is a rule based system consisting of about 500 inference rules that can deal with uncertain evidence and explain its reasoning. The MYCIN project evolved toward GUIDON, an intelligent computer-assisted instruction program that uses a revised version of the MYCIN knowledge base to instruct microbiology and medicine students. The MYCIN project is described in great detail in Shortliffe and Buchanan (1984).

1.3.1.2 On-line Advisory Expert Systems

On-line advisory expert systems receive real-time data through direct links with the process. However, they should not be confused with closed-loop expert systems where the system receives real-time data and also controls the process by changing control variable setpoints. In the case of on-line advisory expert systems, an operator controls process variables as a result of observations and recommendations provided by the system.

Among applications in the mineral industry, Laguitton and Leung (1989) listed the case of a data validation and substitution expert system integrated at the interface of an X-ray analyzer and an existing Distributed Control System. The system was developed using NEXPERT and installed at the Kidd Creek Concentrator. Failures in the automatic sampling and analyzing systems are identified and on-stream analysis are validated and modified if needed.

1.3.2 Components of Advisory Expert Systems

Figure 1.3 shows a diagram of the principal constituents of an on-line advisory expert system and how they interact with the consultation and development environment.
Real-time expert systems can be broken down into four main components: a knowledge base, an inference engine, a user interface and a process interface [Meech and Harris, 1992]. The knowledge base contains the expertise that humans use to make decisions. This knowledge is generally expressed by IF-THEN-ELSE rules. These relationships are developed by a knowledge engineer from material gathered through meetings with the expert. The brain of the expert system is the inference engine, also known as the rule interpreter. This component provides a methodology to reason about the information contained in the knowledge base. The user interface provides a communication link between the end-user and the expert system. Through this module, the expert system can display plant data, send advice, ask questions or send explanations to the user. As well, the user can update information and answer questions. The task of the process interface component involves acquiring and managing plant data.

1.3.3 Implementing an Advisory Expert System

The objective of advisory expert systems is to transfer expertise from the expert to the computer and then to the trainees. This process involves several steps that will be described below:
1.3.3.1 Suitable Applications

The ES development process starts with the identification of an appropriate problem domain. Waterman (1986) listed several features that suitable domains for advisory ES have in common. First, the expertise has to be strongly dependent on heuristics to find a solution. Expert systems are not appropriate when complex formula processing and intense number crunching are involved. The problem has to be clearly understood and at least one cooperative, proficient expert has to be available, as an expert system is only as good as the best expert. The scope of the system should be a manageable size and the complexity of the problem should be neither too easy nor too difficult for human experts. There should be some tangible benefits in implementing an advisory expert systems such as human expertise is being lost, on-line assistance is needed or other training programs are more costly or have not given good results in the past. Finally, systems initiated and supported by higher management are more likely to succeed than systems initiated by academics or developed as the result of one organization approaching another interested organization with no clear specifications drawn up.

1.3.3.2 Expert System Development Tools Selection

ES development tools, also called ES shells, are computer programs which expedite the creation of expert systems. They provide a means to rapidly develop a system without having to learn AI programming languages. Several expert system shells have been developed and commercialized during the past ten years. The trend in commercial ES development is to move away from Lisp and PROLOG, the first two languages used to program expert systems, and to use conventional object-oriented languages like C. The preferred platform would appear to be micro-computers. Hardware plays an important part in the selection of an appropriate ES shell. While UNIX-type machines provide such capabilities as high speed and multitasking, these systems are more expensive and difficult to maintain than PC-based systems. Beyond the need for a knowledge base and inference
engine, a suitable expert system shell for training applications requires explanation capabilities and a user-friendly interface. Since the expert system is used as a training tool, giving advice alone is not enough; explanatory comments and the reasoning beyond the decision should be available to the trainee to make him understand the process. Hypertext is a very useful media to provide several levels of information to the trainee concerning the process and the domain terminology. The user interface is very often overlooked. Features such as on-line help facilities, graphical displays and windows environment improve the user-friendliness of the advisory expert system. If the system is too clumsy, the users will give up and the system will become useless. The ability to handle uncertainty through fuzzy logic is a useful feature when approximate reasoning is part of the expertise. In the case of an on-line advisory expert system, the selected shell should be able to extract and process real-time data and be compatible with existing data acquisition systems.

1.3.3.3 Selection of the Experts

A suitable expert is someone who has many years of experience and a good understanding of the process, who is able to express his knowledge, who is willing to participate and who has the respect of his peers and subordinates.

It may be suitable, when the knowledge covers several fields of expertise, to use multiple experts. This will have the effect of broadening the coverage of proposed solutions and combining the strengths of different reasoning approaches [Turban, 1990]. However, when more than one expert is consulted, differences in opinion arise owing to a lack of knowledge or statistical uncertainty. These conflicts have to be resolved but fortunately, several methods are available. One method consists of dividing the expertise into subdomains and assigning one expert to each domain to keep interaction among the experts to a minimum. When interaction cannot be avoided, group discussions should be attempted to confront the different expertise. Another method consists of allowing multiple lines of reasoning to coexist. The system can be designed to select one line of
reasoning based on the characteristics of each solution. In any case, confrontation resulting from the conflict resolution process is always followed by better understanding of the knowledge.

1.3.3.4 Knowledge Acquisition

Knowledge acquisition is the process of extracting, structuring, and organizing information from the domain expert and other sources [Waterman, 1986]. Knowledge acquisition probably goes back to Socrates. In *Theaetetus*, Socrates attempts to describe the nature of knowledge and how knowledge can be transferred from one to another.

Knowledge can be extracted from many sources and by using different techniques. The most common form of knowledge acquisition is the face-to-face interview with the expert. This technique consists of posing a series of questions to the expert along a particular line. By interviewing the expert, the knowledge engineer tries to build a representation of the knowledge using the expert's terminology, keeping in mind that the knowledge has to be represented by IF-THEN rules and fuzzy sets. A variation of this method, the two-on-one interviewing technique, is described in Harris et. al. [1989]. The session starts with one knowledge engineer posing questions to the expert while the other makes notes. Before beginning a new session, the knowledge engineers trade positions and revise the notes taken during the previous interview with the expert.

J. Cullen and A. Bryman [1988] conducted a study on the knowledge acquisition strategies used in the development of seventy different expert systems in Britain and the United States. About one quarter of the expert systems sampled were developed for manufacturing activities, one quarter for technical diagnostic and one quarter for classification functions. The study showed that the most popular knowledge acquisition technique, used in the development of over a third of these systems, was fast-prototyping. This technique consists of extracting knowledge from the expert through a series of interviews followed by rapid development of a prototype working expert system. This
prototype is then used to prompt the expert to refine the existing knowledge base and to supply explanations.

Several other techniques are also available: observation of the expert at work, written questionnaires, analysis of documented knowledge and computer-aided methods. However, for the development of tutoring and training expert systems, these techniques show several inadequacies.

From the observation of the expert at work, the knowledge engineer can extract rules related to the expert's actions under different scenarios but the reasons behind the different actions taken by the expert may remain unknown, leading to an advisory expert system that cannot explain its advice. The written questionnaires, by forcing experts to write down their expertise, results in shorter answers sometimes difficult to read. Edwards [1990] reports that "... the written responses to the first questionnaires was of such poor quality that this method of knowledge solicitation was stopped". Experts are usually able to express themselves in spoken rather than in written English. Analysis of documented knowledge is seldom recommended when human experts are available. Written information is often incomplete and out of date and the knowledge engineer is subject to his own misinterpretation of the information. Computed-aided knowledge acquisition is still in its infancy and cannot provide explanations and reasoning scheme.

Knowledge acquisition has been described as the bottleneck of expert system development by several authors. Feigenbaum and McCorduck [1983] were probably the first to appraise the problems related to knowledge acquisition:

"[An expert's] knowledge is currently acquired in a very painstaking way; individual computer scientists work with individual experts to explicate the expert's heuristics - to mine those jewels of knowledge out of their heads one by one ... the problem of knowledge acquisition is the critical bottleneck in artificial intelligence."
To facilitate the knowledge elicitation process, the interview should be structured to guide the expert toward solving the different problems that will be encountered by the trainee. An open-ended discussion leads to open-ended answers. A successful technique consists of selecting a series of problems or situations for which the trainee will need advice. For each situation, the expert is asked to list the different reasons causing this problem. The expert then comes up with a strategy to verify each cause by looking at different indicators. When the cause of the process upset is determined, the expert suggests a series of actions to troubleshoot the problem. The different actions performed by the expert are then explained in great detail to incorporate explanation facilities into the expert system. This interviewing method allows the study of each problem systematically and provides the trainee with the reasoning strategy used by the expert and explanations on how to solve the different problems.

1.3.3.5 Knowledge Representation

The knowledge acquired through the knowledge acquisition process needs to be stored and structured into the knowledge base. Knowledge can be categorized as declarative or procedural. A procedural representation scheme deals with actions or procedures while declarative schemes are used to represent facts and assertion. There exists several knowledge representation schemes including semantic networks, logical formulations, frames and production rules. The last two are clearly the most popular and appropriate techniques to represent knowledge within an advisory expert system.

In a rule-based expert system, the knowledge is expressed as "IF this condition occurs AND/OR this other condition occurs THEN some action/result/conclusion will occur". The rules can be autonomous or related to other rules by their premises or their conclusion. When the condition in a premise of a rule is set in the conclusion of an other rule, it causes the system to backward-chain through the knowledge base to instantiate this
condition. One can see that the set of rules behave synergistically, yielding better results than the sum of the rules taken separately.

The frame structure is more complex than the rule-based systems. A frame is a data structure that includes attributes particular to this object. Frames are arranged in a hierarchy in which the attributes can be inherited from a parent frame to the children frames. Each frame includes slots, which are sets of attributes describing the objects, and facets which contain the procedure required to find attribute values.

Knowledge about the process can also be represented in explanations and Hypertext. Explanation can be given on the reasoning strategy (How did the system arrive at this conclusion), on the reasons why the computer asks the user to provide some information and on how the information requested by the expert system can be found. Additional information on the knowledge domain and on-line help can be presented in the form of Hypertext. Hypertext is an electronic document where information from within the document can be accessed by using dynamic links between words and pages of information.

1.3.3.6 Validation

An expert system developed in isolation from the ultimate users of the system is almost certainly doomed to failure. It is essential to incorporate feedback from different experts and from the users of the system through the development phase. One validation method gaining popularity is fast-prototyping. As discussed earlier, a prototype of the system is developed along the knowledge acquisition process. The results of the small-scale expert system is analyzed by the expert and the graphical user interface friendliness is judged by the end user. Incremental prototyping is essential in large systems because taking the wrong track can lead to a poorly structured system that will end-up on the shelf. Getting the expert and the user involved during the development of the knowledge base also helps to sell the system to the skeptics, sustain the expert's interest and get more
support from top management. This prevents the expert system from being viewed as the knowledge engineer's system. Testing the system off-line or in a simulated environment before implementing it on-line is a safe practice. The validation may reveal cases not handled by the knowledge base and conflicting rules.

1.3.3.7 Implementation

When the system has reached an acceptable level of stability and quality, it is ready to be put into the field. However, success in the laboratory does not guarantee success in the plant. Several factors, of both a human and technical nature, can bring rejection of the system by the end-user. One problem most often encountered is acceptance by the user. Fear of change, lost of decision autonomy and self-esteem, and worries that the workers duties and responsibilities will be diminished or degraded are all concerns expressed by the workforce. The main reason for these misconceptions is a lack of communication between the developers and the end-users. Some worker fears are justified since expert systems can be viewed as a replacement for the workforce. It is important that the goal of the expert system, i.e. to train and assist the less experienced workers, is communicated as widely as possible and that experienced workers get involved in the development and validation of the expert system to foster a climate of acceptability among the people who will use the system. Technical factors may also be responsible for an implementation failure. If the level of complexity of the system is too high, the users will be reluctant to consult the expert system and may develop a fear of "crashing" the system by entering wrong data or clicking on the wrong button. Most users do not have the level of familiarity with computers that developers have. The basic rule is "keep the user interface as simple as possible". A basic training program offered to all end-users is the best way to ensure full comprehension of the system. Another technical problem jeopardizing the implementation is real-time data acquisition. The user will just walk away from the system if the response
time is too long. Process interfacing efficiency should be verified during the expert system shell selection process.

1.3.3.8 Evaluation

Once the system has been installed and running for a while, it is a good idea to conduct a thorough evaluation of the benefits gained by the system. The difficulties that stand in the way of evaluation studies are numerous. Since the advisory system is not aimed at optimizing plant performance by taking direct control actions but is rather aimed at improving operator performance, it may be hard to define a "gold standard" against which to compare the system's achievements. To base the evaluation on an increase in production or a decrease in costs seems appropriate for a process control system but represents an incomplete yardstick to evaluate a training system. An advisory system, by its nature, is designed to communicate and exchange information with trainees. Consequently, the user friendliness, the quality of the information and the metaknowledge attached to the system are as important as the correctness of the advice. Performance evaluation attempting to demonstrate that the system is able to handle every case in its domain should be performed first, as the end-users are not very forgiving of incorrect conclusions reached by the system.

Turban [1990] listed some of the issues that have to be considered in the selection of the evaluation process. First, the characteristics that should be evaluated have to be addressed. The system should be evaluated on the correctness of its recommendations but also on the user's acceptance and frequency of use, on the material learned by the trainees and on the improvement in the novice ability to troubleshoot process upsets. How the performance should be evaluated is another difficulty to be studied. The users knowledge gained by consulting the expert system can be evaluated by testing the users ability to solve particular problems before and after system implementation. Plant upset frequency before and after installation can also indicate the benefits gained by the system. As many of
the benefits gained by advisory expert systems, such as personnel skill level improvement, standardization of operating practices, formalization of the process knowledge, are intangible, these are more difficult to quantify.

Another issue to be addressed is that expert systems are known to "degrade gracefully". It has been observed that training systems receive a lot of attention at first. A novice turns to the handy expert system to troubleshoot operation problems while an expert explores the limits of the system or double-checks his decisions. As the novice slides up the learning curve and builds up confidence in his judgment, the advisory system becomes less and less useful. In some aspects, the declining consultation frequency can be viewed as a sign of success when the decrease in use of the system corresponds to an improvement in the worker's skills. In other words, successful systems put themselves out of work.

1.3.4 Advantages of Advisory Training Systems

In training applications, expert systems show several advantages over ICAI and as part of training programs:

- Since the knowledge is separated from the reasoning algorithm, the expertise is easy to program and upgrade. As the expertise is expressed in the form of IF-THEN rules that use high-level English-like language, rules can be added or changed by the users as new knowledge comes up.
- Expert systems also allow the capture of an individual's knowledge, preventing the brain-drain effect that takes place when a skillful employee retires or quit. By capturing this knowledge, a new person coming into the company can be trained through supplementary use of the expert system.
- Expert systems have a natural exploratory style of use which may encourage trainee participation. The expert system can be used to troubleshoot an actual problem but can also be used as a simulator, allowing a user to evaluate what-if scenarios and improve his knowledge at a faster rate. When information about the knowledge is added in the
form of Hypertext, novices can probe deeper into the knowledge domain while experts can get advice quickly without wading through reams of elementary information.

- In terms of the human-machine interaction, expert systems can explain their actions when the user queries why a particular decision was made. This is a major advantage of expert systems over conventional programming and neural networks. Explanation and justification is done by tracing back the rules involved in the final decision and through explanatory notes attached to conclusions.

- Expert systems can deal with heuristic reasoning, incomplete data and uncertainty factors much like a human expert would do. The knowledge of an expert can be expressed using heuristic expressions such as "Low", "High", or "Ok" and advice can be given with a confidence level depending on the degree of certainty in the facts. In contrast with conventional programming, expert systems can, like human experts, work with incomplete information.

- Expert systems are available 24 hours a day and seven days a week when needed. As technology evolves, experts will become more scarce and in demand and operators will have to be trained regularly to cope with the new technology. An expert system can be as good as human specialists and can help unskilled and inexperienced workers in performing complex jobs on all shifts. Furthermore, it reduces the time input of professional staff when training new staff and solving circuit problems.

- The development of an advisory expert system results in better organization of the knowledge. Knowledge clarification is considered to be a major spin-off of the production of tutoring systems. Lippert [1989] mentions that a common report from knowledge engineers is that the task of constructing an expert system demands such a detailed, intensive reflection on the representation, the completeness and the structure of the knowledge that experts themselves often see how incomplete and redundant their own knowledge is and often generate new connections in the knowledge domain not previously recognized.
1.3.5 Limitations of Advisory Expert Systems

Expert systems are not a panacea for all training problems faced by industry. There are projects involving the use of expert system to train workers that fail. Several factors inhibit installation of an on-line advisory expert system:

- The knowledge is so "compiled" that experts have difficulty in explaining their expertise with complete effectiveness. If explanations cannot be obtained because the reasons leading to a conclusion are not known by the expert, then the expert system will not perform adequately as a training tool.

- The knowledge is not available or is only available from books or laboratory results. Starting an advisory expert system thinking that the expertise will be developed along the way is a bad strategy. Solid, practical expertise must exist before the start of the project.

- Real-time data are noisy, full of errors or may change at very high frequency. When the expert system cannot extract reliable data then serious problems may arise in the interpretation of the process state.

- The knowledge domain is too broad. Expert systems work well in narrow application. The development of extensive knowledge bases may lead to heavy systems hard to maintain and debug.

- The management is not supportive of the project or experts are unwilling to participate. Several people are involved in the development of an expert system and without the full commitment of all the parties, the system is doomed to failure.

1.3.6 Learning from Advisory Expert Systems

Even though expert systems have been extensively used as training tools, very little has been done to evaluate their capability to improve worker skills. Several successful stories of advisory expert system applications have been reported but no research has been pursued to compare the rate of learning of conventional training sessions versus intelligent tutoring systems. M. R. Kundu [1992] states that
"In the context of training and education, the effectiveness of AI and Expert Systems machine has not been proven in psychological and pedagogical terms as they relate to learning effectiveness."

Dreyfus and Dreyfus [1986] go further by affirming that:

"Machine intelligence will probably never replace human expertise - in teaching, healing, or fighting wars - because we ourselves are not thinking machines."

Basically, their criticism suggests that "thinking" machines cannot match intuitive intelligence that human beings have and that substituting symbol manipulation for real human sensations and emotions can destroy the richness of full existence as human beings. However, Dreyfus and Dreyfus do not provide empirical support for their claims.

More recently, Fedorowitcz, Oz, and Berger [1992] conducted a study to evaluate how an expert system affects the learning rate of students. The experiment involved two groups of 18 graduate and senior business students who were asked to solve a series of problems over a five day period. One group had access to an advisory expert systems designed by a financial consultant for internal corporate use; the other group did not use an expert system. Both groups did not have experience in the area of concentration for the study and showed virtually identical scores at the beginning of the experiment. However, as the experiment progressed, the differential between expert system users and non-users continually increased. When the learning curves of the two groups were compared, the group who had access to the expert system was pushed up the learning curve at a faster rate than those participants lacking an expert system.

This experiment raises several important questions. How does expert system training compare to conventional training, like courses and human consultants? Could a poorly designed expert system slow down the rate of learning? Would an expert system increase the rate of learning of older and non-computer literate trainees? Clearly, there is a need for more research in the field of psychological and pedagogical impact of advisory expert system on trainees. However, even though it was not clearly established how expert
systems should be used to maximize the rate of learning, several industrial applications of advisory expert systems (Psotka et. al. [1988], Lippert [1989], Meech [1990], and Touchstone et. al.[1990]) showed great success. NASA and the American Air Force, which have always used simulation programs to train their personnel, have been integrating intelligent tutoring systems and consultant expert systems into their training programs for the past 10 years. Liebowitz [1990] mentions the case of an advisory expert system used to train boiler plant operators. The system was so successful that the insurance company, who had grave concerns about the lack of training of boiler plant operators, reinstated its insurance policy on the boiler plant. Clearly, advisory expert systems have gained acceptance and are now widely used as tools to help train individuals.

1.3.7 Applications of Expert Systems as Industrial Training Tools

Several examples of successful applications of on-line advisory expert systems are described in the literature. Two applications, an on-line advisor for an oil refinery and an off-line guidance system for a lead smelter, were selected because they were developed effectively and were implemented successfully.

1.3.7.1 The Chevron Corp. Refinery Operator Advisor

In 1989, the Chevron Corporation refinery of Richmond, California, developed an on-line expert system to advise and train their operators [Touchstone et. al., 1990]. The system can operate on-line, meaning that it has access to real-time plant data through a serial link to the plant's monitoring computer. Based on high-level information about the refinery operation and time-tested knowledge of experienced operators, the system makes recommendations and backs them up with explanations. The Richmond refinery realized that operating a process plant is a skilled job requiring a great deal of experience. However, experience is gained with time and often at the expense of costly errors. This is where the expert system can be advantageous to capture and pass the experience of veteran operators and lessen differences between operator crews.
The expert system was developed using an object-oriented programming language. The knowledge base is a composite of knowledge drawn from the experience of several operators and plant engineers. The system was designed so that the knowledge base can be changed easily or updated and used for training as an off-line simulator as well. The user interface is a window-based environment allowing the operator to jump to different nodes in the knowledge base, browse through the advice and even modify or add new rules to the knowledge base. The expert system runs on a MacIntosh personal computer and was designed using HyperCard, an authoring tool and information organizer.

The expert system performs a two-step analysis of the plant data. First, a report presenting the plant's current performance situation is generated. The plant measurements are replaced by a word pattern describing if the values are High, Ok or Low. The verbal classification is formed using fuzzy logic to convert numbers from real-time data into a word list. Then, when the current situation has been determined, the knowledge base is searched for matching advice or a series of advice. The advice report includes a synopsis of the situation, recommendations to troubleshoot the problem and reasons to support the advice if requested by the operator. Because it is believed that advice is best given only when asked for, the system's advice is displayed only if the operator requests it.

Chevron Corp. recognized that the major benefits of installing an advisory expert system was that it forced operators and engineers to think systematically about how to run the plant. The cooperative team-building process resulted in an increase and a standardization of the knowledge. Now that knowledge is contained electronically, it is easier to access and update than instruction manuals.

1.3.7.2 The Lead Blast Furnace Operator Guidance System

Two different off-line advisory expert systems were developed for the Lead Blast Furnace operation at Pasminco Metals-BHAS, Australia [Freeman et. al., 1990]. The first system encapsulates the expertise regarding the operation of the lead blast furnace and
was developed as part of a process improvement program aimed at increasing the lead production. The second system provides information on the meaning of different assays and the possible effects that these could have on the operation.

The process was particularly appropriate for an advisory expert system since some furnace parameter measurements have no instrumentation. Therefore, control of the furnace is heavily dependent on the judgment of the operators and their appreciation of the process measurements. Coke addition, among other operating variable, is based on observations such as fume colours, sounds emanating from the furnace and tuyere brightness. An inexperienced operator can easily misinterpret these indicators and misjudge coke addition rate. As the furnace operation has a large lag time, inefficient use of coke can result in reduction in production rate or excessive production costs. It was decided to make the expertise of the Operating Superintendent, who has many years of experience of running the blast furnace, available to furnace operators 24 hours a day, 365 days a year.

The expert system was developed using Comdale/X, an off-line Windows-based expert system shell developed by Comdale Technologies Inc. The knowledge was extracted through a series of interviews with the Operating Superintendent. The system identifies the operating conditions by asking questions of the user about the furnace operating condition and diagnoses the problems from observed symptoms. The expert system makes use of fuzzy sets to translate language concepts such as "Frequent" or "High".

The second expert system determines if the predicted assays calculated by a Database program are low, high or normal. Assays of the past two days are kept in a database program. Every time new assays of the previous shift are entered in the database, predicted assays for the coming shift are calculated using linear regression. Then the calculated assays are passed to the expert system which examine the predicted assays, corrects the assay value and sends warnings of possible implications which are determined
from assays values. Complete development of both expert systems took approximately 40 man-days.

The total cost of the project was estimated at $46 000 and required 40 man-days for the development and refinement of the knowledge base. The main benefits of the project are a 50% reduction in Call-Outs and an estimated 1% saving in coke consumption. The authors pointed out that the development of the expert system resulted in a better understanding in the operation of the blast furnace by the operating personnel and are now considering the application of a real-time process control expert system on the blast furnace.
CHAPTER 2 - Knowledge Domain: Operating Practice of the Flotation Circuit at Highland Valley Copper.

"Heinlein's Law: One man's magic is another man's engineering".

2.1 Domain Selection

The purpose of this study is to assess the merits of a real-time advisory expert system as a training tool. The copper flotation circuit at Highland Valley Copper (HVC) was chosen for the application because the need for training in the flotation area was clearly identified. Moreover, real-time data was accessible through a Distributed Control System, several cooperative flotation experts were ready to share their knowledge and management showed interest in expert system technology.

In late 1990, a management consultant hired to audit the mining operation at HVC pointed out that "... everyone in the mining and milling process is working for the flotation operator...". This phrase was used to demonstrate the need for more control and more training in the flotation area, especially for relief-operators. Several training programs have been tried over the past few years but no formal program was in existence (Raabe, 1992). It was also identified that various operators arrive at different conclusions under similar conditions. This lack of standardization creates a situation where operators must make significant changes at the start of their shift to undo the 'mess' the previous operator has left them.

Operation of the flotation circuit of Highland Valley Copper is considered more an art than a science. The large number of rules-of-thumb developed over the years by experienced flotation operators constitutes a suitable expertise for development of a tutorial tool. As a Distributed Control System is already installed at HVC, the advisory expert system can have access to real-time operating data and is able to use the same information as that used by the flotation operators to make their decisions.
Since the process control department wanted to experiment with expert systems to evaluate the potential of this new technology, a decision was made to develop an on-line flotation advisory system rather than using a conventional training program. Management recognized that certain characteristics of an expert system could provide an appropriate tool for training [Raabe, 1992]: The capability to explain actions, the ability to deal with uncertainty and heuristics, the ease to write and maintain the program and the capacity to use real-time information from the plant are all expert system features beneficial for training.

2.2 The Copper Flotation Circuit at HVC

Highland Valley Copper (HVC) operates an open pit copper mine in Logan Lake, B.C. The concentrator has a rated capacity of 130 000 tonnes per day with an ore averaging 0.45% copper and 0.008% molybdenum. Bornite and chalcopyrite are the principal copper minerals present in the ore. The bornite/chalcopyrite ratio varies from 2.5 to 0.2 depending of the ore type [Levanaho et. al., 1992]. Quartz and feldspar constitute most of the gangue material and pyrite accounts for less than 0.5% of the mineral composition.

The feed is distributed through five parallel grinding and flotation lines, designated as A, B, C, D, and E line. The expert system was installed only on A, B, and C flotation lines to limit the expertise to a manageable size. Figure 2.1 shows a flowsheet of the A, B, and C grinding and flotation circuits at HVC. For each grinding line, primary grinding is accomplished through a Semi-Autogeneous mill. The SAG mill products are screened and the undersize material is combined with the ball mill discharges and sent to a cyclone while the oversize is fed back to the SAG mill. The cyclone underflow feeds two ball mill in parallel for further grinding. Line A and B are identically sized with 32 feet diameter SAG mills and 16.5' x 23' ball mills, processing 1150 tonnes/h. Line C uses a 34 feet diameter SAG mill and two 16.5' x 27' ball mills to process 1600 tonnes/h. The cyclone overflow feeds the bulk flotation circuit directly, as there is no conditioning stage.
Flotation is carried out through a conventional bulk flotation circuit. The copper/molybdenum rougher concentrate of each line is sent to a common cleaning circuit for further treatment while the scavenger concentrate is recycled to the rougher feed. The bulk flotation final concentrate is sent to a selective flotation circuit where molybdenum is separated from the copper. Due to the high bornite and low pyrite content of the ore, high copper concentrate grades (40%-42%) are easily achieved with recoveries of 88%.

Fuel oil is added at the primary mills, Potassium Amyl Xanthate (PAX) and Pine Oil are added at the ball mills, and Dow 250 and PAX addition rates are made to the rougher and the scavenger flotation cells. The pulp pH is controlled through the addition
of lime at the primary mills. When oxidized ore is present, sodium hydrosulfide is added to the scavengers.

With the exception of the on-stream analysis equipment, there is not much process instrumentation in the HVC flotation circuits. There is no particle size monitor, no flotation feed density gauge, no flotation pH meters, and no assays of intermediate process streams. Only the cyclone overflow and the scavenger tailings of the bulk flotation roughers of each line are sampled for on-stream X-ray analysis. The flotation cell levels are measured but this information is not sent to the DCS and therefore not displayed on the flotation operator control station. The limited monitoring equipment of the flotation circuit is attributed to the high capital and maintenance costs of instrumentation for a mill the size of HVC.

2.3 The Flotation Circuit Operating Strategy

As there is very little instrumentation on the flotation circuit, operators have developed, over the years, a flotation control strategy based on froth conditions. An experienced operator can tell if too much pine oil is being added or more air is required at the scavengers just by looking at the froth characteristics. The philosophy tries to maintain optimum froth conditions by balancing reagents and physical flotation parameters regardless of recovery or grade. Maintaining optimum froth conditions makes the flotation circuit more 'forgiving' and less sensitive to ore and tonnage changes. Glembotski [1963] described the importance of froth characteristics in the operation of a flotation circuit :

"The extent and efficiency of flotation control can be judged quite accurately from the appearance of the froth - its structure, mineral content, color, etc. Therefore, in controlling the process it is necessary to remember which froth gives the best results and under which conditions it is produced."

The desired froth characteristics are assessed in a qualitative manner, in terms of its color, bubble size distribution, thickness and movement. When a non-optimum froth is identified at the rougher or scavenger flotation bank, proper reagent changes and physical
parameters adjustments are made to bring back the optimum froth. Once optimal froth condition can be maintained at the roughers and scavengers of the bulk flotation circuit, further fine tuning of the reagents can be done to optimize the recovery. However, it can take years for less experienced operators to learn how to 'read' the froth and attain proficiency in the art of flotation. Thus the need for an advisory expert system.

Phase 1 of this project has been described elsewhere [Benford and Meech, 1992] and was used to acquire and refine knowledge about froth conditions into an off-line tutorial system. Initially, 8 rougher and 4 scavenger froth types were defined. After implementation and testing by the operators, it was found that some froth conditions were not described through the existing terminology. The froth types were reorganized into a hierarchy that contains 10 different froth types for the roughers and 6 for the scavengers. Figure 2.2 and Figure 2.3 show a description of the hierarchical structure of rougher and scavenger froth types respectively.

Since the scavenger concentrate of the bulk flotation circuit is recycled to the rougher feed, both the rougher and the scavenger froth types must be assessed in order to identify the causes of a poor operating condition. This means that 60 rougher and scavenger froth combinations (some being more common than others and some being clearly improbable) were necessary to describe all possible states. Each combination can result from one or more of several poor operating conditions. For example, an Optimum-Big Bubble froth is usually caused by too much pine oil while a Tight-Not moving-Broken-up-Quiet Pulp froth may originates from too much collector, not enough frother, low cell level or a high pulp density.
# ROUGHER FROTH TYPES

## Optimum froth
- Bubbles ranging in size from 2.5 cm to 6 cm, covered with copper minerals, but the larger bubbles show windows. The froth is fairly thick (3 cm or deeper) and flows steadily over the lip. When the top layer is scrapped away, clean whiter froth shows below. It is watery looking but not foamy.

### Normal copper color
- Normal optimum froth condition.

### Big bubble
- This froth has bubbles as large as baseballs.

### Bluish-grey
- Optimum froth with a bluish-grey color

## Tight froth
- The froth bubbles are small and loaded with copper minerals. No windows are visible on the bubbles. The bubble surface looks gritty. There is no whitish froth below the top froth layer.

### Not moving
- Froth covers the flotation cell
  - The froth has collapsed as a result of a build-up of copper.

### Broken-up froth
- The froth does not cover the full flotation cell. Patches of pulp are showing and the froth is thin.

#### Quiet pulp
- This is a severely collapsed froth

#### Boiling pulp
- Big air bubbles rise to the surface and create boiling pulp conditions.

### Fast moving
- The froth covers the full flotation cell. It is flowing over the froth lip steadily

## Foamy froth
- Very small bubbles having a white or grey look. It looks like a soap foam and has a deep froth bed.

## Empty froth
- The froth shows big windows and the windows are clear. The surface of the bubbles is smooth, not gritty. The froth covers the flotation cell.

## Grey froth
- The froth has a grey look, sometimes oily. Bubbles can be foamy, the froth bed can be broken up.

---

Figure 2.2 - Rougher froth type descriptions
### SCAVENGER FROTH TYPES

<table>
<thead>
<tr>
<th><strong>Optimum froth</strong></th>
<th>The optimum froth has a deep froth bed, which is flowing over the froth lip continuously. The froth is weak and watery, it breaks down easily. It will show some copper.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low copper</strong></td>
<td>This is the ideal condition. Copper is pulled off the roughers and does not carry over the scavengers.</td>
</tr>
<tr>
<td><strong>High copper</strong></td>
<td>The froth shows a goldish color and the bubbles are covered with copper minerals.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Tight froth</strong></th>
<th>The froth bubbles are small and are loaded with copper minerals. The bubble surface looks gritty like coarse minerals. The froth bed is thin and broken up</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Not moving</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Quiet pulp</strong></td>
<td>This is an indication of a severe build up of copper</td>
</tr>
<tr>
<td><strong>Boiling pulp</strong></td>
<td>Big air bubbles rise to the surface and create boiling conditions.</td>
</tr>
<tr>
<td><strong>Fast moving</strong></td>
<td>Even though the froth is heavy with copper, it still moves well over the flotation lip. This is an indication of a collapsed optimum froth with high copper mineralization.</td>
</tr>
</tbody>
</table>

| **Foamy froth** | Very small bubbles having a white or grey look, looking more like a soap foam than a mineral froth. Mostly, the froth bed is deep. The froth does not look watery, the bubbles are not not clear but whitish opaque. |

Figure 2.3- Scavenger froth type descriptions
2.4 The Formation of Froth at Highland Valley Copper

On the HVC copper flotation circuit, frother is added to assist in maintaining a stable froth which is capable of supporting the minerals carried to the surface until they can be recovered from the flotation cell. Glembotski [1963] points out the important properties that a flotation froth must have:

i) The float mineral particles carried up with the bubbles must remain firmly in the froth; the detachment of floated particles from the froth retards the process and leads to increased losses in the tailings.

ii) The maximum possible supplementary concentration, due to selective detachment of gangue particles, must take place in the froth.

iii) The froth should not be excessively stable, and must break down readily after being removed from the flotation cell, otherwise difficulties will arise.

A multitude of variables affect flotation and several of these influence the froth condition. Frother addition rates will affect the volume, structure and flow of a froth phase by changing the surface tension of the air-water interface. Xanthates, which do not possess any significant liquid/gas surface activity, affects the ability of frother to generate foam [Laskowski, 1993]. Booth and Freyberger [1962] state that frothing is also influenced by the pH of the ore pulp and the presence of oils and greases used as lubricants in mining and pre treatment operations. Disturbances such as ore type changes and feed tonnage and density changes also upset the froth phase.

2.4.1 The Impact of Flotation Parameters on Froth Conditions

The froth plays a major role in the operation and optimization of the flotation circuit at Highland Valley Copper. It has been recognized, over the years, that the formation and maintenance of a satisfactory froth layer on the bulk flotation circuit is a key to maintaining high recoveries. The non-optimum froth conditions identified at HVC are caused by different flotation parameters upsets. Based on the froth condition, proper
adjustments can be made to bring back an optimum froth condition. The main factors influencing the froth are discussed here.

2.4.1.1 Froth Overloading

An overloaded froth is characterized by a collapsed, very tight froth showing small bubbles saturated with copper minerals. Flotation becomes inhibited, that is, hydrophobic particles being transferred to the concentrate launder at a lower rate than expected. This condition corresponds to a Tight froth class at Highland Valley Copper. This froth class is broken up into four froth types for the roughers and three froth types for the scavengers. Froth overloading can be caused by either excessive collector concentration, insufficient frother, a high pulp density or insufficient aeration:

1) Excessive collector concentration

Potassium Amyl Xanthate, with five-carbon aliphatic groups, is one of the most powerful and least selective xanthates. At HVC, it is used as the main copper mineral collector in the bulk and cleaning flotation stages. An excess concentration of PAX results in over-collecting, producing an overloading condition in the froth phase. One hypothesis that could explain this phenomenon is that over-collecting occurs with particles that have such a high degree of hydrophobicity that water rejection from the froth phase detracts from an optimum flowing condition. As a result, the froth collapses and stagnates on the pulp surface. As the collapsed froth covers the flotation cell, decreasing the PAX addition rate will not improve the froth condition. To bring a collapsed froth bed to life, cell levels have to be raised to get rid of the collapsed froth bed. Then, decreasing the PAX addition rate should bring back an optimum froth condition. Raising cell levels is a temporary measure and cell levels should be lowered again once better froth conditions have been reached. A Tight Froth-Fast moving classification is a clear indication that too much PAX is being added since the frother addition rate is high enough to move the froth out of the cell but the excessive collector concentration causes the froth to collapse.
2) Insufficient frother concentration

The frothers used on the bulk flotation circuit of HVC include Dowfroth 250 and pine oil. Dowfroth 250, which belongs to the chemical family of the polypropylene glycols, is characterized by low viscosity and complete water solubility. The Dowfroth frothing agents are also known to carry through prolonged flotation stages and to produce fine and widely dispersed bubbles. A Tight Froth-Not moving classification may be the result of a weak froth phase. Lynch et. al [1981] noticed that at low frother addition rates the froth tends to collapse easily. By increasing the Dow 250 addition rate, the froth becomes more stable and the transfer rate from the froth to the concentrate launder increases. However, too much PAX and Dow 250 creates a Tight froth-Fast moving condition where the froth is collapsed due to overcollecting but the excess frother moves the froth layer consistently over the flotation cell lips.

3) High pulp density and insufficient aeration

A Tight froth-Not moving-Quiet pulp condition can result from insufficient aeration. When the air flow and bubble production rates are low, saturation of the bubble surfaces by mineral particles occurs but the transfer rate of floated material from the froth to the launder is low, leading to froth overloading. Lynch et. al [1981] observed that at high air flow rates, cell performance deteriorates because the impeller is no longer able to mix the air intimately with the pulp and a reduction in the air swept volume occurs accompanied by severe turbulence and deposition of particles in portions of the cell. Conversely, a Tight froth-Not moving-Boiling pulp state can be a sign of too much air.

The flotation feed density is one of the main process disturbances at Highland Valley Copper. As water is added at different points in the grinding circuit and on the pump floor, and as there is no density measurements on the grinding and flotation circuits, the flotation feed density cannot be maintained constant. At high densities, the agitator disperses less air and generates larger bubbles. The high pulp density slows air bubble rising velocity and leads to air bubble coalescence. A Tight froth-Not moving-Boiling pulp
condition is generally caused by a high pulp density as the larger bubbles create boiling at the froth interface. The high density can cause the roughers to slow down to the point where no concentrate is pulled off, causing the froth to collapse.

2.4.1.2 Excess Pine Oil

Pine oil is primarily used to promote the flotation of molybdenite, in conjunction with fuel oil. The main frothing agents of pine oil are terpene alcohols, mainly alpha terpineol. Terpene hydrocarbons, also present in pine oil, are reported to enhance collecting action on sulfide minerals. According to Booth and Freyberger [1962], and later Klimpel and Crozier [1989], pine oil is known to generate a small-bubble froth of closely knit texture, which breaks down readily on removal from the flotation cell. It has also been reported that excessive quantities of pine oil tend to flatten the froth, decrease its volume, and cause effervescence at the surface. At Highland Valley Copper, too much pine oil produces a froth with bubbles the size of a fist. The difference between the effect of too much pine oil as described in the literature and as observed at HVC may be caused by different operating conditions and the use of Dowfroth 250 in conjunction with pine oil. When a Big Bubble froth is observed, the operators decrease pine oil addition rate and increase Dow 250 addition rate.

2.4.1.3 Ore Changes

The copper sulfides contained in the ore at Highland Valley Copper are mainly bornite and chalcopyrite [Levanaho, 1992]. The bornite/chalcopyrite ratio of the different ores identified at HVC varies from 2.5 to 0.2. Such large variations in the mineralogical composition of the ore affect the bulk flotation circuit. When high bornite ore is treated, it was demonstrated by Levanaho [1992], that better recoveries can be obtained by decreasing the PAX addition rate and increasing the Dow 250 addition rate. High bornite ores are identified when froth colour becomes bluish-grey.
Sporadically, copper oxide ore from surface zones of the open pit is sent to the bulk flotation circuit. Oxide ore is identified by the brownish color of the ore on the stockpile and by a sudden decrease in recovery. Sodium sulfide is added to the rougher and scavenger banks of the bulk flotation circuit to coat the surface of copper oxides with sulfides which are needed for the collector to work efficiently. However, when used in excess, sodium sulfide depresses copper sulfides. An excess of sodium sulfide will produce a Foamy froth at the roughers.

2.4.1.4 Effect of Lime and Oil Contaminants

Lime addition is used by HVC flotation operators to stabilize the frothing reagents and maintain bubble size. Although the fundamentals of this effect are not well understood, it has been noted by flotation operators that too much lime results in a Foamy froth while insufficient lime can cause the froth to turn to a Big Bubble condition. However, changes in the lime addition rate should be considered only as a temporary solution. Lime adjustments improve the froth quality but do not solve the problem that is causing the froth to be non-optimum.

Oil contamination from mill lubricant and accidental oil spills has been described by Taggart [1945] as producing a small-bubble, highly fluid froth carrying a heavy solids load with little or no selectivity. The effect of oil contamination shows rapidly on the bulk flotation circuit as the froth turns to a Grey froth condition. Contamination by trunion gear cleaning agents (Varsol and Traxol) is known to produce a Foamy froth. Oil spill in the pit can also lead to contamination problems.

2.4.2 An Example of Bad Froth Condition Troubleshooting at HVC

A bad froth condition can be the result of different causes and necessitate a series of different actions before a more stable froth condition is obtained. A good example of bad froth condition troubleshooting is the following:
Rougher froth condition: Tight froth - Not moving - Froth covers the flotation cell
Scavenger froth condition: Tight froth - Not moving - Quiet pulp

This froth condition indicates a totally overloaded circuit. The first action taken by an experienced operator would be to off-load the circuit by temporarily raising the scavenger and the rougher cell levels. Experience has shown that getting rid of a collapsed froth bed by raising the cell levels and then making the appropriate reagent changes is the best strategy to bring a collapsed froth bed back to life. The second action would be to decrease PAX addition to the rougher banks, as a tight froth is generally an indication of too much collector. However, if the recovery drops following the PAX addition rate change, the operator would reestablish the PAX level and conclude that the tight froth condition may be the result of insufficient frother. The Dow 250 addition rate will then be increased at the scavengers. More frother will produce finer bubbles and a less tight froth. If the froth condition does not improve following these changes, the pulp density will be measured and water will be added to the grinding circuit. The high pulp density can cause the roughers and the scavengers to slow down to the point where no concentrate is pulled off. As high pulp density is an uncommon cause for a tight froth, reagent changes are looked at first.

3.1 The Knowledge Acquisition Process at HVC

"The clarity of the expertise is inversely proportional to the number of experts".

Knowledge acquisition on the operation of A, B, C flotation lines was first performed by Paul Benford for the development of an off-line advisory expert system [Benford and Meech, 1992]. The off-line expert system was successful at providing an opportunity to rationalize the expertise and present it under a Hypertext format. Use of the system by the operators led to a new definition of the froth description types. Agreement was achieved in setting up a hierarchical structure to these descriptions, which essentially rendered the knowledge structure obsolete. The knowledge acquisition and the structure of the knowledge base had to be redone from scratch using the new froth types.

During development of a supervisory expert system at Brenda Mines Inc. in 1989, four different techniques of soliciting information were used: Observation of the operator in action, various types of operator interviews, hands-on operation and written questionnaire. After assessing the strengths and weaknesses of each knowledge acquisition methods, it was found that:

"By far, the most effective form of knowledge solicitation for the operation of the copper flotation circuit at Brenda Mines was found to be the oral interview" [Edwards and Mular, 1992].

Based on Brenda's experience, it was decided to acquire the knowledge through interviews with experienced operators and senior metallurgists.

At HVC, interviews were conducted in the lunch room or at the operator work place. This would allow the operator to demonstrate the different froth types or operating actions taken through the DCS directly to the knowledge engineer. Being close to the
flotation circuit makes it easier for the operator and the knowledge engineer to understand one another. The expert crew consisted in three full-time experienced operators on the ABC copper flotation circuit and the senior metallurgist. Full time flotation operators of D and E line contributed to the revision of the knowledge base since both rougher copper flotation circuits are similar.

The approach taken was to identify a series of causes for each of the 60 froth combinations. A typical question asked of the experts was: "What could cause the froth condition to be such at the roughers and such at the scavengers?". Generally, more than one cause was found for each froth condition and the expert was asked to prioritize them in order of frequency of occurrence. A proper action was attached to each cause. For example, the knowledge engineer would ask: "Now, if this froth condition is caused by this, which action would you take first?". Finally, the expert would be asked to explain why this specific action was suggested. Usually, the explanations would be provided by the senior metallurgist. Table 3.1 shows an example of the structure of the knowledge acquired for a Tight froth - Not moving - Broken-up - Boiling pulp at the rougher and an Optimum - Low copper froth at the scavenger banks.

<table>
<thead>
<tr>
<th>Causes</th>
<th>Actions</th>
<th>Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulp density is too high.</td>
<td>Increase cyclone O/F water</td>
<td>High densities affect the capability of the agitators to disperse air.</td>
</tr>
<tr>
<td>Too much air at the roughers.</td>
<td>Decrease air to the rougher cells</td>
<td>Too much air will create boiling conditions because the agitator will not be able to disperse the air properly.</td>
</tr>
<tr>
<td>Too much collector to the ball mill.</td>
<td>Decrease PAX to the ball mill</td>
<td>Excessive PAX results in over collecting and creates a collapsed, tight froth.</td>
</tr>
<tr>
<td>Not enough frother to the roughers.</td>
<td>Increase DOW to the roughers.</td>
<td>More frother will help create finer bubbles by decreasing the surface tension of the water.</td>
</tr>
</tbody>
</table>

Table 3.1 - An example of the knowledge acquired for one froth condition.
The acquisition of knowledge was performed in parallel with system development. The interview sessions proved quite demanding for the experts as well as for the knowledge engineer. To picture two froth conditions (one at the roughers and one at the scavengers), to determine the different causes for each condition and to find out the appropriate action is quite a mentally exhaustive exercise. Consequently, several interviews were necessary to go through all 60 different froth combinations.

Experienced operators who participated in the development of the expertise agreed on which action to take about 80% of the time. With the few conflicts that did occur, the senior metallurgist made the decision regarding which action was most appropriate for the given froth condition.

Before starting to interview the experts, a questionnaire was used to evaluate the operating strategy used by the relief flotation operators. The "Questionnaire on Flotation Practice at FiVC" was distributed to seven relief operators (see Appendix A). For each of the 10 copper rougher and scavenger froth conditions described in the questionnaire, the operators were asked to pick, among a list of actions, the 3 most likely changes to improve froth condition. It was found that most relief operators do have the same operating strategy of the flotation circuit. By comparing the answers of the relief operators to the experts strategy, it appeared that relief operators have a tendency to change reagent concentrations first in order to improve a froth condition while experts would change physical parameters, such as air flowrate, cell level or pulp density before changing reagent concentrations. In many cases, a change in reagent concentration corrects a situation temporarily and locally by acting as a "band-aid" while optimizing a physical parameter improves a froth condition by acting on the cause of a bad froth condition. An on-line expert system that could minimize the unnecessary and often expensive reagent changes by suggesting to change the air flowrate or cell levels instead was seen, at this stage, as very beneficial.
3.2 Selection of the Expert System Shell

The application was constructed using Comdale/C, a real-time expert system shell marketed by Comdale Technologies, Toronto, Canada. Comdale/C is a development tool for creating real-time on-line supervisory control systems. It consists of a series of individually executable modules which obtain and manage information from the plant. Among other functions, these modules are responsible for data acquisition, real-time reasoning, interaction with human operators and explanations of actions taken. Comdale/C is equipped with two important user interface modules, Process View and Expert View, which display diagrams of the process and generate messages sent from the knowledge base, alarm administrator or scheduler modules in the QNX Windows environment. The system also supports Hypertext files, which provide a flexible approach to obtaining information within the system.

The decision of opting for Comdale/C was made by HVC process control staff. The selection was primarily based on the connectivity of the expert system to the Bailey Net-90 process control system already in place. At the time of selection, Comdale/C was the only on-line expert system which could provide a real-time interface with the Bailey Net-90 system. Furthermore, Comdale/C runs under the QNX operating system, used in the Bailey PC-based network. It was also felt that using a commercial expert system shell was less risky, easier to maintain and would require less development time than conventional programming. Comdale offers certain features that were considered essential for developing an advisory system [Raabe, 1992]: The ability to explain its action, a Hypertext utility, the ability to deal with uncertainty and the ability to use symbols rather than numbers. Finally, Comdale had the expertise in developing expert systems for mineral processing plants and successful applications were put in place on grinding circuits in several mills in Canada.
3.3 Structure of the Knowledge Base

"Computers are not intelligent; They only think they are."

Two primary objectives were followed through the development of the expert system. One was to ensure that maintaining the knowledge base would be an easy task. As the operating strategy evolves with ore changes and as additional information from the plant (such as assays, pH levels, etc.) becomes available, modifications will have to be made to the knowledge base by the HVC process engineers. The second feature was to design the expert system to deliver its conclusions quickly. The operators cannot spend several minutes in front of a screen waiting for answers from the expert system. A respond time of 1 to 2 seconds was the designed target.

The heart of any expert system, and also the most time consuming aspect of development, is the knowledge base. The knowledge base structure used at HVC was inspired from the Comdale Technologies conceptual model, a backward chaining algorithm befitting process control applications [Meech and Harris, 1992]. Since this application does not perform control actions, some changes to the conceptual model were made. A simplified algorithm of the knowledge base is presented in Figure 3.1.

The first rule is a controlling rule that is used by the expert system to attach a cause to a specific froth condition. The system then backward-chains to a second rule that use measured variables to conclude on the presence of the specific cause being examined. All causes involving reagents are verified by examining the current addition rate. For example, if the roughers show a Foamy froth, which may be caused by too much Pine Oil, and the Pine Oil addition rate is low, then this cause is ruled out and the other causes for a Foamy froth are evaluated. For every froth condition, fuzzy sets are used to express the degree of confidence in high and low reagent levels. Experienced flotation operators were asked how confident they were in stating that a particular reagent was high or low under a certain froth condition and their expertise was translated into fuzzy sets.
Figure 3.1 - Simplified algorithm and rule structure of the knowledge base

On the mill floor at HVC, reagent addition rates are expressed in cc/min rather than grams/tonne. The consequence of expressing the reagent addition rates in cc/min instead of grams/tonne is that the degree of confidence in a reagent addition rate being high or low does not take into account the current tonnage. A reagent addition rate considered as low at 1150 t/h may be considered normal or appropriate at a lower tonnage. As flotation operators are not used to expressing reagent addition rates in grams/tonne, the expertise necessary to come up with a fuzzy set that would describe the relation between the tonnage and the reagent addition rates was very hard to extract. However, HVC flotation experts pointed out that the degree of confidence in the concept "reagent X addition rate is high" also changes depending on the mineralogy of the ore being floated. For example, an ore with a high bornite content, which is characterized by a bluish-grey froth, requires about 30% of the PAX consumption of chalcopyrite ore. Consequently, a different fuzzy set is used to describe PAX addition rate when a bluish-grey froth is identified. An example of a fuzzy relationship between the PAX addition rate at the A1 line scavengers and a belief in the PAX addition rate being high, is shown in Figure 3.2
Causes involving non-measured flotation parameters or parameters not available to the Bailey system, such as pH, cell levels, pulp density, air flowrates, particle size and rougher concentrate grades, cannot be verified. Consequently, the knowledge base generates a list of advice rather than the most probable advice. The advice given by the system are ranked according to their probability of occurrence as established by the flotation experts. When two causes have the same probability of occurrence, the knowledge base was designed to suggest changes in physical flotation parameters such as pulp density, cell levels and air flowrates, before advising changes in reagent addition rates.

Advice is given one piece at a time, so the operator can go on the plant and verify the problem cause. If either the cause is ruled out or the froth condition does not improve after implementing the first item, the operator can request the second piece of advice. For example, if the system first recommends lowering the pulp density but pulp density cannot be lowered or else the tailings line will plug, then the operator can look at the second item. An explanation is attached to each advice to justify why this item is given so that novice operators can learn from the expert system, as shown in Figure 3.3.
Figure 3.3 - Structure of the expert system routine

Although the knowledge base totals 280 rules, the rule structure and inference strategy are configured to minimize the number of rules called on each consultation. This results in only a 1 to 2 second delay before the system comes up with advice. This configuration also provides the advantage of being very easy to modify. As more flotation parameters become available, only a few rules have to be changed in order to make the knowledge base use this additional information to verify the problem causes.

As the listing of the knowledge base is over 150 pages long, the principal rules are shown in two tables of the key rules regarding advice given for different froth combinations in Appendix C. Table C-1 describes the different actions advised by the expert system for each froth condition while the explanations attached to each advice are shown in Table C-2.

3.4 Features of the flotation advisory expert system

"A gram of application is worth a tonne of abstraction".

3.4.1 Graphical User Interface

The goal of this expert system is to give real-time advice to the less-experienced and relief operators on how to reach optimum froth conditions. As described earlier, the
operating strategy of the bulk flotation circuit is to maintain optimum froth at the rougher and scavenger flotation banks. As there is no existing way to monitor the froth condition automatically, the expert system is operator driven. Advice is given upon request, when the operator identifies poor froth conditions.

It was found important to come up with an appealing and efficient user interface to ensure that operators use the system. The froth types at the rougher and scavenger banks of A, B and C flotation line appear in the lower half of the screen. The Expert View window occupies the upper half of the screen to display messages forwarded to the operator by the knowledge base (See Figure 3.4). By clicking on one of the flotation cells, a new display will come up presenting the 10 rougher froth types and the 6 scavenger froth types from which an experienced operator can select the ones that best describe the current froth conditions (See Figure 3.5)

![Figure 3.4 - Main operator interface](image-url)
The expert system will then use this new information together with plant data acquired from the LAN-90 to run the knowledge base. One to two seconds later, the expert system comes up with the best advice for the given operating conditions.

If the operator is not familiar with the froth type descriptions, two options are available to help select the appropriate froth name. A hypertext document is linked to the "Help" button. Hypertext is like an electronic book. It is a powerful and quick means to access specific information. Clicking on a highlighted key-word in a hypertext document will display a new page giving more information about this key-word. All rougher and scavenger froth types are described in this document, making it easy to learn what a "Tight froth- Not moving- Quiet pulp" really looks like. A second hypertext document has been incorporated within this expert system. It consists of a "Copper Flotation Recipe Book" written by HVC personnel to describe the theory of flotation process, the mineralogy and the geology of HVC ore, the effect of circulating loads, and the terminology used in flotation.

During system testing, a number of relief operators were observed consulting this document and they responded favorably to the opportunity to learn more about their field.

<table>
<thead>
<tr>
<th>Roughers</th>
<th>Scavengers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optiminm Froth</td>
<td>Optiminm Froth</td>
</tr>
<tr>
<td>Normal copper color</td>
<td>Lower copper</td>
</tr>
<tr>
<td>Big bubbles</td>
<td>Higher copper</td>
</tr>
<tr>
<td>Blush grey froth</td>
<td></td>
</tr>
<tr>
<td>Tight Froth</td>
<td>Tight Froth</td>
</tr>
<tr>
<td>Not moving:</td>
<td>Not moving:</td>
</tr>
<tr>
<td>Froth covers float cell</td>
<td>Quiet pulp</td>
</tr>
<tr>
<td>Broken up froth</td>
<td>Boiling pulp</td>
</tr>
<tr>
<td>Quiet</td>
<td>Moving:</td>
</tr>
<tr>
<td>Boiling</td>
<td>Fast moving</td>
</tr>
<tr>
<td>Moving:</td>
<td></td>
</tr>
<tr>
<td>Fast moving froth</td>
<td></td>
</tr>
<tr>
<td>Empty Froth</td>
<td></td>
</tr>
<tr>
<td>Grey froth</td>
<td></td>
</tr>
<tr>
<td>Foamy Froth</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3.5 - Froth type selection interface**
### 3.4.2 Metaknowledge

A relief operator not familiar with the froth names can also have the expert system identify the appropriate froth type for him. By clicking on the "I don't know" button on the froth type description screen, the expert system will run a routine to infer the froth type. A series of questions on bubble size, color and appearance, the flow of the froth over the lip and the pulp condition are asked of the operator. The froth types are organized through a dichotomistic chart, as shown on Figure 3.6, which facilitates the inferencing strategy. When enough froth characteristics are known, the expert system determines the froth type and gives its advice.

![Figure 3.6 - Dichotomistic chart of the rougher froth types](image)

Since the expert system is mainly used to provide real-time training for relief operators, it was found that giving advice was not enough. The system also had to explain its advice so that operators could learn and understand the logic behind the strategy. Explanations are linked to all advice and made accessible to the operator simply by
clicking on the advice line displayed on the Expert View Window. For example, clicking on the advice:

"Increase the scavenger cells levels temporarily to off-load the circuit"

will open a window giving the following explanation:

"To bring back a collapsed froth bed to life necessitates too much reagent. First, get rid of the collapsed froth bed by raising the cell levels. Then, making the recommended reagent changes should bring back an optimum froth. However, one should bear in mind that raising the cell levels is a temporary measure and that the cell levels should be lowered once better froth conditions have been reached."

One week after the implementation of the on-line advisory expert system on the flotation circuit, an experienced operator who was quick to perceive the advantages and potential of the expert system came up with a request. He told us that it would be useful if the expert system could keep track of the reagent changes being made over a 24 hour period. This way, if a recovery problem exists at the start of the shift, the operator could avoid repeating the unsuccessful reagent changes made by the previous operator and get better results quicker. It would also put an end to a tendency that certain operators had of playing practical jokes by increasing frother or PAX addition rate at the end of their shift.

The reagent tracking module consists of a 20 rule knowledge base designed to scan all reagent addition rates every 2 minutes and detect any increase or decrease from the previous scanned value. An operator can examine a list of all reagent changes made over the past shift and know what to expect at the start of his shift.

3.4.3 Installation and maintenance of the expert system

The Comdale C software was installed on a 386 personal computer with 13 Mb of RAM. A communication board was added to interface with the LAN-90 network. The computer was protected from dust by a heat-exchanger sealed enclosure and installed in the plant, beside the flotation operator's booth. Since floor vibrations affected the hard disk, program files were moved to a hard-disk located on a remote station of the LAN-90
network. The computer installed on the floor was used only for its CPU as a diskless station. A booting program was written in the QNX configuration file to load QNX Windows, Comdale C and all the knowledge bases automatically from the remote station.

The knowledge base contains 280 rules, from which 180 check reagent levels and come up with solutions for the different froth conditions. The knowledge base also includes 176 objects, 60 classes and 6 hypertext documents providing information on the froth types, the ore types and a recipe book on flotation.

The 99 reagent levels used as inputs to the knowledge base are read every 20 seconds while the 24 assay values and tonnage feedrates are read every 60 seconds. The information is extracted from the Bailey system using a communication interface developed by Comdale Technologies Inc.

A maintenance book was provided to HVC personnel to facilitate expert system maintenance. The maintenance guide contains a problem solver section as well as the procedure to install new software versions via the modem, descriptions of all the program and Comdale configuration files developed at HVC.

The knowledge acquisition, the writing of the program, the installation of the expert system and training of the operators took five months to the knowledge engineer. Three experienced flotation operators and the senior process engineer at HVC spent about 150 hours on the project sharing their knowledge as flotation experts.
CHAPTER 4 - Using On-line Trend Analysis to Assist Operators in Filtering Out Plant Information.

"When you've plugged in all formulae, but have no clear position, then that's time you should rely on gut-felt intuition."

4.1 Introduction

Although the utilization of distributed control systems leads to substantial savings in product yield increase and quality, work has to be done to accommodate facilities for intelligent interpretation of sensor data and fault diagnosis. The plant status may change dramatically within a few minutes and the large number of variables that are monitored and alarms that are provided make necessary the use of an expert-system reasoning scheme.

Real-time trend analysis of flotation plant data is an important but sometimes difficult human-thought process. While experienced flotation operators can usually quickly filter out spurious assay upsets, novices must spend considerable time acquiring such skill. When the number of assay trends are high, updating the memory of current plant situations can be onerous, resulting in omissions or other failures.

Trending analysis consists of examining time-series data and identifying significant increase or decrease in a signal variable. Although this may be considered a simple task for an experienced plant operator, analyzing time-series can be quite complicated to computerize. Humans are able to grasp inexact concepts directly, and to filter out data without performing a detailed mathematical analysis. Standard time-series analysis techniques such as the autocorrelation function, power spectrum, ARMA filters, and process models, are not easy to program in a real-time environment. [Hodouin and Bazin, 1985] As a result, there are many processes where operators and engineers change control variables by analyzing production trends based on their judgment and experience.
This chapter presents the development of an expert system aimed at assisting operators in the analysis and filtering of flotation plant data. The on-line trend analysis expert system was developed and installed at HVC to provide an additional tool to assist the novice operators in analyzing tailings grades and feed tonnage variations. The trend analysis was developed to study how on-line diagnosis of time series could be designed using expert system technology but verification of the correctness and consistency of the advice generated by the trend analysis expert system lies outside the scope of this thesis.

4.2 Trend Analysis : The Problem

Conventional process control is often unsuitable for processes with large lag times, unpredictable transient states or unmeasurable controlled variables. Examples include cement kilns and reheate furnaces: it can take from 6 to 12 hours for a kiln to respond completely to a load change. Several expert systems applications have been developed for control and monitoring in the mineral process industry [Laguitton and Leung, 1989]. Off-line rule-based forecasting have also been developed to make annual extrapolation for economic and demographic time series [Collopy and Armstrong, 1992].

Many plants use time-series analysis of operating variables for quality control, reagent optimization and to maximize productivity. Based on time series analysis, operating variables are adjusted to stabilize or improve the process. Less experienced operators have more difficulty in analyzing these signals and must receive training. Furthermore, for complex processes such as those involved in the chemical and metallurgical industries, the number of different time-series to analyze can be high. Updating the memory of current plant situations can be onerous resulting in omissions and other failures.

Figure 4.1 shows three time series all trending down. When looking at these plots, it is obvious that the variable has been decreasing for the past 80 minutes. Although these signals have different characteristics, a human can filter out data and easily conclude about the general trend of the signal. However, conventional computer analysis of noisy signals
such as signal B and those showing short term peaks or valleys like signal C may lead to faulty conclusions.

![Time series examples](image)

Figure 4.1 - Time series examples

### 4.3 Intelligent Alarms: The Solution

Intelligent alarms that use fuzzy logic and rules of thumb to analyze time-series have many advantages over conventional upper limit/lower limit alarms:

1) Intelligent alarms trigger only when a significant increase or decrease of the variable occurs over a time period. This strategy allows detection of circuit upsets at a very early stage.

2) Intelligent alarms recognize short term peaks and noisy signals. The number of false alarms is reduced.

3) Different types of alarm signals are implemented depending on the rate of change of a variable or on the degree of belief in that change.
4) Several time series can be analyzed over a long time period to detect process upsets and prevent equipment failure. For example, in the cement industry, a number of long term trends are used to identify conditions that indicate build-up of material within the kiln [Benford, 1993].

The structure of expert system-based intelligent alarms include rules, fuzzy logic, and temporal-reasoning functions. Good knowledge of the process dynamics is essential to construct rules that construe changes in input variables and loads. The rules express relationships between process states and controlled variables that define the operating strategy. The strategy is expressed as a set of linguistic decision rules of the form:

\[
\text{IF } \text{"power draw has been trending down for 10 minutes" AND "hydrostatic pressure is high"
THEN "trigger SAG mill overload alarm"}
\]

The heuristic terms used in this rule are handled using fuzzy logic. Membership grades are assigned to the expressions "trending down" and "high" through fuzzy sets related to measured input data. In order to evaluate if a signal is changing, temporal-reasoning functions determine the rate of change and weighted average of the variable over a period of time.

4.4 **Application of a Trend Analysis Expert System at HVC**

A real-time expert system was installed on the A, B, C flotation circuits of Highland Valley Copper to assist in trend analysis. Flotation operators manipulate control variables manually based on the value of two input variables. The first one is the froth condition which is visually evaluated by the operator. As this variable cannot yet be measured directly, conventional process control cannot be applied for reagent addition to the flotation circuit.

The second input variable is process recovery, which is inferred from the metal content of the feed and tailings streams of the circuit. An on-stream X-ray analyzer assays
Using On-line Trend Analysis to Assist Operators in Filtering out Plant Information

each stream at intervals of 6 minutes. The intelligent alarm developed for this application sends a message to the operator when a significant increase or decrease in the metal content of a stream is detected over a variety of time interval periods. With information from the trend analysis expert system and the froth condition, the operator can determine the best operating strategy.

A schematic diagram of the components of the trend analysis expert system is shown in Figure 4.2.

![Figure 4.2 - Trend analysis expert system components](image)

Relief operators experience difficulty in analyzing assay trends when "bad" assays are received from the on-stream analyzer. These problems occur when samples are contaminated, an X-ray cell window is dirty, or maintenance is being conducted on the analyzer. Several rules were included in the trend analysis expert system to filter out bad assays and make sure that no conclusion is reached regarding trending when these conditions exist. The filter detects sudden changes in assay values and assess values outside certain limits to conclude that the assay is bad. From operator experience, a sudden peak assay value which is more than 15% plus or minus the previous assay value is considered a bad assay.

The intelligent alarm uses linear regression and a moving average of the assay value over a given time period to conclude if the assays are trending up, trending down or are remaining constant. A typical rule reads as follows:
Using On-line Trend Analysis to Assist Operators in Filtering out Plant Information

IF the rate of change of a stream assay is significantly positive over a time period
AND the weighted average over the first half of the time period is lower than the
weighted average over the second half of the time period
AND the assays are not bad assays
THEN send a message to the operator indicating that the assay value of this
stream has been trending up over the past "x" minutes

The first premise calculates the rate of change of the assay value over a specific
time period. The rate of change is calculated over the time period using the slope between
the first assay value of the sampling interval and the last value of the sampling interval.
The second premise verifies if the signal is trending up consistently over the time period,
by comparing if the weighted average of the assay values over the first half of the time
period is lower than the weighted average over the last half of the time period. The third
premise verifies if there is any bad assay value within the time horizon. If a bad assay, i.e.
an assay value which is more than 15% plus or minus the previous assay, is detected, no
conclusion will be reached regarding this time series. When the premises concludes that
the assay value has been trending up or down during the time period, a message in the
form of « The A-Line tailings assay increased over the past 24 minutes » is displayed in the
Expert View window of the expert system.

Figure 4.3-A gives an example of a clear "constant" increase in the assay values
over 8 sampling intervals, where the slope is higher than 10% and the weighted average of
the 4 first samples, WA1, is lower than the weighted average of the 4 last samples, WA2.
Figure 4.3-B shows a peak value at the last assay, which is regarded as a bad assay, and
so, the expert system will not trigger a trending up alarm in this case. Figure 4.3-C shows
a positive slope but the assay value are oscillating and are not clearly trending up. Since
the weighted average of the first half of the signal is not clearly lower than the weighted
average of the second half of the signal, the expert system will not conclude that the assay
values are trending up in this case. In order to detect quick and slow changes, time series are analyzed over three different time horizons - 4, 8 and 12 sampling intervals. The trend analysis expert system put in place on the flotation circuit at HVC consisted of 51 rules. Seven rules were dedicated to filtering bad feed and tails assay values.

The main advantage of this expert system is to allow an operator returning to his booth after evaluating the froth condition to see the assay changes that occurred during his absence. By clicking on a button, all messages sent by the intelligent alarm are displayed for each flotation line. Without this module, an operator would have to examine 17 different trends to discover the changes that took place while he was away. This module is also useful for relief operators to gain confidence in their analysis of the circuit and to learn when a feed or tailings assay has changed significantly.
After two months of implementation, operator comments were very positive and the trend analysis expert system detected most significant assay changes. However, about 20% of all the messages sent by the trend analysis program were false alarms.

The source of error of the false alarms was identified as being due to inconsistent sampling intervals. It was discovered that the on-stream analyzer cycle time was changing when sample cells were shut down. As the expert system analyzes the trends every cycle time precisely, this inconsistency caused erroneous alarm messages. A different analysis strategy has been studied to improve the effectiveness of the intelligent alarm. This new strategy uses fuzzy logic to attach a degree of belief in trending up or trending down to each new on-stream analysis value and to accumulate these degrees of belief over the duration of the time period. Each new analysis adds its degree of belief to the accumulated degree of belief and every assay leaving the time horizon is subtracted from the accumulated degree of belief. When the accumulated degree of belief in trending up or trending down reaches a certain level, an alarm message is sent to the operator. The operators can adjust the confidence level above which an alarm is triggered in order to give more or less sensitivity in the analysis. Using temporal reasoning functions, the trend analysis expert system is activated only when the assay values are updated by the on-stream analyzer, thus eliminating problems related to the inconsistent cycling period.

The fuzzy sets used to describe the degree of belief in trending up or trending down are based on a possibility curve which represents the likelihood of a sudden increase or decrease in the assay value. For example, a 10% increase from the previous assay value is frequent and would be given a high degree of belief in trending up while a 2% or 25% increase would reflect a non significant increase and a contaminated sample respectively and therefore would be given a low degree of belief in trending up.
Figure 4.4 shows a fuzzy set defining the degree of belief in trending-up from rate of change values over a period of time. Figure 4.5 shows the trends of the degrees of belief in trending up and trending down of a simulated time-series. The results from this simulation proved to be correct 100% of the time with no generation of false alarms.

Figure 4.5 - Cumulative degree of belief method

Unfortunately, the modified trend analysis expert system was developed too late and it has not been possible to install it on-line at HVC and verify the consistency of the
system in an industrial environment. There has been no data collected during the time the first trend analyzer was installed on-line because of the number of false alarms created by the inconsistent sampling intervals. However, during the time the trend analysis module was installed on-line, it was estimated by the operators and the knowledge engineer that most trending messages were correct but that about 20% of false alarms were generated.

The knowledge base listings of the first trend analysis system using the rate of change of the assay value over a time period and the second trend analysis system using fuzzy sets are enclosed in Appendix B and are referred to as TREND2.KNW and FUZTREND5.KNW respectively. TREND2.KNW contains 51 rules and monitors 6 streams over 3 different time periods while FUZTREND5.KNW counts 9 rules and 31 fuzzy sets and monitors 3 streams over 3 different time periods. Note how fuzzy logic significantly reduces the required number of rules.

4.5 Other Applications for Trending Analysis Using an Expert System

The trend analysis module could be used by less experienced operators as a supervisor to monitor all factors affecting the flotation circuit and to determine causes to recovery changes or to track the effect of any changes in reagent addition rates on the recovery.

As a significant drop in the recovery or an increase in tailings assay value is detected, the expert system could use the tonnage or head grade information available through the DCS to determine a reason for the change in recovery. For instance, if there was a significant increase in tonnage followed by a drop in recovery with no change in reagents addition rates, then the expert system could suggest adjusting the reagents. The expert system would look over the shoulder of the relief operator, advise him of a degrading condition, point out a possible reason and come up with a suggestion to improve the recovery. This strategy may reduce the instances of over-operation, in which too many changes are made. This will also require the expert system to be very accurate as
all advice may be taken literally, i.e. when the expert system gives the advice not to react, the operator may take it even if he knows this advice to be false.

The expert system could also be used to track the results of experiments made by the operator on a flotation bank. The operator makes a change on one of the three parallel flotation lines and triggers the expert system to monitor the degree of success, measured by the improvement in recovery. The improvement in froth condition is another measure of the degree of success, but this indication is strictly operator input and thus the expert system cannot add anything to what the operator observes. The degree of success will depend upon relative changes in the parallel flotation lines, but will also be influenced by the variability of the process and changes in throughput, head grades, density, etc. If the circuit is very unstable, it will be very difficult to determine if the changes made were successful or not. A trend analysis expert system could detect an unstable condition and suggest to the operator to postpone changes until the circuit is more stable.
CHAPTER 5 - Evaluation of the Expert System

"Once a program is running successfully, it has become obsolete".

5.1 The Evaluation Procedure

The evaluation of the expert system serves two purposes: To verify the quality of the system's decisions and advice and to validate if the final product complies with the requirements it was intended to satisfy. Lydiard [1992] makes a clear distinction between the verification and validation processes. The verification can be summed up as "Are we building the product right". Verification is an activity which should ensure that the knowledge base incorporates all the elements of the expertise and that the expert system is capable of consistently arriving at the correct answers. The completeness of the knowledge base, the correctness and the consistency of the advice and explanations attached, the speed of system response, and the structure and maintainability of the system are all characteristics that need to be evaluated. Verification should be performed frequently during the development to ensure that the knowledge base is consistent with the expertise used to develop it.

The validation step is aimed at answering "Are we building the right product". Through validation, the knowledge engineer insures that the advisory expert system conforms with the end-user needs and requirements. The assessment of the qualitative characteristics of the system, such as user-friendliness, presentation of the information, clarity of the terminology and the explanations, are part of the validation process. Qualitative evaluation of an advisory expert system becomes primordial as benefits of a training program depend to a great extent on operator acceptance. Evaluation of acceptability by a user should be performed after the system knowledge base has been verified since end-users are usually not very forgiving of decision-making errors in the system.
The correctness of the advice generated by the knowledge base of the advisory expert system was verified by HVC flotation experts while the qualitative characteristics of the system were assessed by the flotation operators and the management.

5.2 Verification of the Expert System

The verification process consisted of determining the competency and the completeness of the advice and the explanations given for every single pair of froth conditions. The competency of the system was assessed by comparing the quality of the system’s advice with that obtained from a source of knowledge other than the flotation operators who served as experts. The senior metallurgist verified the competency of the advice and added or modified the explanations every second day or so throughout the knowledge acquisition process. In addition, flotation operators on the D & E lines were asked to use the on-line expert system at the end of the different phases of the knowledge base and comment on the correctness of the advice and the completeness of the knowledge base. The D&E rougher and scavenger flotation lines are similar to the A, B, and C lines and D&E lines operators have many years of experience on all five flotation circuits.

The backward chaining structure of the knowledge base was designed to generate similar advice to similar froth conditions, ensuring that the knowledge base is consistent and will not be contradictory in any way. The search strategy of the knowledge base was also designed to ensure a fast system response. The consistency and the efficiency, i.e. the system response speed, were tested by the knowledge engineer on the completed system once it has been implemented on-line. System advice proved to be consistent all the time and the advice and explanations were given within 1 to 2 seconds after the request was made.

After the expert system was installed on-line and operators were trained to use it, two experienced flotation operators who served as experts were asked to fill evaluation daily reports (see Appendix A). The operators were asked to describe a non-optimum froth condition encountered during their shift, the action taken to improve the froth condition, the
parameters they considered before they decided on a specific action, and the outcome of the action. Then they compared their action to the advice given by the expert system for the same froth condition. This spot-check evaluation, although incomplete because a limited number of scenarios were observed, was conducted primarily to bench-test the on-line version of the final product and to expose any data acquisition problem that could not have been detected during the off-line knowledge base verification. It also served as an incentive for the operators to use the system and explore its capability. Five reports were filled in with details and for four of them, the operator applied the operating strategy that would have been suggested by the expert system. In one of the reports, the operator suggested to increase the frother addition rate to the roughers while the expert system suggested to off-load the circuit by raising the cell levels, to decrease the collector addition rate and finally to increase the frother level to the scavengers. The argument of the operator was as follow:

« I find that if you froth off the roughers enough, the scavengers take care of themselves to a large degree »

Although the strategy proposed by the operator may work most of the time, the advice given by the expert system was not modified because a majority of experts agreed that it is a more beneficial and economical option to try to off-load the circuit and decrease the collector level first rather than increasing the collector addition rate to the roughers.

5.3 Validation of the Expert System

Validation of the expert system was performed using four different techniques: Interviews with operators, evaluation forms distributed to the end-users, a record of the frequency of use, and an evaluation performed by HVC management.
5.3.1 Interviews with Operators

One way to get direct impressions on the expert system user-friendliness is to talk with the operators as they are using the expert system during their shift. It was found that some operators have more facility to express themselves verbally rather than filling in written reports and that they usually feel more comfortable to express their views on the expert system directly to the knowledge engineer rather than putting it in writing.

After two weeks of trial with the expert system, interviews were conducted with two full-time ABC line flotation operators. They felt that the expert system was "important for relief operators, especially during the holiday season". They do not use the expert system that much as they view the advice as information they already know. They read the hypertext and prefer the hypertext format to the actual book. It was also mentioned that there was more information in the hypertext than in the original book on the operation of the flotation circuit and that it would be interesting if more pictures could be added to the hypertext.

5.3.2 Evaluation Forms

Evaluation forms were distributed to 4 full time flotation operators on ABC line, one full time flotation operator on D and E line who was acting as a relief operator on ABC line and three relief flotation operators on ABC line. They were asked to fill in the form after four shifts of operation during which the expert system was available to them. The Evaluation form is shown in Appendix A. The answers are summarized in Table 5.1.
<table>
<thead>
<tr>
<th>Question</th>
<th>Full time operators</th>
<th>Relief operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1) - Frequency of use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1 to 3 times</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3 to 8 times</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Question 2) - User friendliness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very easy to use</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>In general, easy to use</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Difficult to use</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Question 3) - Correctness of the advice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct all the time</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>It makes sense 80% of the time</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Question 4) - Correctness of the explanations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct all the time</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>It makes sense 80% of the time</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Correct 50% of the time</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Question 5) - Trend analysis messages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I look at them a few times during a shift</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>They are quite useful</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>I do not use this information</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Question 6) - Reagent tracking module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I look at it all the time</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I look at it a few times during a shift</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I look at it at the beginning of my shift</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>I do not use this information</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Question 7) - Learning from the expert system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quite a lot</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>It gave me some ideas</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Not very much</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Nothing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.1 - Answers to the evaluation forms

From the evaluation form answers, it can be seen that the expert system is referred to by about half the full time operators and all the relief operators at a frequency of 1 to 8 times per four shift work period. All the operators but one found the system to be easy or very easy to use. During the training sessions on the expert system given to the operators, it was found
that most of them were already acquainted with the Windows environment and the operation of the mouse through their personal computers. As the expert system is operated though an environment they were already familiar with, it is no surprise that they found the expert system easy to use.

The correctness of the advice and the explanations was ranked as being correct 80% of the time or more by all the full time operators and by all the relief operators but one. Although this questions was asked to both full time and relief operators, it should be noted that full time operators are more qualified to answer these two questions than relief operators. The correctness of advice and explanations was verified through the different phases of the development of the knowledge base by the experts. However, it was considered necessary to evaluate the conclusions and explanations given by the expert system installed on-line under production conditions.

The trend analysis and the reagent tracking module were found quite useful and were referred to regularly. The full time operators seemed to appreciate the reagent tracking module and referred to it at the beginning of their shift. Among the suggestions to improve the system, it was mentioned that there could be more information on ore types and how different ore types can be recognized by looking at the froth. It was also suggested to take into consideration the fact that froth conditions change from cell to cell in some cases while the expert system considers that the froth is consistent on a flotation bank.

Night shift operators were also encouraged to write down their comments in a log book. Most of the comments recorded regarded little bugs in the expert system and suggestions to improve the Hypertext or the display layouts. One of the most useful comment came from a relief operator on his first night shift who had not been briefed on the new advisory expert system yet:

« The big clock on the screen is about all this expert system is good for. »

As the operator was not familiar with the QNX Windows environment, he experienced difficulties in communicating with the expert system and got frustrated. His comment pointed
out the importance of training on what the expert system does and how to use it to gain the operators acceptance. A two hour short course was given to all the flotation operators. The goal of the advisory expert system and the content of the knowledge base were explained and exercises were given on how to get advice, explanations and hypertext information from the expert system.

5.3.3 Frequency of Use

Over a period of 5 weeks, the frequency of use of the expert system was monitored. Every time an advice was requested by a flotation operator, the advice given and the date and time were recorded in a file. The record keeping file of all the advice generated by the expert system is a feature incorporated in Comdale/C. From September 1st to October 9th 1992, the expert system was consulted 102 times. During that period, mainly full time operators were running the flotation circuits. The consultations are sporadic and the number of advice given per shift varied from 0 to 11, averaging 1.3 consultation per shift. The frequency of use did not decline over the test period, as shown in Table 5.2

<table>
<thead>
<tr>
<th>Period</th>
<th>Flotation line</th>
<th>Number of consultations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 1st to Sept. 14th</td>
<td>A line</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>B line</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>C line</td>
<td>10</td>
</tr>
<tr>
<td>Sept. 15th to Sept. 23rd</td>
<td>A line</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>B line</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>C line</td>
<td>6</td>
</tr>
<tr>
<td>Sept. 24th to Oct. 9th</td>
<td>A line</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>B line</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>C line</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 5.2 - Frequency of use

There is no general tendency on the type of advice given as consultations were made for different froth conditions.
5.3.4 Management evaluation

To validate if the final product conformed with criteria pre-established with HVC management, a questionnaire was presented to the senior control engineer six months after the implementation of the advisory expert system. The evaluation form is shown at Appendix A. Management felt that the expert system met half their expectations. This is a result of very high expectations at the start of the project because they were hoping «...for something which even experienced operators could use ». The development of the expert system helped increase their knowledge of the flotation circuit a little. The main benefit of developing the expert system was that it helped very much in formalizing the knowledge on the flotation circuit. The management cannot state if the expert system helped the relief operators to increase their knowledge on the flotation circuit.

They reported that:

« The operators are frustrated with many aspects in flotation and the expert system is considered only a minor benefit relatively to other problems. »

It is felt that the expert system did not help full time operators.

« This is in part due to their initial attitude and that the knowledge base is too simplistic for them, while the hypertext is insufficiently developed ».

The advisory expert system achieved more than the other training programs tried at HVC in the past. As the expert system is a permanent installation, it should have a longer effect. However, the development of the expert system cost considerably more than other training programs implemented at HVC. At this stage, there is no evidence that any operators have changed their strategy in running the flotation circuit. Finally, there are plans to develop other expert system applications on other areas of the HVC mill.
6.1 On the Spin-offs Gained from the Development of the Advisory Expert System

The major spin-off that came from the implementation of the on-line flotation advisor, according to operators and management at HVC, is the development of a common terminology and the formalization of the expertise.

Development of the off-line expert system by Paul Benford and its evaluation by the flotation operators demonstrated that several froth types had been missed and that terminology for the froth types were found difficult to understand. In consultation with the operators, the froth types were rearranged in a hierarchical structure which included the additional froth descriptions. The first prototype of the expert system thus proved to be a useful exercise in rationalizing and structuring a froth recognition procedure. The development of the expert system brought a common terminology used by all operators to describe froth conditions which facilitate communication between operators.

Although the operating strategy developed over the years by the flotation operators is based on the froth appearance and that reagent changes are made accordingly to the froth condition at the rougher and scavenger flotation banks, there was no written document on the experience acquired by the flotation operators. By defining the froth types and taking the time to analyze what causes all the different bad froth conditions, improved standardization of the operating practice results. The development of the advisory expert system nurtured discussions on operating practices and gave an opportunity to the flotation experts to share their expertise and organize their knowledge systematically so that it can be incorporated to the knowledge base in a rational way and shared to less experienced operators. To break down compiled knowledge such as the expertise acquired by the operators over the years fostered a shared understanding about how the flotation circuit is, and sometimes should be, run. The cooperation between the plant engineer and the operators that comes from this shared information process can be compared to results achieved by quality improvement teams.
It was found that the expert system, once installed, also served as a communication link between the metallurgist and the operators. Modifications can easily be implemented to the knowledge base to suggest new operating strategies to the flotation operators. For example, laboratory tests showed that when an Optimum - Bluish-grey froth (an indication of high bornite ore) was observed at the rougher cells, better recoveries were obtained by cutting down PAX consumption by 30% and by doubling the frother addition rate. The new reagent addition rates were communicated to the full-time operators and changes were made to the knowledge base to include the new operating strategy. The relief operators became aware of this new reagent combination through the use of the on-line advisory system.

6.2 On Elements of the Expert System that Were Successful

The strategy used in the development of the knowledge base was well suited to a training tool application. The incremental prototyping allowed for constant revision and testing by the expert, insuring that the knowledge base was complete and well structured. The development of the knowledge in the working environment of the experts makes it easier to gain acceptance and cooperation of the operators. Being close to the flotation floor, often in the flotation operator control booth, made it easier for the experts to explain a particular aspect of their operating practices to the knowledge engineer.

The graphical user interface gained acceptance from the operators very easily. Some operators were already used to the Windows environment of the Comdale/X system, through the use of personal computers. The graphics were simple but explicit and the QNX Windows environment was intuitive, reducing the training time to a minimum. The hypertext technology proved to be very useful to provide the operators with an electronic training manual visually appealing and easy to access. Because of the new format, the document was consulted by both relief and experienced operators. In order to be accepted and therefore used by the operators, an on-line advisory expert system has to provide information quickly on a clear format.
The constant availability of the advisory expert system proved to be helpful to relief operators who have been away from the flotation circuit for a long period of time. The system can provide advice 24 hours a day, seven days a week and never judges the operator. The following comment is an excerpt of the « Evaluation Form of the Flotation Expert System » filled by a relief operator:

« I found it (the expert system) quite helpful for myself, a relief operator, as it tends to get you going in the proper direction rather than making the wrong moves. »

6.3 Limitations of the Expert System Technology Used as a Training Tool

The main limitation of the system comes from the fact that the advisor is operator-driven. The froth condition is an operator input which cannot be inferred or read by the system. If the operator misreads the froth type or neglects to notify the system about a new froth condition, the advisor will not provide the right series of action to bring back an optimum froth. Since the advice is dependent on operator input, the system could not be used for supervisory control and implement changes by itself on the reagent addition rates. Development of an on-line vision analysis system could overcome this limitation but this is a difficult problem to tackle.

Operator acceptance of the expert system technology is a key issue for development of a successful training tool. At HVC, most experienced operators who helped in the development of the knowledge base were quite enthusiastic about the training capabilities of the system. However, two operators were less optimistic and one of the two systematically refused to collaborate in the knowledge acquisition process and tried to discourage the other operators from doing so. The reason why the operator refused to share his expertise is that he would have preferred to be hired as a consultant or to be promoted shiftboss or trainer. He felt that it was not part of his duties to share his knowledge on the flotation circuit operating strategy and that he should be paid extra time. The operator also argued that it is not suitable to learn froth recognition technique and the art of maintaining certain froth characteristics from a machine and that the interpersonal relationship that builds up between the trainer and the trainee were an important constituent of the learning process that could not be experienced through a computer assisted learning technique.
The development strategy was to work with those operators who were enthusiastic about the idea from the beginning. As the system took shape, some disinclined operators gained interest in the project. Sessions to demystify expert system technology and training on how to use the advisory system were essential to gain cooperation.

The advisory system is a learning tool which cannot substitute entirely for the proficiency gained by practice and instructions from a more experienced operator. It should be used as a constituent of a training program, helpful in organizing and communicating the knowledge and providing advice when needed but lacking on the supervision of the knowledge acquisition process and incapable to adapt its training program to the trainee. A training program would be incomplete if it would rely solely on an advisory expert system to guide trainees in the operation of a flotation circuit.

The implementation of this real-time on-line expert system took five months. Those who are contemplating expert systems are well-advised that development is time consuming. The personnel involved in the project will require training in the use of the development tool and in the field of expert systems. With new technology, there may be software and hardware related problems that arise. Consequently, the best advice would be to start with a small application for which the expertise is well defined. Then, as personnel become more acquainted with the software, bigger applications that progress toward supervisory control can be attempted where this technology has the most chance to pay off big-time. However, personnel availability and communication interface problems between systems can become a limitation.

6.4 Evaluation of the Expert System

The advisory expert system implemented on the HVC flotation circuit was judged solely on its qualitative merits. A quantitative evaluation aimed at comparing the flotation circuit performance before and after the implementation of the advisory expert system, for example, would not have been advisable. The goal of this experiment was to evaluate in which way an on-line advisory expert system can be used to assist operators in troubleshooting the flotation circuit.
It would have been interesting to evaluate the operating strategy of the relief flotation operators before and after the implementation of the system, to assess if the on-line advisor impacted on the operating practices of the operators. It was mentioned earlier in this document that in some cases, the expert system will recommend modifications of physical parameters, such as pulp density, cell levels and air flowrates, before advising reagent changes. It was found through a questionnaire that this strategy is in opposition to most operators habit of changing reagents first. Changing reagents is easier, but in some cases, this will provide only a short term remedy while changing the physical parameters can solve the problem directly. For example, if the cause of a boiling pulp condition is a high density, then adding frother may help to create finer bubbles and get rid of the boiling condition but it is better and cheaper to modify the pulp density. The extra frother may come back to haunt the process later on by recirculation of middlings streams. It was expected that the expert system would have changed the way certain operators use reagents which can translate into reagent savings.

A month and a half after the expert system was implemented, the questionnaire on flotation practice was redistributed to the relief operators in order to evaluate if the expert system strategy had an influence on their operating practice. Unfortunately, the questionnaire was seen as a form of evaluation of the operators performance and the relief operators were discouraged to fill in the questionnaire by a union representative.

6.5 Future Work That Could Be Done to Improve the Expert System

The experiences and lessons learned from this project should lend support to successful work with other applications. Supervisory control of the circuit in which the operators are closed out of the loop should be a major goal. Operators can act to over-ride the expert system should it be implementing poor decisions. It is only through direct control that significant benefits can be quantified and achieved.

As mentioned earlier, one limitation of using an advisory expert system to troubleshoot flotation circuits is that the system is operator driven. One way to overcome this situation would be
to investigate the use of a camera installed over the flotation bank coupled to an image analysis software to infer the froth type. This system could feed the expert system with the froth condition on a continuous basis and generate advice by itself when bad froth conditions are detected. An attempt to find the dependence between the metal content in the flotation froth and its image was found in the literature [Kordek and Lenczowski, 1988].

Further work could be done in incorporating the trend analysis module to the advisory expert system to detect conditions that would lead to a bad froth condition.
CONCLUSIONS

An on-line advisory expert system has been developed and implemented on the A,B,C flotation circuit at Highland Valley Copper. The principal benefits and limitations of the use of expert system technology in training development systems are summarized below.

- Real-time advisory expert systems add value to a training program by providing on-line advice, explanations linked to all advice and hypertext documents. There are things that a machine cannot teach, froth recognition being one example. But having an expert available 24 hours a day, as a helper that watches the circuit while the operator is away, is certainly beneficial to training.

- The activity of building the expert system itself helps in structuring and increasing the level of knowledge by stimulating exchanges between operators. By defining the froth types and taking the time to analyze what causes all the different bad froth conditions, improved standardization of the operating practice results. Development of the training tool becomes part of the training itself.

Different techniques were used to validate the system and evaluate how it conforms with the operator needs and requirements. The following operator appreciation were obtained.

- Relief operators have been quite enthusiastic about the system. Since they sometimes go several months without working on flotation, they really appreciate having an « expert » that they can consult anytime, either to increase their knowledge of the circuit or to troubleshoot a problem. Experienced operators do not think that the system is helpful to them but most of them have some faith in this new approach for training novice operators.

- A trend analysis expert system can be developed in a short period of time using very simple curve analysis techniques and provide guidance to relief operators by pointing out tonnage or grade changes that may upset the flotation circuit. Full-time operators seem to
appreciate the trending analysis module, as it facilitates their evaluation of the circuit conditions. Access to reagent changes made on previous shifts also proved to be beneficial.
REFERENCES


References


Hodouin, D. and Bazin, C., 1985, Application of time series analysis to mineral processing, Proceeding of the 87th General Meeting of the Canadian Institute of Mining and Metallurgy, pp. 34.


APPENDIX A

*Questionnaires and Evaluation Forms*

- Questionnaire on Flotation Practice at HVC
- Flotation Expert System Daily Report
- Evaluation Form of the Expert System
- Managerial Expert System Evaluation Form
Memo on the Flotation Expert System

DATE: Oct 14th 1992

TO: ABC - Bulk flotation full time and relief operators

FROM: Philippe Poirier

SUBJECT: Questionnaire on flotation practice

The Expert System has been running consistently for almost two months now. As you all had time to experience it, I would really appreciate if you could now spend a few minutes to answer the following questionnaire. You will probably recognize the first part of the questionnaire. The reason why I ask you to fill it in again is to compare the flotation practice before and after the implementation of the Expert System and to evaluate if the flotation practice is more uniform among the operators.

At the end, you will also find a short evaluation form. Your opinion on the Expert System will be very helpful for my thesis.

As you will notice, I do not ask for a name on the questionnaire. I prefer an honest opinion without a name over a 'politically proper' one with a name.

I promise that this will be the last questionnaire I will ever ask you to fill! Thank you.

Philippe Poirier
Graduate student, UBC
TO : Mill Senior Foremen

FROM : Hans Raabe

SUBJECT : Expert System Questionnaire

October 16, 1992

The Flotation Expert System was developed with the help from UBC graduate students. The students use the experience gained from working on the system to write a thesis (an engineering report) which is required for their graduation.

Philippe Poirier, who is the student, which worked on the expert system last, wants to include an evaluation of the system in his thesis. To that effect, he has produced a couple of questionnaires, for the flotation operators to complete. This includes all standard- and relief- operators who had a chance to work with the expert system.

The first questionnaire is identical to the one presented some six months ago. We would like the operators to complete the form without the use of the expert system. We are not interested in the answers that the expert system will give; rather, we would like to see what the operators believe the right answer is.

The second questionnaire is an evaluation of the expert system by the operators. Do they use it? Is it easy to use? etc.

Any other comments on the expert system, good or bad, will be appreciated.

We are not trying to white-wash the expert system. Rather, we want to find out what the user, the flotation operator, thinks of the program.

Note that all questionnaires are name-less. There are no repercussions to being frank.

Hans Raabe
Senior Process Engineer
Please, answer on the answer sheet attached at the end of this questionnaire. For each question, select, among the list of actions presented on the answer sheet, the 3 most likely changes to improve froth condition. When you feel that it is possible to do so, indicate which action you would do in first, second and third place by writing 1, 2 and 3 on the answer sheet. If you prefer to, you can just cross the three actions you would do without specifying the order.

Example:

Sample:
If the recovery of a given bank is low and the froth condition is the following:

**Head end rougher froth condition :** Empty froth
Description : The froth shows big windows and the windows are clear, dull looking; ceiling lights reflect in them. The surface of the bubbles is smooth, not gritty. The froth covers the flotation cell. The shiny surface of the bubbles tells you that they are not recovering anything. No gritty surface at all.

**Scavenger bank froth condition :** Empty froth
Description : See below.

What would you do in the first, second and third place to get better froth condition ?
(See how the answers are marked on the answer sheet, on the last page of this questionnaire.)

Question 1)

If the recovery of a given bank is low and the froth condition is the following:

**Head end rougher froth condition :** Optimum - Normal copper
Description: This is the type of froth we want to maintain. The froth is characterized by bubbles ranging in size from 1" to 2.5". The bubbles are covered with copper minerals, but the larger bubbles show windows. The froth covers the full flotation cell and is fairly thick; 1" or deeper. The froth is moving steadily over the lip. When the top layer is scraped away, clean whiter froth shows below. The froth has less copper and supports the top layer of froth.

**Scavenger bank froth condition :** Tight froth - Not moving - Broken-up - Boiling pulp
Description : The froth bubbles are small and are loaded with copper minerals. The bubble surface looks 'gritty', like coarse minerals. The froth bed is thin and broken up. The froth layer is generally very thin. The pulp is 'boiling', waving with occasional air gushes.

What would you do in the first, second and third place to get better froth condition ?
Question 2)

If the recovery of a given bank is low and the froth condition is the following:

*Head end rougher froth condition*: Optimum - Normal copper

Description: This is the type of froth we want to maintain. The froth is characterized by bubbles ranging in size from 1" to 2.5". The bubbles are covered with copper minerals but the larger bubbles show windows. The froth covers the full flotation cell and is fairly thick; 1" or deeper. The froth is moving steadily over the lip. When the top layer is scraped away, clean whiter froth shows below. The froth has less copper and supports the top layer of froth.

*Scavenger bank froth condition*: Foamy froth

Description: Very small bubbles having a white or grey look. It can be easily confused with the optimum froth, but it looks more like a soap foam than a mineral froth. Mostly, the froth bed is deep. The froth does not look watery, the bubbles are not clear but whitish opaque.

What would you do in the first, second and third place to get better froth condition?

Question 3)

If the recovery of a given bank is low and the froth condition is the following:

*Head end rougher froth condition*: Optimum - Big bubbles

Description: This is the type of froth we want to maintain. The froth is characterized by bubbles ranging in size from 1" to 2.5". The bubbles are covered with copper minerals but the larger bubbles show windows. The froth covers the full flotation cell and is fairly thick; 1" or deeper. The froth is moving steadily over the lip. The froth has bubbles as large as baseballs or a fist.

*Scavenger bank froth condition*: Optimum - Low copper

Description: This is the ideal condition. Copper is pulled off the roughers and does not carry over in the scavengers. The froth bed is deep and flowing over the froth lip continuously. The froth is weak and watery, it breaks down easily.

What would you do in the first, second and third place to get better froth condition?
Question 4)

If the recovery of a given bank is low and the froth condition is the following:

*Head end rougher froth condition*: Empty froth
- Description: The froth shows big windows and the windows are clear, dull looking; ceiling lights reflect in them. The surface of the bubbles is smooth, not gritty. The froth covers the flotation cell. The shiny surface of the bubbles tells you that they are not recovering anything. No gritty surface at all.

*Scavenger bank froth condition*: Optimum - Low copper
- Description: See Question 4.

What would you do in the first, second and third place to get better froth condition?

Question 5)

If the recovery of a given bank is low and the froth condition is the following:

*Head end rougher froth condition*: Tight froth - Not moving - Froth covers the flot. cell
- Description: The froth bubbles are small and are loaded with copper minerals. No windows are visible on the bubbles. The bubble surface looks 'gritty', like coarse minerals. There is no whitish froth below the top layer of froth. The froth is NOT broken up, but you can tell that it has collapsed as a result of a build-up of copper.

*Scavenger bank froth condition*: Tight froth - Not moving - Broken-up - Quiet pulp
- Description: The froth bubbles are small and are loaded with copper minerals. The bubble surface looks 'gritty', like coarse minerals. The froth bed is thin and broken up. The froth layer is generally very thin and is not flowing over the lip. The pulp is 'quiet', i.e. not boiling.

What would you do in the first, second and third place to get better froth condition?
Question 6)

If the recovery of a given bank is low and the froth condition is the following:

*Head end rougher froth condition*: Tight froth - Fast moving
Description: The froth bubbles are small and are loaded with copper minerals. No bubbles are visible on the bubbles. The bubble surface looks 'gritty', like coarse minerals. There is no whitish froth below the top layer of froth. The froth covers the full flotation cell. It is not sitting but is flowing over the froth lip steadily. This is similar to the 'tight and runny' froth of the old froth classification.

*Scavenger bank froth condition*: Optimum - Low copper
Description: See Question 4

What would you do in the first, second and third place to get better froth condition?

Question 7)

If the recovery of a given bank is low and the froth condition is the following:

*Head end rougher froth condition*: Grey froth
Description: The froth has a grey look, sometimes oily. Bubbles can be foamy, the froth bed can be broken up. Froth condition is not optimum which distinguishes it from bluish-grey froth.

*Scavenger bank froth condition*: Optimum - Low copper
Description: See Question 4

What would you do in the first, second and third place to get better froth condition?

Question 8)

If the recovery of a given bank is low and the froth condition is the following:

*Head end rougher froth condition*: Optimum - Normal copper color
Description: See Question 3)

*Scavenger bank froth condition*: Optimum - High copper
Description: Same as 'Copper froth - High Volume' in the old froth classification. This froth has a deep froth bed, which is flowing over the froth lip continuously. The froth shows some copper. This can be an indication of a developing copper overloading.

What would you do in the first, second and third place to get better froth condition?
Question 9)

If the recovery of a given bank is low and the froth condition is the following:

**Head end rougher froth condition**: Optimum - Bluish-Grey
Description: This froth looks like Optimum froth but has a bluish-grey colour. This is an indication of high Bornite in the flotation feed.

**Scavenger bank froth condition**: Tight froth - Not moving - Broken-up - Boiling pulp
Description: The froth bubbles are small and are loaded with copper minerals. The bubble surface looks 'gritty', like coarse minerals. The froth bed is thin and broken up. The froth layer is generally very thin. The pulp is 'boiling', waving with occasional air gushes.

What would you do in the first, second and third place to get better froth condition?

Question 10)

If the recovery of a given bank is low and the froth condition is the following:

**Head end rougher froth condition**: Foamy froth
Description: Very small bubbles having a white or grey look. It looks more like soap foam than a mineral froth. Frequently a deep froth bed.

**Scavenger bank froth condition**: Tight froth - Not moving - Broken-up - Quiet pulp
Description: The froth bubbles are small and are loaded with copper minerals. The bubble surface looks 'gritty' like coarse minerals. The froth bed is thin and broken up. This is an indication of a severe build-up of copper.

What would you do in the first, second and third place to get better froth condition?

Comments:

Thank you.
Philippe Poirier, UBC grad. student
Metallurgical Departement
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Please check here:
- I am a relief operator
- I am a regular operator

92
The Expert System has been running in the ABC flotation operator's booth for approximately one month now. Some of that time, it was less than reliable, mainly due to hardware problems with the computer it is running on. These problems have been resolved and over the last week the Expert System has been reliable.

The knowledge coded in the system came from a selected number of operators, myself and Ross Giles. It is important that we make sure that the advice it gives is correct. We need the assistance of all operators to verify that this is the case.

Attached is a copy of the "Flotation Expert System Daily Report". I would like every operator to fill one of these sheets every shift. The objective is for you to check if the advice the Expert System gives you is correct. Also, please review the explanations given for the advice; do they make sense, are they wrong, etc. There is a folder in your booth to hold the copies of the sheet; we will empty this regularly.

You will notice that you are not required to give your name or shift on the report. If you don't mind, give it anyway; this will allow us to discuss your findings directly with you. However, if you want to be very critical, leave your name off. I prefer an honest opinion without a name over a 'politically proper one' with a name.

Be honest with us; but remember what we are trying to do.

The Expert System, as it is now, is relatively simple. Most experienced operators will know most of it already. At this point the system is most useful for the inexperienced operators. We must make sure, however, that the advice it gives them is correct. This is why we need your involvement.

This is the first stage of the development. We had to start somewhere, and froth recognition is the most important- and most difficult- part of flotation operation. Before we proceed any further, this section has to be correct.

Any suggestions or problems you find with the system will be appreciated. Think about the following questions: Is it easy to use? Does it present the advice in an easy to use format; for
instance, do you like the 'more advise' button, or would you like all advise at once? Are there enough froth types or did we forget any? Can you recognize the froth types on the float banks or is this still vague?
Also, what other information would you like the Expert System to give you?

Please help us in assessing if the Expert System can be a valuable tool for bulk flotation, or if we should stop development at this point.

Hans Raabe
Senior Process Engineer

M. Freberg
Superintendent Mill Operations
FLOTATION EXPERT SYSTEM DAILY REPORT

In order to improve the expert system and validate the advices, we would like you to fill this short report during your shift. We would like to focus on one action that you did today on one flotation line in order to improve the recovery or the froth condition. Just describe the froth and what you did. Then compare it to the expert system advice and give us your comments. Thank you.

I am a: ____ Full time operator ____ Relief operator

Select a flotation line (A, B or C) on which you worked during your shift: __________

How would you describe the froth condition of the rougher and scavenger of this line at the beginning of your shift (you can use the same terminology as the expert system or describe the froth in your own words):

Which action(s) did you take to improve the froth condition of this line:
(Ex.: Increase Pax from 200 to 250 cc, decrease cell level, etc.)

Which other parameter(s) than the froth type did you consider before you made a change (Ex.: Density was high, tails assay were trending down, etc):

What was the outcome of the action taken on this flotation line:
(Ex.: Froth went from big bubbles to optimum, recovery increased, etc)
For the same froth condition at the rougher and the scavenger, what are the advices given by the expert system:

Would you suggest any changes to the advice given by the expert system for this particular froth condition:
(Ex.: Change the order, add an advice, etc.)

Any other comments on what we could do to improve the expert system?:

916
DATE : Dec 10th 1992

TO: ABC - Bulk flotation operators (full-time and relief)

FROM : Philippe Poirier

Even though the expert system is down at the moment, you all had a chance to experience with it earlier. I would really appreciate if you could now spend a few minutes to answer the following questionnaire. Your opinion on the expert system will be very helpful at this stage of the project.

Please return the questionnaire to Hans or put it in the enveloppe in the flotation operator's booth when you are done. Thank you for your cooperation.

Philippe Poirier
Graduate student, UBC
Evaluation Form of the Flotation Expert System

I am a relief operator [ ]
I am a full time operator [ ]

1) How many times per 4 day work period do you use the Flotation Expert System?

[ ] Never.
[ ] 1 to 3 times.
[ ] 3 to 8 times.
[ ] More than 8 times.

2) How do you rate the user friendliness of the operator interface?

[ ] Very easy to use.
[ ] In general, easy to use.
[ ] Not so easy to use.
[ ] Difficult to use.

3) How do you rate the correctness of the advices?

[ ] Correct all the time.
[ ] Correct 50% of the time.
[ ] It makes sense 80% of the time.
[ ] It never makes sense.

4) How do you rate the correctness of the explanations given when you click on the advice?

[ ] Correct all the time.
[ ] Correct 50% of the time.
[ ] It makes sense 80% of the time.
[ ] It never makes sense.

5) How useful are the trend analysis messages (the messages that come on the screen to indicate if the grades are trending up or down or if the ball mill is down, etc.)?

[ ] I look at them all the time.
[ ] I look at them a few times during a shift.
[ ] They are quite useful.
[ ] I do not use this information.

6) How useful is the reagent tracking module (the 'Reagent' button that brings the last reagent changes that were made)?

[ ] I look at it all the time.
[ ] I look at it a few times during a shift.
[ ] I look at it at the beginning of my shift.
[ ] I do not use this information.

7) How much did you learn from the Expert System?

[ ] Quite a lot.
[ ] It gave me some new ideas.
[ ] Not very much.
[ ] Nothing.

8) Would you like to see something added or changed on the Expert System (use the back of the sheet if you run out of room)?
Dear Mr. Raabe, Dear Mr. Scott

The flotation advisory expert system has been installed on the bulk flotation circuit for a few months now. As your operators have now used it for a while, I imagine you are in a good position to evaluate the benefits and drawbacks of the system. Your evaluation and comments are essential for me to find out if expert systems make good training tools.

I would be very pleased if you could spend a few minutes of your time to fill in this questionnaire. Do not hesitate to comment on your answers. Thank you in advance for your help. Please send me back this evaluation with the operator's questionnaires when you have received all of them.

1) Does the Advisory Expert System installed on the flotation circuit meet your expectations, i.e. does it achieve the initial goal of providing the flotation operators with a good training tool?

<table>
<thead>
<tr>
<th>It met all my expectations</th>
<th>It met most of my expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>It met half my expectations</td>
<td>It did not meet my expectations</td>
</tr>
</tbody>
</table>

2) Do you believe that the development of the expert system helped:

a) to increase your knowledge of the flotation circuit?

<table>
<thead>
<tr>
<th>It helped very much</th>
<th>It helped a little</th>
</tr>
</thead>
<tbody>
<tr>
<td>It did not help at all</td>
<td>I do not know</td>
</tr>
</tbody>
</table>
b) to formalize your knowledge of the flotation circuit?

<table>
<thead>
<tr>
<th>It helped very much</th>
<th>It helped a little</th>
</tr>
</thead>
<tbody>
<tr>
<td>It did not help at all</td>
<td>I do not know</td>
</tr>
</tbody>
</table>

Comments:

3) Do you believe that the development of the expert system helped:
   a) the relief operators to increase their knowledge of the flotation circuit?

<table>
<thead>
<tr>
<th>It helped very much</th>
<th>It helped a little</th>
</tr>
</thead>
<tbody>
<tr>
<td>It did not help at all</td>
<td>I do not know</td>
</tr>
</tbody>
</table>

Comments:

b) the full-time operators to increase their knowledge of the flotation circuit?

<table>
<thead>
<tr>
<th>It helped very much</th>
<th>It helped a little</th>
</tr>
</thead>
<tbody>
<tr>
<td>It did not help at all</td>
<td>I do not know</td>
</tr>
</tbody>
</table>

Comments:

4) How does the advisory expert system compares with other training programs tried at HVC in the past?

<table>
<thead>
<tr>
<th>It achieved more</th>
<th>It achieved about the same</th>
</tr>
</thead>
<tbody>
<tr>
<td>It achieved less</td>
<td>I cannot say</td>
</tr>
</tbody>
</table>

Comments:
5) How does the cost of the advisory expert system compare with the cost of other training programs implemented at HVC?

<table>
<thead>
<tr>
<th>It cost more</th>
<th>It cost about the same</th>
</tr>
</thead>
<tbody>
<tr>
<td>It cost less</td>
<td>I cannot say</td>
</tr>
</tbody>
</table>

Comments:

6) Is there evidence that some of the operators have changed their strategy in running the flotation circuit since the advisory expert system was installed?

<table>
<thead>
<tr>
<th>There are strong evidence</th>
<th>There are some evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>There are small evidence</td>
<td>There are no evidence</td>
</tr>
<tr>
<td>I do not know</td>
<td></td>
</tr>
</tbody>
</table>

Comments:

7) Do you plan to develop other expert system applications at your mill?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

Comments:
APPENDIX B

Listings of Trend Analysis Knowledge Bases

TREND2.KNW
FUZTREND5.KNW
TREND 2.KNW
Object
@name = A1
@attribute = cu_feed_assay.@float, cu_tail_assay.@float
endObject

Object
@name = A2
@attribute = cu_feed_assay.@float, cu_tail_assay.@float
endObject

Object
@name = accept
@attribute = assay.ok, assay_A.ok, assay_B.ok, assay_C.ok, assay_C2.ok, feed_assay_A.ok, feed_assay_B.ok, feed_assay_C.ok
endObject

Object
@name = avg_A_ton
@attribute = rate_change_twoh_sec.@float
endObject

Object
@name = avg_A_tonn
@attribute = one_hundr_sec.@float, two_hundr_sec.@float
endObject

Object
@name = A_comb
@attribute = cu_feed_assay.@float, cu_tail_assay.@float
endObject

Object
@name = A_feed
@attribute = cu_rate_tonnage.@float, cu_tonnage_rate.@float
endObject

Object
@name = B1
@attribute = cu_feed_assay.@float, cu_tail_assay.@float
endObject

Object
@name = B2
@attribute = cu_feed_assay.@float, cu_tail_assay.@float
endObject

Object
@name = B_comb
@attribute = cu_feed_assay.@float, cu_tail_assay.@float
endObject

Object
@name = B_feed
@attribute = cu_tonnage_rate.@float
endObject

Object
@name = C1
@attribute = cu_feed_assay.@float, cu_tail_assay.@float
endObject

Object
@name = C2
@attribute = cu_feed_assay.@float, cu_tail_assay.@float
endObject

Object
@name = C3
@attribute = cu_tail_assay.@float
endObject

Object
@name = C4
@attribute = cu_tail_assay.@float
endObject

Object
@name = C_comb
@attribute = cu_feed_assay.@float, cu_tail_assay.@float
endObject

Object
@name = C_feed
@attribute = cu_tonnage_rate.@float
endObject

Object
@name = ratechange_24m
@attribute = A_comb_cu_tls.@float
endObject

Object
@name = timeavg_24m
@attribute = A_comb_cu_tls.@float
endObject

Object
@name = valueat_1s
@attribute = A_comb_cu_tls.@float
endObject

Object
@name = valueat_24m
@attribute = A_comb_cu_tls.@float
endObject

Rule
@name = A_feed_assay_decrease_45m
IF accept.feed_assay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_feed_assay.@float , 1, 2880 ) < -0.037000
AND TIMEAVERAGE (A_comb.cu_feed_assay.@float , 1, 2880 ) < 0.600000 * ( VALUEAT (A_comb.cu_feed_assay.@float , 1) + VALUEAT (A_comb.cu_feed_assay.@float , 2880 ) )
AND TIMEAVERAGE (A_comb.cu_feed_assay.@float , 1) + VALUEAT (A_comb.cu_feed_assay.@float , 2880 ) )
THEN TEXT ("The A-line feed assay decreased over the past 48 min.", "Aline")
THEN WAIT ($Rule, "A_feed_assay_decrease_45m", 5760)
endRule

Rule
@name = A_feed_assay_decrease_96m
IF accept.feed_assay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_feed_assay.@float , 1, 5760 ) < -0.017360
AND TIMEAVERAGE (A_comb.cu_feed_assay.@float , 1, 5760 ) < 0.600000 * ( VALUEAT (A_comb.cu_feed_assay.@float , 1) + VALUEAT (A_comb.cu_feed_assay.@float , 5760 ) )
AND TIMEAVERAGE (A_comb.cu_feed_assay.@float , 1) + VALUEAT (A_comb.cu_feed_assay.@float , 5760 ) )
THEN TEXT ("The A-line feed assay decreased over the past 96 min.", "Aline")
THEN WAIT ($Rule, "A_feed_assay_decrease_96m", 5760)
endRule

Rule
@name = A_feed_assay_increase_48m
IF accept.feed_assay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_feed_assay.@float , 1, 2880 ) > 0.037000
AND TIMEAVERAGE (A_comb.cu_feed_assay.@float , 1, 2880 ) < 0.600000 * ( VALUEAT (A_comb.cu_feed_assay.@float , 1) + VALUEAT (A_comb.cu_feed_assay.@float , 2880 ) )
AND TIMEAVERAGE (A_comb.cu_feed_assay.@float , 1) + VALUEAT (A_comb.cu_feed_assay.@float , 2880 ) )
THEN TEXT ("The A-line feed assay increased over the past 48 min.", "Aline")
THEN WAIT ($Rule, "A_feed_assay_increase_48m", 5760)
endRule

Rule
@name = A_feed_assay_increase_96m
IF accept.feed_assay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_feed_assay.@float , 1, 5760 ) > 0.017360
AND TIMEAVERAGE (A_comb.cu_feed_assay.@float , 1, 5760 ) < 0.600000 * ( VALUEAT (A_comb.cu_feed_assay.@float , 1) + VALUEAT (A_comb.cu_feed_assay.@float , 5760 ) )
AND TIMEAVERAGE (A_comb.cu_feed_assay.@float , 1) + VALUEAT (A_comb.cu_feed_assay.@float , 5760 ) )
THEN TEXT ("The A-line feed assay increased over the past 96 min.", "Aline")
THEN WAIT ($Rule, "A_feed_assay_increase_96m", 5760)
endRule

Rule
@name = A_tls_assay_decrease_24m
IF accept.assay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_tail_assay.@float , 1, 1450) < -0.006900
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float , 1, 1450) < 0.600000 * ( VALUEAT (A_comb.cu_tail_assay.@float , 1) + VALUEAT (A_comb.cu_tail_assay.@float , 1450) )
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float , 1) + VALUEAT (A_comb.cu_tail_assay.@float , 1450) )
THEN TEXT ("The A-line feed assay decreased over the past 24 min.", "Aline")
THEN WAIT ($Rule, "A_tls_assay_decrease_24m", 5760)
endRule

Rule
@name = A_tls_assay_increase_24m
IF accept.assay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_tail_assay.@float , 1, 1450) > 0.006900
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float , 1, 1450) < 0.600000 * ( VALUEAT (A_comb.cu_tail_assay.@float , 1) + VALUEAT (A_comb.cu_tail_assay.@float , 1450) )
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float , 1) + VALUEAT (A_comb.cu_tail_assay.@float , 1450) )
THEN TEXT ("The A-line feed assay increased over the past 24 min.", "Aline")
THEN WAIT ($Rule, "A_tls_assay_increase_24m", 5760)
endRule
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float, 1, 1450) > 0.400000 * (VALUEAT (A_comb.cu_tail_assay.@float, 1) + VALUEAT (A_comb.cu_tail_assay.@float, 1450))
THEN TEXT ("The A-line tailings assay decreased over the past 24 min.", "Aline")
THEN WAIT ($Rule, "A_tls_assay_decrease_24m", 4320)
endRule

Rule
@name = A_tls_assay_decrease_48m
IF acceptassay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_tail_assay.@float, 1, 2880) < -0.003470
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float, 1, 2880) < 0.600000 * (VALUEAT (A_comb.cu_tail_assay.@float, 1) + VALUEAT (A_comb.cu_tail_assay.@float, 2880))
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float, 1, 2880) > 0.400000 * (VALUEAT (A_comb.cu_tail_assay.@float, 1) + VALUEAT (A_comb.cu_tail_assay.@float, 2880))
THEN TEXT ("The A-line tailings assay decreased over the past 48 min.", "Aline")
THEN WAIT ($Rule, "A_tls_assay_decrease_48m", 4320)
endRule

Rule
@name = A_tls_assay_decrease_72m
IF acceptassay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_tail_assay.@float, 1, 4320) < -0.002310
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float, 1, 4320) < 0.600000 * (VALUEAT (A_comb.cu_tail_assay.@float, 1) + VALUEAT (A_comb.cu_tail_assay.@float, 4320))
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float, 1, 4320) > 0.400000 * (VALUEAT (A_comb.cu_tail_assay.@float, 1) + VALUEAT (A_comb.cu_tail_assay.@float, 4320))
THEN TEXT ("The A-line tailings assay decreased over the past 72 min.", "Aline")
THEN WAIT ($Rule, "A_tls_assay_decrease_72m", 4300)
endRule

Rule
@name = A_tls_assay_increase_24m
IF acceptassay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_tail_assay.@float, 1, 1450) > 0.006900
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float, 1, 1450) < 0.600000 * (VALUEAT (A_comb.cu_tail_assay.@float, 1) + VALUEAT (A_comb.cu_tail_assay.@float, 1450))
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float, 1, 1450) > 0.400000 * (VALUEAT (A_comb.cu_tail_assay.@float, 1) + VALUEAT (A_comb.cu_tail_assay.@float, 1450))
THEN TEXT ("The A-line tailings assay increased over the past 24 min.", "Aline")
THEN WAIT ($Rule, "A_tls_assay_increase_24m", 4320)
endRule

Rule
@name = A_tls_assay_increase_48_m
IF acceptassay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_tail_assay.@float, 1, 2880) > 0.003470
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float, 1, 2880) < 0.600000 * (VALUEAT (A_comb.cu_tail_assay.@float, 1) + VALUEAT (A_comb.cu_tail_assay.@float, 2880))
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float, 1, 2880) > 0.400000 * (VALUEAT (A_comb.cu_tail_assay.@float, 1) + VALUEAT (A_comb.cu_tail_assay.@float, 2880))
THEN TEXT ("The A-line tailings assay increased over the past 48 min.", "Aline")
THEN WAIT ($Rule, "A_tls_assay_increase_48_m", 4320)
endRule
Rule
@name = A_tls_assay_increase_72m
IF accept.assay_A.ok is TRUE
AND 1000 * RATEOFCHANGE (A_comb.cu_tail_assay.@float , 1, 4320 ) > 0.002310
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float , 1, 4320 ) < 0.600000 * (VALUEAT (A_comb.cu_tail_assay.@float , 1) + VALUEAT (A_comb.cu_tail_assay.@float , 4320 ))
AND TIMEAVERAGE (A_comb.cu_tail_assay.@float , 1, 4320 ) > 0.400000 * (VALUEAT (A_comb.cu_tail_assay.@float , 1) + VALUEAT (A_comb.cu_tail_assay.@float , 4320 ))
THEN TEXT ("The A-line tailings assay increased over the past 72 min.", "Aline")
THEN WAIT (SRule, "A_tls_assay_increase_72m", 4300)
endRule

Rule
@name = B_feed_assay_decrease_48m
IF accept.feed_assay_B.ok is TRUE
AND 1000 * RATEOFCHANGE (B_comb.cu_feed_assay.@float , 1, 2880 ) < -0.037000
AND TIMEAVERAGE (B_comb.cu_feed_assay.@float , 1, 2880 ) < 0.600000 * (VALUEAT (B_comb.cu_feed_assay.@float , 1) + VALUEAT (B_comb.cu_feed_assay.@float , 2880 ))
AND TIMEAVERAGE (B_comb.cu_feed_assay.@float , 1, 2880 ) > 0.400000 * (VALUEAT (B_comb.cu_feed_assay.@float , 1) + VALUEAT (B_comb.cu_feed_assay.@float , 2880 ))
THEN TEXT ("The B-line feed assay decreased over the past 48 min.", "Bline")
THEN WAIT (SRule, "B_feed_assay_decrease_48m", 5760)
endRule

Rule
@name = B_feed_assay_decrease_96m
IF accept.feed_assay_B.ok is TRUE
AND 1000 * RATEOFCHANGE (B_comb.cu_feed_assay.@float , 1, 5760 ) < -0.017360
AND TIMEAVERAGE (B_comb.cu_feed_assay.@float , 1, 5760 ) < 0.600000 * (VALUEAT (B_comb.cu_feed_assay.@float , 1) + VALUEAT (B_comb.cu_feed_assay.@float , 5760 ))
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THEN TEXT ("The B-line tailings assay decreased over the past 48 min.", "Bline")
THEN WAIT ($Rule, "B_tls_assay_decrease_48m", 4320)
endRule

Rule
@name = B_tls_assay_decrease_72m
IF accept.assay_B.ok is TRUE
AND 1000 * RATEOFCHANGE (B_comb.cu_tail_assay.@float, 1, 4320) < -0.002310
AND TIMEAVERAGE (B_comb.cu_tail_assay.@float, 1, 4320) < 0.600000 * (VALUEAT (B_comb.cu_tail_assay.@float, 1) + VALUEAT (B_comb.cu_tail_assay.@float, 4320))
AND TIMEAVERAGE (B_comb.cu_tail_assay.@float, 1, 4320) > 0.400000 * (VALUEAT (B_comb.cu_tail_assay.@float, 1) + VALUEAT (B_comb.cu_tail_assay.@float, 4320))
THEN TEXT ("The B-line tailings assay decreased over the past 72 min.", "Bline")
THEN WAIT ($Rule, "B_tls_assay_decrease_72m", 4320)
endRule

Rule
@name = B_tls_assay_increase_24m
IF accept.assay_B.ok is TRUE
AND 1000 * RATEOFCHANGE (B_comb.cu_tail_assay.@float, 1, 1450) > 0.006900
AND TIMEAVERAGE (B_comb.cu_tail_assay.@float, 1, 1450) < 0.600000 * (VALUEAT (B_comb.cu_tail_assay.@float, 1) + VALUEAT (B_comb.cu_tail_assay.@float, 1450))
AND TIMEAVERAGE (B_comb.cu_tail_assay.@float, 1, 1450) > 0.400000 * (VALUEAT (B_comb.cu_tail_assay.@float, 1) + VALUEAT (B_comb.cu_tail_assay.@float, 1450))
THEN TEXT ("The B-line tailings assay increased over the past 24 min.", "Bline")
THEN WAIT ($Rule, "B_tls_assay_increase_24m", 4320)
endRule
Rule
@name = B_tls_assay_increase_48m
IF accept.assay_B.ok is TRUE
AND 1000 * RATEOFCHANGE ( B_comb.cu_tail_assay.@float , 1, 2880 ) > 0.003470
AND TIMEAVERAGE ( B_comb.cu_tail_assay.@float , 1, 2880 ) < 0.600000 * ( VALUEAT ( B_comb.cu_tail_assay.@float , 1 ) + VALUEAT ( B_comb.cu_tail_assay.@float , 2880 ) )
AND TIMEAVERAGE ( B_comb.cu_tail_assay.@float , 1, 2880 ) > 0.400000 * ( VALUEAT ( B_comb.cu_tail_assay.@float , 1 ) + VALUEAT ( B_comb.cu_tail_assay.@float , 2880 ) )
THEN TEXT ("The B-line tailings assay increased over the past 48 min.", "Bline")
THEN WAIT ( $Rule, "B_tls_assay_increase_48m", 4320 )
endRule

Rule
@name = B_tls_assay_increase_72m
IF accept.assay_B.ok is TRUE
AND 1000 * RATEOFCHANGE ( B_comb.cu_tail_assay.@float , 1, 4320 ) > 0.002310
AND TIMEAVERAGE ( B_comb.cu_tail_assay.@float , 1, 4320 ) < 0.600000 * ( VALUEAT ( B_comb.cu_tail_assay.@float , 1 ) + VALUEAT ( B_comb.cu_tail_assay.@float , 4320 ) )
AND TIMEAVERAGE ( B_comb.cu_tail_assay.@float , 1, 4320 ) > 0.400000 * ( VALUEAT ( B_comb.cu_tail_assay.@float , 1 ) + VALUEAT ( B_comb.cu_tail_assay.@float , 4320 ) )
THEN TEXT ("The B-line tailings assay increased over the past 72 min.", "Bline")
THEN WAIT ( $Rule, "B_tls_assay_increase_72m", 4320 )
endRule

Rule
@name = check_feed_assay_value_A
IF RELATIVECHANGE ( A1.cu_feed_assay.@float , 1, 1460 ) > 0.000104
OR RELATIVECHANGE ( A2.cu_feed_assay.@float , 1, 1460 ) > 0.000104
OR RELATIVECHANGE ( A1.cu_feed_assay.@float , 1, 1460 ) < -0.000104
OR RELATIVECHANGE ( A2.cu_feed_assay.@float , 1, 1460 ) < -0.000104
OR RELATIVECHANGE ( A1.cu_feed_assay.@float , 4300, 5760 ) > 0.000104
OR RELATIVECHANGE ( A2.cu_feed_assay.@float , 4300, 5760 ) > 0.000104
OR RELATIVECHANGE ( A1.cu_feed_assay.@float , 4300, 5760 ) < -0.000104
OR RELATIVECHANGE ( A2.cu_feed_assay.@float , 4300, 5760 ) < -0.000104
OR RELATIVECHANGE ( A1.cu_feed_assay.@float , 1420, 2880 ) > 0.000104
OR RELATIVECHANGE ( A2.cu_feed_assay.@float , 1420, 2880 ) > 0.000104
OR RELATIVECHANGE ( A1.cu_feed_assay.@float , 1420, 2880 ) < -0.000104
OR RELATIVECHANGE ( A2.cu_feed_assay.@float , 1420, 2880 ) < -0.000104
OR ANYTIMEDURING ( 1, 2880, "A_comb.cu_feed_assay.@float == 0" )
OR ANYTIMEDURING ( 1, 5760, "A_comb.cu_feed_assay.@float == 0" )
OR A_comb.cu_feed_assay.@float < 0.100000
OR A_comb.cu_feed_assay.@float > 0.800000
OR A_feed.cu_tonnage_rate.@float < 60
THEN accept.feed_assay_A.ok is FALSE
ELSE accept.feed_assay_A.ok is TRUE
endRule

Rule
@name = check_feed_assay_value_B
IF RELATIVECHANGE ( B1.cu_feed_assay.@float , 1, 1460 ) > 0.000104
OR RELATIVECHANGE ( B2.cu_feed_assay.@float , 1, 1460 ) > 0.000104
OR RELATIVECHANGE ( B1.cu_feed_assay.@float , 1, 1460 ) < -0.000104
OR RELATIVECHANGE ( B2.cu_feed_assay.@float , 1, 1460 ) < -0.000104
OR RELATIVECHANGE ( B1.cu_feed_assay.@float , 4300, 5760 ) > 0.000104

OR RELATIVECHANGE (B2.cu_feed_assay.@float, 4300, 5760) > 0.000104
OR RELATIVECHANGE (B1.cu_feed_assay.@float, 4300, 5760) < -0.000104
OR RELATIVECHANGE (B2.cu_feed_assay.@float, 4300, 5760) < -0.000104
OR RELATIVECHANGE (B1.cu_feed_assay.@float, 1420, 2880) > 0.000104
OR RELATIVECHANGE (B2.cu_feed_assay.@float, 1420, 2880) > 0.000104
OR RELATIVECHANGE (B1.cu_feed_assay.@float, 1420, 2880) < -0.000104
OR RELATIVECHANGE (B2.cu_feed_assay.@float, 1420, 2880) < -0.000104
OR ANYTIMEDURING (1, 2880, "B_comb.cu_feed_assay.@float == 0")
OR ANYTIMEDURING (1, 5760, "B_comb.cu_feed_assay.@float == 0")
OR B_comb.cu_feed_assay.@float < 0.100000
OR B_comb.cu_feed_assay.@float > 0.800000
OR B_feed.cu_tonnage_rate.@float < 60
THEN accept.feed_assay_B.ok is FALSE
ELSE accept.feed_assay_B.ok is TRUE
endRule

Rule
@name = check_feed_assay_value_C
IF RELATIVECHANGE (C1.cu_feed_assay.@float, 1, 1460) > 0.000104
OR RELATIVECHANGE (C2.cu_feed_assay.@float, 1, 1460) > 0.000104
OR RELATIVECHANGE (C1.cu_feed_assay.@float, 1, 1460) < -0.000104
OR RELATIVECHANGE (C2.cu_feed_assay.@float, 1, 1460) < -0.000104
OR RELATIVECHANGE (C1.cu_feed_assay.@float, 4300, 5760) > 0.000104
OR RELATIVECHANGE (C2.cu_feed_assay.@float, 4300, 5760) > 0.000104
OR RELATIVECHANGE (C1.cu_feed_assay.@float, 4300, 5760) < -0.000104
OR RELATIVECHANGE (C2.cu_feed_assay.@float, 4300, 5760) < -0.000104
OR RELATIVECHANGE (C1.cu_feed_assay.@float, 1420, 2880) > 0.000104
OR RELATIVECHANGE (C2.cu_feed_assay.@float, 1420, 2880) > 0.000104
OR RELATIVECHANGE (C1.cu_feed_assay.@float, 1420, 2880) < -0.000104
OR RELATIVECHANGE (C2.cu_feed_assay.@float, 1420, 2880) < -0.000104
OR ANYTIMEDURING (1, 2880, "C_comb.cu_feed_assay.@float == 0")
OR ANYTIMEDURING (1, 5760, "C_comb.cu_feed_assay.@float == 0")
OR VALUEAT (C_comb.cu_feed_assay.@float, 2880) == 0
OR VALUEAT (C_comb.cu_feed_assay.@float, 5760) == 0
OR C_comb.cu_feed_assay.@float > 0.800000
OR C_feed.cu_tonnage_rate.@float < 60
THEN accept.feed_assay_C.ok is FALSE
ELSE accept.feed_assay_C.ok is TRUE
endRule

Rule
@name = check_peak_tails_value_C2
IF RELATIVECHANGE (C3.cu_tail_assay.@float, 1, 1100) > 0.000182
OR RELATIVECHANGE (C4.cu_tail_assay.@float, 1, 1100) > 0.000182
OR RELATIVECHANGE (C3.cu_tail_assay.@float, 1, 1100) < -0.000182
OR RELATIVECHANGE (C4.cu_tail_assay.@float, 1, 1100) < -0.000182
OR RELATIVECHANGE (C3.cu_tail_assay.@float, 700, 1440) > 0.000274
OR RELATIVECHANGE (C4.cu_tail_assay.@float, 700, 1440) > 0.000274
OR RELATIVECHANGE (C3.cu_tail_assay.@float, 2140, 2880) > 0.000274
OR RELATIVECHANGE (C4.cu_tail_assay.@float, 2140, 2880) > 0.000274
OR RELATIVECHANGE (C3.cu_tail_assay.@float, 3580, 4320) > 0.000274
OR RELATIVECHANGE (C4.cu_tail_assay.@float, 3580, 4320) > 0.000274
OR RELATIVECHANGE (C3.cu_tail_assay.@float, 700, 1440) < -0.000274
OR RELATIVECHANGE (C4.cu_tail_assay.@float, 700, 1440) < -0.000274
OR RELATIVECHANGE (C3.cu_tail_assay.@float, 2140, 2880) < -0.000274
OR RELATIVECHANGE (C4.cu_tail_assay.@float, 2140, 2880) < -0.000274
OR RELATIVECHANGE ( C3.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR RELATIVECHANGE ( C4.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( C4.cu_tail_assay.@float , 2140, 2880 ) < -0.000274
OR RELATIVECHANGE ( C4.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
THEN accept.assay_C.ok is FALSE
ELSE accept.assay_C.ok is TRUE
endRule

Rule
@name = check_peak_tail_assay_value_B
IF RELATIVECHANGE ( B1.cu_tail_assay.@float , 1, 1100 ) > 0.000182
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 1, 1100 ) > 0.000182
OR RELATIVECHANGE ( B1.cu_tail_assay.@float , 1, 1100 ) < -0.000182
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 1, 1100 ) < -0.000182
OR RELATIVECHANGE ( B1.cu_tail_assay.@float , 700, 1440 ) > 0.000274
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 700, 1440 ) > 0.000274
OR RELATIVECHANGE ( B1.cu_tail_assay.@float , 3580, 4320 ) > 0.000274
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 3580, 4320 ) > 0.000274
OR RELATIVECHANGE ( B1.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( B1.cu_tail_assay.@float , 2140, 2880 ) > 0.000274
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 2140, 2880 ) > 0.000274
OR RELATIVECHANGE ( B1.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR RELATIVECHANGE ( B1.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( B1.cu_tail_assay.@float , 2140, 2880 ) < -0.000274
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 2140, 2880 ) < -0.000274
OR RELATIVECHANGE ( B1.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR RELATIVECHANGE ( B2.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR B_comb.cu_tail_assay.@float == 0
OR B_comb.cu_tail_assay.@float == 0
OR B_comb.cu_tail_assay.@float == 0
OR B_comb.cu_tail_assay.@float < 0.010000
OR B_comb.cu_tail_assay.@float > 0.120000
OR B_feed.cu_tonnage_rate.@float < 60
THEN accept.assay_B.ok is FALSE
ELSE accept.assay_B.ok is TRUE
endRule

Rule
@name = check_peak_tls_assay_value_A
IF RELATIVECHANGE ( A1.cu_tail_assay.@float , 1, 1100 ) > 0.000182
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 1, 1100 ) > 0.000182
OR RELATIVECHANGE ( A1.cu_tail_assay.@float , 1, 1100 ) < -0.000182
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 1, 1100 ) < -0.000182
OR RELATIVECHANGE ( A1.cu_tail_assay.@float , 700, 1440 ) > 0.000274
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 700, 1440 ) > 0.000274
OR RELATIVECHANGE ( A1.cu_tail_assay.@float , 3580, 4320 ) > 0.000274
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 3580, 4320 ) > 0.000274
OR RELATIVECHANGE ( A1.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( A1.cu_tail_assay.@float , 2140, 2880 ) > 0.000274
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 2140, 2880 ) > 0.000274
OR RELATIVECHANGE ( A1.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR RELATIVECHANGE ( A1.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( A1.cu_tail_assay.@float , 2140, 2880 ) < -0.000274
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 2140, 2880 ) < -0.000274
OR RELATIVECHANGE ( A1.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR RELATIVECHANGE ( A2.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR ANYTIMEDURING (1, 1440, "A_comb.cu_tail_assay.@float == 0")
OR ANYTIMEDURING (1, 2880, "A_comb.cu_tail_assay.@float == 0")
OR ANYTIMEDURING (1, 4320, "A_comb.cu_tail_assay.@float == 0")
OR A_comb.cu_tail_assay.@float < 0.010000
OR A_comb.cu_tail_assay.@float > 0.120000
OR A_feed.cu_tonnage_rate.@float < 60
THEN accept.assay_A.ok is FALSE
ELSE accept.assay_A.ok is TRUE
endRule

Rule
@name = check_peak_tls_assay_value_C
IF RELATIVECHANGE ( C1.cu_tail_assay.@float , 1, 1100 ) > 0.000182
OR RELATIVECHANGE ( C2.cu_tail_assay.@float , 1, 1100 ) > 0.000182
OR RELATIVECHANGE ( C1.cu_tail_assay.@float , 1, 1100 ) < -0.000182
OR RELATIVECHANGE ( C2.cu_tail_assay.@float , 1, 1100 ) < -0.000182
OR RELATIVECHANGE ( C1.cu_tail_assay.@float , 3580, 4320 ) > 0.000274
OR RELATIVECHANGE ( C1.cu_tail_assay.@float , 2140, 2880 ) > 0.000274
OR RELATIVECHANGE ( C2.cu_tail_assay.@float , 3580, 4320 ) > 0.000274
OR RELATIVECHANGE ( C2.cu_tail_assay.@float , 2140, 2880 ) > 0.000274
OR RELATIVECHANGE ( C1.cu_tail_assay.@float , 700, 1440 ) > 0.000274
OR RELATIVECHANGE ( C2.cu_tail_assay.@float , 700, 1440 ) > 0.000274
OR RELATIVECHANGE ( C1.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( C2.cu_tail_assay.@float , 700, 1440 ) < -0.000274
OR RELATIVECHANGE ( C1.cu_tail_assay.@float , 2140, 2880 ) < -0.000274
OR RELATIVECHANGE ( C2.cu_tail_assay.@float , 2140, 2880 ) < -0.000274
OR RELATIVECHANGE ( C1.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR RELATIVECHANGE ( C2.cu_tail_assay.@float , 3580, 4320 ) < -0.000274
OR ANYTIMEDURING (1, 1440, "C_comb.cu_tail_assay.@float == 0")
OR ANYTIMEDURING (1, 2880, "C_comb.cu_tail_assay.@float == 0")
OR ANYTIMEDURING (1, 4320, "C_comb.cu_tail_assay.@float == 0")
OR C_comb.cu_tail_assay.@float < 0.010000
OR C_comb.cu_tail_assay.@float > 0.120000
OR C_feed.cu_tonnage_rate.@float < 60
THEN accept.assay_C.ok is FALSE
ELSE accept.assay_C.ok is TRUE
endRule

Rule
@name = C_feed_assay_decrease_48m
IF accept.feed_assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE ( C_comb.cu_feed_assay.@float , 1, 2880 ) < -0.037000
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 2880 ) < 0.600000 * ( VALUEAT ( C_comb.cu_feed_assay.@float , 1 ) + VALUEAT ( C_comb.cu_feed_assay.@float , 2880 ) )
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 2880 ) > 0.400000 * ( VALUEAT ( C_comb.cu_feed_assay.@float , 1 ) + VALUEAT ( C_comb.cu_feed_assay.@float , 2880 ) )
THEN TEXT ("The C-line feed assay decreased over the past 48 min.", "Cline")
THEN WAIT ($Rule, "C_feed_assay_decrease_48m", 5760)
endRule

Rule
@name = C_feed_assay_decrease_96m
IF accept.feed_assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE ( C_comb.cu_feed_assay.@float , 1, 5760 ) < -0.017360
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 5760 ) < 0.300000 * ( VALUEAT ( C_comb.cu_feed_assay.@float , 1 ) + VALUEAT ( C_comb.cu_feed_assay.@float , 5760 ) )
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 5760 ) > 0.200000 * ( VALUEAT ( C_comb.cu_feed_assay.@float , 1 ) + VALUEAT ( C_comb.cu_feed_assay.@float , 5760 ) )
THEN TEXT ("The C-line feed assay decreased over the past 96 min.", "Cline")
THEN WAIT ($Rule, "C_feed_assay_decrease_96m", 5760)
endRule
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 5760) < 0.600000 * (VALUEAT (C_comb.cu_feed_assay.@float , 1) + VALUEAT (C_comb.cu_feed_assay.@float , 5760))
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 5760) > 0.400000 * (VALUEAT (C_comb.cu_feed_assay.@float , 1) + VALUEAT (C_comb.cu_feed_assay.@float , 5760))
THEN TEXT ("The C-line feed assay decreased over the past 96 min.", "Cline")
THEN WAIT ( $Rule, "C_feed_assay_decrease_96m", 5760 )
endRule

Rule
@name = C_feed_assay_increase_48m
IF accept.feed_assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE ( C_comb.cu_feed_assay.@float , 1, 2880 ) > 0.037000
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 2880 ) < 0.650000 * (VALUEAT (C_comb.cu_feed_assay.@float , 1) + VALUEAT (C_comb.cu_feed_assay.@float , 2880))
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 2880 ) > 0.350000 * (VALUEAT (C_comb.cu_feed_assay.@float , 1) + VALUEAT (C_comb.cu_feed_assay.@float , 2880))
THEN TEXT ("The C-line feed assay increased over the past 48 min.", "Cline")
THEN WAIT ( $Rule, "C_feed_assay_increase_48m", 5760 )
endRule

Rule
@name = C_feed_assay_increase_96m
IF accept.feed_assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE ( C_comb.cu_feed_assay.@float , 1, 5760 ) > 0.017360
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 5760 ) < 0.600000 * (VALUEAT (C_comb.cu_feed_assay.@float , 1) + VALUEAT (C_comb.cu_feed_assay.@float , 5760))
AND TIMEAVERAGE ( C_comb.cu_feed_assay.@float , 1, 5760 ) > 0.350000 * (VALUEAT (C_comb.cu_feed_assay.@float , 1) + VALUEAT (C_comb.cu_feed_assay.@float , 5760))
THEN TEXT ("The C-line feed assay increased over the past 96 min.", "Cline")
THEN WAIT ( $Rule, "C_feed_assay_increase_96m", 5760 )
endRule

Rule
@name = C_tls_assay_decrease_24m
IF accept assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE ( C_comb.cu_tail_assay.@float , 1, 1450 ) < -0.006900
AND TIMEAVERAGE ( C_comb.cu_tail_assay.@float , 1, 1450 ) < 0.600000 * (VALUEAT (C_comb.cu_tail_assay.@float , 1) + VALUEAT (C_comb.cu_tail_assay.@float , 1450))
AND TIMEAVERAGE ( C_comb.cu_tail_assay.@float , 1, 1450 ) > 0.400000 * (VALUEAT (C_comb.cu_tail_assay.@float , 1) + VALUEAT (C_comb.cu_tail_assay.@float , 1450))
THEN TEXT ("The C-line tailings assay decreased over the past 24 min.", "Cline")
THEN WAIT ( $Rule, "C_tls_assay_decrease_24m", 4320 )
endRule

Rule
@name = C_tls_assay_decrease_48m
IF accept assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE ( C_comb.cu_tail_assay.@float , 1, 2880 ) < -0.003470
AND TIMEAVERAGE ( C_comb.cu_tail_assay.@float , 1, 2880 ) < 0.600000 * (VALUEAT (C_comb.cu_tail_assay.@float , 1) + VALUEAT (C_comb.cu_tail_assay.@float , 2880))
AND TIMEAVERAGE ( C_comb.cu_tail_assay.@float , 1, 2880 ) > 0.400000 * (VALUEAT (C_comb.cu_tail_assay.@float , 1) + VALUEAT (C_comb.cu_tail_assay.@float , 2880))
THEN TEXT ("The C-line tailings assay decreased over the past 48 min.", "Cline")
THEN WAIT ( $Rule, "C_tls_assay_decrease_48m", 4320 )
Rule
@name = C_tls_assay_decrease_72m
IF accept.assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE (C_comb.cu_tail_assay.@float, 1, 4320) < -0.002310
AND TIMEAVERAGE (C_comb.cu_tail_assay.@float, 1, 4320) < 0.600000 * (VALUEAT (C_comb.cu_tail_assay.@float, 1) + VALUEAT (C_comb.cu_tail_assay.@float, 4320))
AND TIMEAVERAGE (C_comb.cu_tail_assay.@float, 1, 4320) > 0.400000 * (VALUEAT (C_comb.cu_tail_assay.@float, 1) + VALUEAT (C_comb.cu_tail_assay.@float, 4320))
THEN TEXT ("The C-line tailings assay decreased over the past 72 min.", "Cline")
THEN WAIT ($Rule, "C_tls_assay_decrease_72m", 4320)
endRule

Rule
@name = C_tls_assay_increase_24m
IF accept.assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE (C_comb.cu_tail_assay.@float, 1, 1450) > 0.006900
AND TIMEAVERAGE (C_comb.cu_tail_assay.@float, 1, 1450) < 0.600000 * (VALUEAT (C_comb.cu_tail_assay.@float, 1) + VALUEAT (C_comb.cu_tail_assay.@float, 1450))
AND TIMEAVERAGE (C_comb.cu_tail_assay.@float, 1, 1450) > 0.400000 * (VALUEAT (C_comb.cu_tail_assay.@float, 1) + VALUEAT (C_comb.cu_tail_assay.@float, 1450))
THEN TEXT ("The C-line tailings assay increased over the past 24 min.", "Cline")
THEN WAIT ($Rule, "C_tls_assay_increase_24m", 4320)
endRule

Rule
@name = C_tls_assay_increase_48m
IF accept.assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE (C_comb.cu_tail_assay.@float, 1, 2880) > 0.003470
AND TIMEAVERAGE (C_comb.cu_tail_assay.@float, 1, 2880) < 0.600000 * (VALUEAT (C_comb.cu_tail_assay.@float, 1) + VALUEAT (C_comb.cu_tail_assay.@float, 2880))
AND TIMEAVERAGE (C_comb.cu_tail_assay.@float, 1, 2880) > 0.400000 * (VALUEAT (C_comb.cu_tail_assay.@float, 1) + VALUEAT (C_comb.cu_tail_assay.@float, 2880))
THEN TEXT ("The C-line tailings assay increased over the past 48 min.", "Cline")
THEN WAIT ($Rule, "C_tls_assay_increase_48m", 4320)
endRule

Rule
@name = C_tls_assay_increase_72m
IF accept.assay_C.ok is TRUE
AND 1000 * RATEOFCHANGE (C_comb.cu_tail_assay.@float, 1, 4320) > 0.002310
AND TIMEAVERAGE (C_comb.cu_tail_assay.@float, 1, 4320) < 0.600000 * (VALUEAT (C_comb.cu_tail_assay.@float, 1) + VALUEAT (C_comb.cu_tail_assay.@float, 4320))
AND TIMEAVERAGE (C_comb.cu_tail_assay.@float, 1, 4320) > 0.400000 * (VALUEAT (C_comb.cu_tail_assay.@float, 1) + VALUEAT (C_comb.cu_tail_assay.@float, 4320))
THEN TEXT ("The C-line tailings assay increased over the past 72 min.", "Cline")
THEN WAIT ($Rule, "C_tls_assay_increase_72m", 4320)
endRule

Rule
@name = display_avg_values
IF T
THEN avg_A_tonnage_rate.one_hundr_sec.@float = TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 1, 100)
THEN avg_A_tonnage_rate.two_hundr_sec.@float = TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 1, 200)
THEN avg_A_tonnage_rate.rate_change_twoh_sec.@float = RATEOFCHANGE (A_feed.cu_tonnage_rate.@float , 1, 200)
endRule

@name = display_cu_tails_assay
IF T
THEN ratechange_24m.A_comb_cu_tails.@float = RATEOFCHANGE (A_comb.cu_tail_assay.@float , 1, 1450)
THEN timeavg_24m.A_comb_cu_tails.@float = TIMEAVERAGE (A_comb.cu_tail_assay.@float , 1, 1450)
THEN valueat_ls.A_comb_cu_tails.@float = VALUEAT (A_comb.cu_tail_assay.@float , 1)
THEN valueat_24m.A_comb_cu_tails.@float = VALUEAT (A_comb.cu_tail_assay.@float , 1440)
endRule

@name = display_message
IF A_feed.cu_tonnage_rate.@float > 100000
THEN TEXT ("Hi there!")
THEN TEXT ("I am testing a new program that will")
THEN TEXT ("keep track of the tonnage and recovery")
THEN TEXT ("changes. All sorts of messages will appear")
THEN TEXT ("in this window but don't worry, you can")
THEN TEXT ("still use the expert system. Just ignore")
THEN TEXT ("the messages that don't come from the")
THEN TEXT ("expert system. Sorry for the inconvenient.")
THEN TEXT ("Phil.")
THEN WAIT ($Rule, "display_message", 20000)
endRule

@name = tonn_Aline_shut_down
IF RATEOFCHANGE (A_feed.cu_tonnage_rate.@float , 1, 60) < -10
AND A_feed.cu_tonnage_rate.@float < 50
THEN TEXT ("A line grinding circuit has been shut down", "Aline")
THEN WAIT ($Rule, "tonn_Aline_shut_down", 600)
endRule

@name = tonn_Aline_startup
IF RATEOFCHANGE (A_feed.cu_tonnage_rate.@float , 1, 30) > 20
AND A_feed.cu_tonnage_rate.@float > 50
THEN TEXT ("A line grinding circuit has been started up", "Aline")
THEN WAIT ($Rule, "tonn_Aline_startup", 600)
endRule

@name = tonn_A_line_decrease
IF TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 1, 300) < TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 300, 600)
AND RATEOFCHANGE (A_feed.cu_tonnage_rate.@float , 1, 600 ) < -0.300000
OR TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 1, 600 ) < TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 600, 1200 )
AND RATEOFCHANGE (A_feed.cu_tonnage_rate.@float , 1, 1200 ) < -0.150000
THEN TEXT ("The tonnage on A line is decreasing", "Aline")
THEN WAIT ($Rule, "tonn_A_line_decrease", 600 )
endRule

Rule
@name = tonn_A_line_increase
IF TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 1, 300 ) > TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 300, 600 )
AND RATEOFCHANGE (A_feed.cu_tonnage_rate.@float , 1, 600 ) > 0.300000
OR TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 1, 600 ) > TIMEAVERAGE (A_feed.cu_tonnage_rate.@float , 600, 1200 )
AND RATEOFCHANGE (A_feed.cu_tonnage_rate.@float , 1, 1200 ) > 0.150000
OR RATEOFCHANGE (A_feed.cu_tonnage_rate.@float , 1, 30 ) > 10
THEN TEXT ("The tonnage on A line is increasing", "Aline")
THEN WAIT ($Rule, "tonn_A_line_increase", 600 )
endRule

Rule
@name = tonn_Bline_shutdown
IF RATEOFCHANGE (B_feed.cu_tonnage_rate.@float , 1, 60 ) < -10
AND B_feed.cu_tonnage_rate.@float < 50
THEN TEXT ("B line grinding circuit has been shut down", "Bline")
THEN WAIT ($Rule, "tonn_Bline_shutdown", 600 )
endRule

Rule
@name = tonn_Bline_startup
IF RATEOFCHANGE (B_feed.cu_tonnage_rate.@float , 1, 30 ) > 20
AND B_feed.cu_tonnage_rate.@float > 50
THEN TEXT ("B line grinding circuit has been started up", "Bline")
THEN WAIT ($Rule, "tonn_Bline_startup", 600 )
endRule

Rule
@name = tonn_B_line_decrease
IF TIMEAVERAGE (B_feed.cu_tonnage_rate.@float , 1, 300 ) < TIMEAVERAGE (B_feed.cu_tonnage_rate.@float , 300, 600 )
AND RATEOFCHANGE (B_feed.cu_tonnage_rate.@float , 1, 600 ) < -0.300000
OR TIMEAVERAGE (B_feed.cu_tonnage_rate.@float , 1, 600 ) < TIMEAVERAGE (B_feed.cu_tonnage_rate.@float , 600, 1200 )
AND RATEOFCHANGE (B_feed.cu_tonnage_rate.@float , 1, 1200 ) < -0.150000
OR RATEOFCHANGE (B_feed.cu_tonnage_rate.@float , 1, 30 ) < -10
THEN TEXT ("The tonnage on B line is decreasing", "Bline")
THEN WAIT ($Rule, "tonn_B_line_decrease", 600 )
endRule

Rule
@name = tonn_B_line_increase
IF TIMEAVERAGE (B_feed.cu_tonnage_rate.@float , 1, 300 ) > TIMEAVERAGE (B_feed.cu_tonnage_rate.@float , 300, 600 )
AND RATEOFCHANGE (B_feed.cu_tonnage_rate.@float, 1, 600) > 0.300000
OR TIMEAVERAGE (B_feed.cu_tonnage_rate.@float, 1, 600) > TIMEAVERAGE (B_feed.cu_tonnage_rate.@float, 600, 1200)
AND RATEOFCHANGE (B_feed.cu_tonnage_rate.@float, 1, 1200) > 0.150000
THEN TEXT ("The tonnage on B line is increasing", "Bline")
THEN WAIT ($Rule, "tonn_B_line_increase", 600)
endRule

Rule
@name = tonn_Cline_shutdown
IF RATEOFCHANGE (C_feed.cu_tonnage_rate.@float, 1, 60) < -10
AND C_feed.cu_tonnage_rate.@float < 50
THEN TEXT ("C line grinding circuit has been shut down", "Cline")
THEN WAIT ($Rule, "tonn_Cline_shutdown", 600)
endRule

Rule
@name = tonn_Cline_startup
IF RATEOFCHANGE (C_feed.cu_tonnage_rate.@float, 1, 30) > 20
AND C_feed.cu_tonnage_rate.@float > 50
THEN TEXT ("C line grinding circuit has been started up", "Cline")
THEN WAIT ($Rule, "tonn_Cline_startup", 600)
endRule

Rule
@name = tonn_C_line_decrease
IF TIMEAVERAGE (C_feed.cu_tonnage_rate.@float, 1, 300) < TIMEAVERAGE (C_feed.cu_tonnage_rate.@float, 300, 600)
AND RATEOFCHANGE (C_feed.cu_tonnage_rate.@float, 1, 600) < -0.300000
OR TIMEAVERAGE (C_feed.cu_tonnage_rate.@float, 1, 600) < TIMEAVERAGE (C_feed.cu_tonnage_rate.@float, 600, 1200)
AND RATEOFCHANGE (C_feed.cu_tonnage_rate.@float, 1, 1200) < -0.150000
OR RATEOFCHANGE (C_feed.cu_tonnage_rate.@float, 1, 30) < -10
THEN TEXT ("The tonnage on C line is decreasing", "Cline")
THEN WAIT ($Rule, "tonn_C_line_decrease", 600)
endRule

Rule
@name = tonn_C_line_increase
IF TIMEAVERAGE (C_feed.cu_tonnage_rate.@float, 1, 300) < TIMEAVERAGE (C_feed.cu_tonnage_rate.@float, 300, 600)
AND RATEOFCHANGE (C_feed.cu_tonnage_rate.@float, 1, 600) > 0.300000
OR TIMEAVERAGE (C_feed.cu_tonnage_rate.@float, 1, 600) < TIMEAVERAGE (C_feed.cu_tonnage_rate.@float, 600, 1200)
AND RATEOFCHANGE (C_feed.cu_tonnage_rate.@float, 1, 1200) > 0.150000
THEN TEXT ("The tonnage on C line is increasing", "Cline")
THEN WAIT ($Rule, "tonn_C_line_increase", 600)
endRule

!!! LoadStrategy must go at the end of the Knowledge Base !!!
LoadStrategy
@name = "trend2.stg"
EndLoadStrategy
Object
@name = cert
@attribute = assign_by_user.@float
endObject

Object
@name = changing
@attribute = span.@integer
endObject

Object
@name = changing_down
@attribute = span.@integer
endObject

Object
@name = C_comb
@attribute = cu_feed_assay.@float
endObject

Inference
@name = blabla
@and = $avg
@or = $max
@mathexpr = $min
endInference

Fuzzy
@name = B1_cu_tail_okl
@source = 720 * RELATIVECHANGE ( B1.cu_tail_assay.@float , 0, 360 )
@range = 6
@value = 0.000000, 5.000000, 10.000000, 15.000000, 20.000000, 22.000000
@rank = 1.000000, 12.000000, 15.000000, 20.000000, 8.000000, 1.000000
endFuzzy

Fuzzy
@name = B1_cu_tail_okl2
@source = 720 * RELATIVECHANGE ( B1.cu_tail_assay.@float , 4320, 4680 )
@range = 6
@value = 0.000000, 5.000000, 10.000000, 15.000000, 20.000000, 22.000000
@rank = 1.000000, 12.000000, 15.000000, 20.000000, 8.000000, 1.000000
endFuzzy

Fuzzy
@name = B1_tail_down_okl
@source = 360 * RELATIVECHANGE ( B1.cu_tail_assay.@float , 0, 360 )
@range = 6
@value = -0.220000, -0.200000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 8.000000, 20.000000, 15.000000, 12.000000, 1.000000
endFuzzy

Fuzzy
@name = B1_tail_down_okl2
@source = 360 * RELATIVECHANGE ( B1.cu_tail_assay.@float , 4320, 4680 )
@range = 6
@value = -0.220000, -0.200000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 8.000000, 20.000000, 15.000000, 12.000000, 1.000000
dendFuzzy

Fuzzy
@name = B_CU_F_DOWN_1
@source = 720 * RELATIVECHANGE (B_comb_cu_feed_assay.©float , 0, 720)
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
dendFuzzy

Fuzzy
@name = B_CU_F_DOWN_6
@source = 720 * RELATIVECHANGE (B_comb_cu_feed_assay.©float , 3600, 4320)
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
dendFuzzy

Fuzzy
@name = B_CU_F_UP_1
@source = 720 * RELATIVECHANGE (B_comb_cu_feed_assay.©float , 0, 720)
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
dendFuzzy

Fuzzy
@name = B_CU_F_UP_6
@source = 720 * RELATIVECHANGE (B_comb_cu_feed_assay.©float , 3600, 4320)
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
dendFuzzy

Fuzzy
@name = Cl_cu_tail_okl
@source = 720 * RELATIVECHANGE (Cl.cu_tail_assay.©float , 0, 360)
@range = 6
@value = 0.000000, 5.000000, 10.000000, 15.000000, 20.000000, 22.000000
@rank = 1.000000, 12.000000, 15.000000, 20.000000, 8.000000, 1.000000
dendFuzzy

Fuzzy
@name = Cl_cu_tail_okl2
@source = 720 * RELATIVECHANGE (Cl.cu_tail_assay.©float , 4320, 4680)
@range = 6
@value = 0.000000, 5.000000, 10.000000, 15.000000, 20.000000, 22.000000
@rank = 1.000000, 12.000000, 15.000000, 20.000000, 8.000000, 1.000000
dendFuzzy

Fuzzy
@name = C1_tail_down_okl
@source = 360 * RELATIVECHANGE ( C1_cu_tail_assay.@float , 0, 360 )
@range = 6
@value = -0.220000, -0.200000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 8.000000, 20.000000, 15.000000, 12.000000, 1.000000
endFuzzy

Fuzzy
@name = C1_tail_down_okl2
@source = 360 * RELATIVECHANGE ( C1_cu_tail_assay.@float , 4320, 4680 )
@range = 6
@value = -0.220000, -0.200000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 8.000000, 20.000000, 15.000000, 12.000000, 1.000000
endFuzzy

Fuzzy
@name = C_CU_FEED_DOWN_6
@source = 720 * RELATIVECHANGE ( C_comb_cu_feed_assay.@float , 3600, 4320 )
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
endFuzzy

Fuzzy
@name = C_CU_F_DOWN_1
@source = 720 * RELATIVECHANGE ( C_comb_cu_feed_assay.@float , 0, 720 )
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
endFuzzy

Fuzzy
@name = C_CU_F_UP_1
@source = 720 * RELATIVECHANGE ( C_comb_cu_feed_assay.@float , 0, 720 )
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
endFuzzy

Fuzzy
@name = C_CU_F_UP_6
@source = 720 * RELATIVECHANGE ( C_comb_cu_feed_assay.@float , 3600, 4320 )
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
endFuzzy

Fuzzy
@name = al_cu_tail_okl
@source = 36 * RELATIVECHANGE ( A1_cu_tail_assay.@float , 0, 36 )
@range = 6
@value = 0.000000, 5.000000, 10.000000, 15.000000, 20.000000, 22.000000
@rank = 1.000000, 12.000000, 15.000000, 20.000000, 8.000000, 1.000000
endFuzzy
Fuzzy
@name = al_cu_tail_okl2
@source = 36 * RELATIVECHANGE ( Al.cu_tail_assay.@float , 432, 468 )
@range = 6
@value = 0.000000, 5.000000, 10.000000, 15.000000, 20.000000, 22.000000
@rank = 1.000000, 12.000000, 15.000000, 20.000000, 8.000000, 1.000000
endFuzzy

Fuzzy
@name = al_tail_down_okl
@source = 36 * RELATIVECHANGE ( Al.cu_tail_assay.@float , 0, 36 )
@range = 6
@value = -0.220000, -0.200000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 8.000000, 20.000000, 15.000000, 12.000000, 1.000000
endFuzzy

Fuzzy
@name = al_tail_down_okl2
@source = 36 * RELATIVECHANGE ( Al.cu_tail_assay.@float , 432, 468 )
@range = 6
@value = -0.220000, -0.200000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 8.000000, 20.000000, 15.000000, 12.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_down1
@source = 720 * RELATIVECHANGE ( A_comb.cu_feed_assay.@float , 0, 720 )
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_down2
@source = 720 * RELATIVECHANGE ( A_comb.cu_feed_assay.@float , 720, 1440 )
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_down3
@source = 720 * RELATIVECHANGE ( A_comb.cu_feed_assay.@float , 1440, 2160 )
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_down4
@source = 720 * RELATIVECHANGE ( A_comb.cu_feed_assay.@float , 2160, 2880 )
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_down5
@source = 720 * RELATIVECHANGE (A_comb.cu_feed_assay.@float, 2880, 3600)
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_down6
@source = 720 * RELATIVECHANGE (A_comb.cu_feed_assay.@float, 3600, 4320)
@range = 6
@value = -0.200000, -0.180000, -0.150000, -0.100000, -0.050000, 0.000000
@rank = 1.000000, 7.000000, 27.000000, 20.000000, 15.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_up1
@source = 720 * RELATIVECHANGE (A_comb.cu_feed_assay.@float, 0, 720)
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_up2
@source = 720 * RELATIVECHANGE (A_comb.cu_feed_assay.@float, 720, 1440)
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_up3
@source = 720 * RELATIVECHANGE (A_comb.cu_feed_assay.@float, 1440, 2160)
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_up4
@source = 720 * RELATIVECHANGE (A_comb.cu_feed_assay.@float, 2160, 2880)
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_up5
@source = 720 * RELATIVECHANGE (A_comb.cu_feed_assay.@float, 2880, 3600)
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
endFuzzy

Fuzzy
@name = trnd_up6
@source = 720 * RELATIVECHANGE ( A_comb.cu_feed_assay.@float , 3600, 4320 )
@range = 6
@value = 0.000000, 0.050000, 0.100000, 0.150000, 0.180000, 0.190000
@rank = 1.000000, 15.000000, 20.000000, 27.000000, 7.000000, 1.000000
endFuzzy

Rule
@name = a1_trend_cu_tail
IF T
THEN ASNCERTAINTY ( A1.cuta_up.oka, CERTAINTY ( A1.cuta_up.ok ) + CERTAINTY ( A1.cuta_up.ok1 ) - CERTAINTY ( A1.cuta_up.ok12 ) )
THEN ASNCERTAINTY ( A1.cuta_down.oka, CERTAINTY ( A1.cuta_down.ok ) + CERTAINTY ( A1.cuta_down.ok1 ) - CERTAINTY ( A1.cuta_down.ok12 ) )
THEN ASNCERTAINTY ( A1.cuta_up.ok, CERTAINTY ( A1.cuta_up.oka ) - CERTAINTY ( A1.cuta_down.oka ) )
THEN ASNCERTAINTY ( A1.cuta_down.ok, CERTAINTY ( A1.cuta_down.oka ) - CERTAINTY ( A1.cuta_up.oka ) )
THEN A1_tail.trending_up.@float = CERTAINTY ( A1.cuta_up.ok )
THEN A1_tail.trend_down.@float = CERTAINTY ( A1.cuta_down.ok )
THEN WAIT ( $Rule, "a1_trend_cu_tail", 36 )
endRule

Rule
@name = b1_trend_cu_tail
IF T
THEN ASNCERTAINTY ( B1.cuta_up.oka, CERTAINTY ( B1.cuta_up.ok ) + CERTAINTY ( B1.cuta_up.ok1 ) - CERTAINTY ( B1.cuta_up.ok12 ) )
THEN ASNCERTAINTY ( B1.cuta_down.oka, CERTAINTY ( B1.cuta_down.ok ) + CERTAINTY ( B1.cuta_down.ok1 ) - CERTAINTY ( B1.cuta_down.ok12 ) )
THEN ASNCERTAINTY ( B1.cuta_up.ok, CERTAINTY ( B1.cuta_up.oka ) - CERTAINTY ( B1.cuta_down.oka ) )
THEN ASNCERTAINTY ( B1.cuta_down.ok, CERTAINTY ( B1.cuta_down.oka ) - CERTAINTY ( B1.cuta_up.oka ) )
THEN B1_tail.trending_up.@float = CERTAINTY ( B1.cuta_up.ok )
THEN B1_tail.trend_down.@float = CERTAINTY ( B1.cuta_down.ok )
THEN WAIT ( $Rule, "b1_trend_cu_tail", 36 )
endRule

Rule
@name = c1_trend_cu_tail
IF T
THEN ASNCERTAINTY ( C1.cuta_up.oka, CERTAINTY ( C1.cuta_up.ok ) + CERTAINTY ( C1.cuta_up.ok1 ) - CERTAINTY ( C1.cuta_up.ok12 ) )
THEN ASNCERTAINTY ( C1.cuta_down.oka, CERTAINTY ( C1.cuta_down.ok ) + CERTAINTY ( C1.cuta_down.ok1 ) - CERTAINTY ( C1.cuta_down.ok12 ) )
THEN ASNCERTAINTY ( C1.cuta_up.ok, CERTAINTY ( C1.cuta_up.oka ) - CERTAINTY ( C1.cuta_down.oka ) )
THEN ASNCERTAINTY (Cl.cuta_down.ok, CERTAINTY (Cl.cuta_down.oka) - CERTAINTY (Cl.cuta_up.oka)) THEN Cl_tail.trending_up.@float = CERTAINTY (Cl.cuta_up.ok) THEN Cl_tail.trending_down.@float = CERTAINTY (Cl.cuta_down.ok) THEN WAIT ($Rule, "c1_trend_cu_tail", 36) endRule

Rule
@name = mess_al_tail_down
IF CERTAINTY (Al.cuta_down.ok) > cert.assign_by_user.@float AND TIMEAVERAGE (Al.cu_tail_assay.@float , 0, 180) < 0.850000 * TIMEAVERAGE (Al.cu_tail_assay.@float , 180, 360) THEN avg1.al_cu_tail.@float = TIMEAVERAGE (Al.cu_tail_assay.@float , 0, 180) THEN avg2.al_cu_tail.@float = TIMEAVERAGE (Al.cu_tail_assay.@float , 180, 360) THEN changing.span.@integer = LASTTIME (360, "Al_tail.trending_up.@float <= 12") THEN TEXT ("Al tailings assay has been trending down for the past !$changing.span.@i$! seconds") THEN WAIT ($Rule, "mess_al_tail_down", 432) endRule

Rule
@name = mess_al_tail_up
IF CERTAINTY (Al.cuta_up.ok) > cert.assign_by_user.@float AND TIMEAVERAGE (Al.cu_tail_assay.@float , 0, 180) > 1.150000 * TIMEAVERAGE (Al.cu_tail_assay.@float , 180, 360) THEN avg1.al_cu_tail.@float = TIMEAVERAGE (Al.cu_tail_assay.@float , 0, 180) THEN avg2.al_cu_tail.@float = TIMEAVERAGE (Al.cu_tail_assay.@float , 360, 180) THEN changing.span.@integer = LASTTIME (360, "Al_tail.trending_up.@float <= 12") THEN TEXT ("Al tailings assay has been trending up for the past !$changing.span.@i$! seconds") THEN WAIT ($Rule, "mess_al_tail_up", 432) endRule

Rule
@name = mess_bl_tail_down
IF CERTAINTY (Bl.cuta_down.ok) > cert.assign_by_user.@float AND TIMEAVERAGE (Bl.cu_tail_assay.@float , 0, 2160) < 0.850000 * TIMEAVERAGE (Bl.cu_tail_assay.@float , 2160, 4320) THEN changing.span.@integer = LASTTIME (120, "Bl_tail.trending_up.@float <= 12") THEN TEXT ("Bl tailings assay has been trending down for the past !$changing.span.@i$! seconds") THEN WAIT ($Rule, "mess_bl_tail_down", 432) endRule

Rule
@name = mess_bl_tail_up
IF CERTAINTY (Bl.cuta_up.ok) > cert.assign_by_user.@float AND TIMEAVERAGE (Bl.cu_tail_assay.@float , 0, 2160) > 1.150000 * TIMEAVERAGE (Bl.cu_tail_assay.@float , 2160, 4320) THEN changing.span.@integer = LASTTIME (120, "Bl_tail.trending_up.@float <= 12") THEN TEXT ("Bl tailings assay has been trending up for the past !$changing.span.@i$! seconds") THEN WAIT ($Rule, "mess_bl_tail_up", 432) endRule

Rule
@name = mess_cl_tail_down
IF CERTAINTY (Cl.cuta_down.ok) > cert.assign_by_user.@float AND TIMEAVERAGE (Cl.cu_tail_assay.@float , 0, 180) < 0.850000 * TIMEAVERAGE (Cl.cu_tail_assay.@float , 180, 360) THEN changing.span.@integer = LASTTIME (120, "Cl_tail.trending_up.@float <= 12") THEN TEXT ("Cl tailings assay has been trending down for the past !$changing.span.@i$! seconds") THEN WAIT ($Rule, "mess_cl_tail_down", 432) endRule

Rule
@name = mess_cl_tail_up
IF CERTAINTY (Cl.cuta_up.ok) > cert.assign_by_user.@float AND TIMEAVERAGE (Cl.cu_tail_assay.@float , 0, 180) > 1.150000 * TIMEAVERAGE (Cl.cu_tail_assay.@float , 180, 360) THEN changing.span.@integer = LASTTIME (120, "Cl_tail.trending_up.@float <= 12") THEN TEXT ("Cl tailings assay has been trending up for the past !$changing.span.@i$! seconds") THEN WAIT ($Rule, "mess_cl_tail_up", 432) endRule
Rule
@name = mess_cl_tail_up
IF CERTAINTY (Cl.cuta_up.ok) > cert.assign_by_user.@float
AND TIMEAVERAGE (Cl.cu_tail_assay.@float, 0, 2160) > 1.150000 * TIMEAVERAGE (Cl.cu_tail_assay.@float, 2160, 4320)
THEN changing.span.@integer = LASTTIME (120, "Cl_tail.trending_up.@float <= 12")
THEN TEXT ("CI tailings assay has been trending up for the past $changing.span.@i$! seconds")
THEN WAIT ($Rule, "mess_cl_tail_up", 432)
endRule

Facets
@triplet = A1.cuta_down.ok1
@fuzzy = a1_tail_down_ok1
defFacets

Facets
@triplet = A1.cuta_down.ok12
@fuzzy = a1_tail_down_ok12
defFacets

Facets
@triplet = A1.cuta_up.ok1
@fuzzy = a1_cu_tail_ok1
defFacets

Facets
@triplet = A1.cuta_up.ok12
@fuzzy = a1_cu_tail_ok12
defFacets

Facets
@triplet = B1.cuta_down.ok1
@fuzzy = B1_tail_down_ok1
defFacets

Facets
@triplet = B1.cuta_down.ok12
@fuzzy = B1_tail_down_ok12
defFacets

Facets
@triplet = B1.cuta_up.ok1
@fuzzy = B1_cu_tail_ok1
defFacets

Facets
@triplet = B1.cuta_up.ok12
@fuzzy = B1_cu_tail_ok12
defFacets
@fuzzy = B1_cu_tail_ok12
endFacets

Facets
@triplet = C1.cuta_down.ok1
@fuzzy = C1_tail_down_ok1
endFacets

Facets
@triplet = C1.cuta_down.ok12
@fuzzy = C1_tail_down_ok12
endFacets

Facets
@triplet = C1.cuta_up.ok1
@fuzzy = C1_cu_tail_ok1
endFacets

Facets
@triplet = C1.cuta_up.ok12
@fuzzy = C1_cu_tail_ok12
endFacets

Facets
@triplet = changing.span.@integer
@format = "@T=#F{2}" 
endFacets

Facets
@triplet = changing_down.span.@integer
@format = "@T=#F{2}" 
endFacets

!*** LoadStrategy must go at the end of the Knowledge Base ***!
LoadStrategy
@name = "fuztrnd5.stg"
EndLoadStrategy
APPENDIX C

Tables of the advice and explanations given for each froth condition

Table C-1 - Actions advised by the expert system for each froth combination

Table C-2 - Explanations given for each advice
Table C-1 - Actions advised by the expert system for each froth combination

Froth description key:

<table>
<thead>
<tr>
<th>Rougher froth types</th>
<th>Scavenger froth types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Optimum - Normal copper color</td>
<td>1. Tight froth - Not moving - Boiling pulp</td>
</tr>
<tr>
<td>2. Optimum - Big bubbles froth</td>
<td>2. Optimum - High copper</td>
</tr>
<tr>
<td>3. Tight froth - Not moving - Froth covers the flotation cell</td>
<td>3. Tight froth - Not moving - Quiet pulp</td>
</tr>
<tr>
<td>5. Tight froth - Not moving - Broken-up - Quiet pulp</td>
<td>5. Tight froth - Fast moving</td>
</tr>
<tr>
<td>6. Empty froth</td>
<td>6. Foamy froth</td>
</tr>
<tr>
<td>7. Tight froth - Not moving - Broken-up - Boiling pulp</td>
<td></td>
</tr>
<tr>
<td>8. Optimum - Bluish-grey</td>
<td></td>
</tr>
<tr>
<td>9. Grey froth</td>
<td></td>
</tr>
<tr>
<td>10. Foamy froth</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Froth description</th>
<th>Action advised by the expert system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughers</td>
<td>Scavengers</td>
</tr>
<tr>
<td>1 or 8</td>
<td>1</td>
</tr>
<tr>
<td>Check the pulp density at the tailings and lower it if too high.</td>
<td></td>
</tr>
<tr>
<td>Decrease the air to the scavenger cells.</td>
<td></td>
</tr>
<tr>
<td>Increase the scavenger cell levels temporarily to off-load the circuit.</td>
<td></td>
</tr>
<tr>
<td>Increase your DOW addition rate to the scavengers.</td>
<td></td>
</tr>
<tr>
<td>Decrease your PAX addition rate to the scavengers.</td>
<td></td>
</tr>
<tr>
<td>1 or 8</td>
<td>2</td>
</tr>
<tr>
<td>You may not be pulling the roughers hard enough.</td>
<td></td>
</tr>
<tr>
<td>You should check the dart valves and the air level to the roughers.</td>
<td></td>
</tr>
<tr>
<td>Increase your DOW addition rate to the scavengers.</td>
<td></td>
</tr>
<tr>
<td>1 or 8</td>
<td>3</td>
</tr>
<tr>
<td>Increase the scavenger cell levels temporarily to off-load the circuit.</td>
<td></td>
</tr>
<tr>
<td>Increase your DOW addition rate to the scavengers.</td>
<td></td>
</tr>
<tr>
<td>Decrease your PAX addition rate to the scavengers.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>These are the conditions we are trying to maintain.</td>
<td></td>
</tr>
<tr>
<td>I suggest to do a PAX test on one of the scavenger banks.</td>
<td></td>
</tr>
<tr>
<td>1 or 8</td>
<td>5</td>
</tr>
<tr>
<td>Check if scavenger cells do not need lowering.</td>
<td></td>
</tr>
<tr>
<td>Decrease your PAX addition rate to the scavengers.</td>
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<tr>
<td>1 or 8</td>
<td>6</td>
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<td>2</td>
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<td>4</td>
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<td>2</td>
<td>5</td>
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<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Increase your DOW level to the roughers.
Decrease the DOW addition rate low to the scavengers.
Decrease the air to the scavenger cells.
Increase the scavenger cell levels temporarily to off-load the circuit.
Decrease your PAX addition rate to the scavengers.
Decrease Pine Oil addition rate to the ball mill.
Decrease Pine Oil addition rate to the scavengers.
Decrease Pine Oil addition rate to the scavengers.
Decrease your PAX addition rate to the scavengers.
Decrease Pine Oil addition rate to the ball mill.
Increase your DOW level to the roughers.
Increase your PAX level to the roughers.
Increase lime addition rate to the circuit.
Decrease Pine Oil addition rate to the ball mill.
Decrease your PAX addition rate to the scavengers.
Decrease your PAX addition rate to the ball mill.
Increase lime addition rate to the circuit.
Decrease Pine Oil addition rate to the ball mill.
Increase your DOW level to the roughers.
Increase your PAX level to the roughers.
Increase lime addition rate to the circuit.
Decrease Pine Oil addition rate to the ball mill.
Decrease Pine Oil addition rate to the scavengers.
Decrease your PAX addition rate to the scavengers.
Increase lime addition rate to the circuit.
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Check the pulp density at the tailings and lower it if too high.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decrease the air to the scavenger cells.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Decrease your PAX level to the rougher head end.</td>
</tr>
<tr>
<td></td>
<td>Increase your DOW level to the roughers.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check if cyclone O/F water is not too low.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check rougher pulp levels do not need increasing.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase the air to the rougher cells.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check if pH levels are not too low.</td>
<td></td>
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<tr>
<td>3</td>
<td>3</td>
<td>Increase the scavenger cell levels temporarily to off-load the circuit.</td>
</tr>
<tr>
<td></td>
<td>Decrease your PAX addition rate to the ball mill.</td>
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</tr>
<tr>
<td></td>
<td>Increase your DOW addition rate to the scavengers.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check the pulp density at the tailings and lower it if too high.</td>
<td></td>
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<tr>
<td>3</td>
<td>4</td>
<td>Decrease your PAX level to the rougher head end.</td>
</tr>
<tr>
<td></td>
<td>Increase your DOW addition rate to the scavengers.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check rougher pulp levels do not need increasing.</td>
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<tr>
<td></td>
<td>Check if cyclone O/F water is not too low.</td>
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</tr>
<tr>
<td></td>
<td>Increase the air to the rougher cells.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check if pH levels are not too low.</td>
<td></td>
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<tr>
<td>3</td>
<td>5</td>
<td>Check rougher pulp levels do not need increasing.</td>
</tr>
<tr>
<td></td>
<td>Decrease your PAX level to the ball mill.</td>
<td></td>
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<tr>
<td></td>
<td>Increase your DOW level to the roughers.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check the pulp density at the tailings and lower it if too high.</td>
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<tr>
<td>3</td>
<td>6</td>
<td>If NaHS is added to the scavengers, there is nothing you can do.</td>
</tr>
<tr>
<td></td>
<td>Decrease your PAX addition rate to the ball mill.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Check the pulp density at the tailings and lower it if too high.</td>
</tr>
<tr>
<td></td>
<td>Decrease the air to the scavenger cells.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase your DOW addition rate to the scavengers.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decrease your PAX addition rate to the ball mill.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check if rougher cell levels do not need lowering.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check if pH levels are not too low.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase the scavenger cell levels temporarily to off-load the circuit.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Decrease your PAX level to the rougher head end.</td>
</tr>
<tr>
<td></td>
<td>Check if rougher cell levels do not need lowering.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decrease the DOW addition rate to the rougher head end.</td>
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<tr>
<td>Row</td>
<td>Column</td>
<td>Task Description</td>
</tr>
<tr>
<td>-----</td>
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</tr>
</tbody>
</table>
| 4   | 3      | Check for oil contamination.  
Check if pH levels are not too low.  
Check the pulp density at the tailings and lower it if too high.  
Increase your DOW addition rate to the scavengers.  
Decrease your PAX addition rate to the ball mill.  
Check if rougher cell levels do not need lowering.  
Check if pH levels are not too low.  
Increase the scavenger cell levels temporarily to off-load the circuit. |
| 4   | 4      | Decrease your PAX level to the rougher head end.  
Check if rougher cell levels do not need lowering.  
Decrease the DOW addition rate to the rougher head end.  
Check if pH levels are not too low.  
Check for oil contamination. |
| 4   | 5      | Check if rougher and scavenger cell levels do not need lowering.  
Decrease your PAX addition rate to the ball mill.  
Decrease the DOW addition rate low to the scavengers. |
| 4   | 6      | If NaHS is added to the scavengers, there is nothing you can do.  
Decrease your PAX addition rate to the ball mill. |
| 5   | 1      | Off-load the circuit by temporarily raising the scavenger and rougher cell levels.  
Increase your DOW addition rate to the scavengers.  
Check the pulp density at the tailings and lower it if too high.  
Decrease your PAX addition rate to the ball mill.  
Decrease the air to the scavenger cells. |
| 5   | 2      | Try lowering the pulp levels and adding frother to the rougher cells.  
Check the pulp density at the tailings and lower it if too high.  
Try to increase air to the roughers and check agitators.  
Check for oil contamination. |
| 5   | 3      | Check rougher pulp levels do not need increasing.  
Increase your DOW level to the roughers.  
Decrease your PAX addition rate to the ball mill.  
Check the pulp density at the tailings and lower it if too high.  
Check for oil contamination. |
| 5   | 4      | Check the pulp density at the tailings and lower it if too high.  
Try to increase air to the roughers and check agitators. |
<table>
<thead>
<tr>
<th></th>
<th>Decrease your PAX addition rate to the ball mill.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Increase your DOW level to the roughers.</td>
</tr>
<tr>
<td>5</td>
<td>Check for oil contamination.</td>
</tr>
<tr>
<td>5</td>
<td>Check rougher pulp levels do not need increasing.</td>
</tr>
<tr>
<td>6</td>
<td>Decrease your PAX addition rate to the scavengers.</td>
</tr>
<tr>
<td>6</td>
<td>Increase your DOW level to the roughers.</td>
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<tr>
<td>6</td>
<td>Check the pulp density at the tailings and lower it if too high.</td>
</tr>
<tr>
<td>5</td>
<td>If NaHS is added to the scavengers, there is nothing you can do.</td>
</tr>
<tr>
<td>6</td>
<td>Increase your PAX level to the ball mill.</td>
</tr>
<tr>
<td>6</td>
<td>Check for a plugged reagent line to the ball mill or the rougher end.</td>
</tr>
<tr>
<td>6</td>
<td>Check for oil contamination.</td>
</tr>
<tr>
<td>6</td>
<td>Add NaHS to the scavenger circuit.</td>
</tr>
<tr>
<td>6</td>
<td>Increase your PAX level to the ball mill.</td>
</tr>
<tr>
<td>6</td>
<td>Increase lime addition rate to the circuit.</td>
</tr>
<tr>
<td>6</td>
<td>Unfortunately, I have no advice to give for this froth condition.</td>
</tr>
<tr>
<td>6</td>
<td>Unfortunately, I have no advice to give for this froth condition.</td>
</tr>
<tr>
<td>7</td>
<td>Check the pulp density at the tailings and lower it if too high.</td>
</tr>
<tr>
<td>7</td>
<td>Decrease the air to the rougher cells.</td>
</tr>
<tr>
<td>7</td>
<td>Increase the scavenger cell levels temporarily to off-load the circuit.</td>
</tr>
<tr>
<td>7</td>
<td>Decrease your PAX addition rate to the ball mill.</td>
</tr>
<tr>
<td>7</td>
<td>Check for cyclone oversize.</td>
</tr>
<tr>
<td>7</td>
<td>Check the pulp density at the tailings and lower it if too high.</td>
</tr>
<tr>
<td>7</td>
<td>Decrease the air to the rougher cells.</td>
</tr>
<tr>
<td>7</td>
<td>Decrease your PAX addition rate to the ball mill.</td>
</tr>
<tr>
<td>7</td>
<td>Increase your DOW level to the roughers.</td>
</tr>
<tr>
<td>7</td>
<td>Check for cyclone oversize.</td>
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<td>9</td>
<td>1,2,3,4,5, or 6</td>
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<td>Time</td>
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<td>10</td>
<td>Check for contaminants (soap, NaHS, too much Pine Oil).</td>
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Table C-2 - Explanations given for each advice

<table>
<thead>
<tr>
<th>Advice</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add NaHS to the scavenger circuit.</td>
<td>The empty froth at the rougher may be caused by oxyde ore. You can identify oxide ore on the conveyor belt by its brownish color. NaHS will coat the surface of oxidized ore with sulfides which are needed for the collector to collect the valuable material. However, too much NaHS can depress copper minerals by making the collector inactive. Add NaHS until the final tail copper grade goes down.</td>
</tr>
<tr>
<td>Increase DOW significantly and decrease PAX level.</td>
<td>When high bornite ore is present (bluish or reddish froth color), good recoveries can be obtained by running the circuit with higher than normal DOW levels and lower PAX addition rates. Try this combination if you are losing the recovery with bornite ore.</td>
</tr>
<tr>
<td>You may also consider changing the tails target.</td>
<td>Changing parameters in the system, such as ore changes, may require you to redefine the target for tails assays. This would help you to monitor the system better under these changing conditions.</td>
</tr>
<tr>
<td>Try to increase air to the roughers and check agitators.</td>
<td>You may be able to increase the air flow to the rougher cells and force bubbles further out through the pulp, thus producing a better froth bed. You may notice a flat froth on one of the rougher cells but the others are OK. This may indicate a problem with the agitator of that particular cell indicating that the air is not distributed throughout the cell.</td>
</tr>
<tr>
<td>Check for contaminants (soap, NaHS, too much Pine Oil).</td>
<td>Foamy froth can be the result of one of the following contaminants: soap, too much Pine Oil or DOW (check if the reagent pump or the solenoid valve is stuck open), talc or NaHS. If you are using NaHS because oxide ore is present, then foamy froth is expected and there is nothing you can do about it.</td>
</tr>
<tr>
<td>Check for cyclone oversize.</td>
<td>Oversize particles at the cyclone overflow may be a cause for the boiling froth observed at the roughers. Contact the grinding operator to insure the the grind is not too coarse.</td>
</tr>
<tr>
<td>Check if the pulp density is not too low.</td>
<td>If the density is too low (20%-25%), then foamy froth may occur. Check if the ball mill went down a little while ago.</td>
</tr>
<tr>
<td>Check for oil contamination.</td>
<td>Check all possible sources: Leaks form oil line, bad order of reagent lines, incorrectly entered setpoints, stuck valves, leaking lines, etc. Contact the grinding circuit operator and ask him to check for any oil leaks around the mills and conveyor belts.</td>
</tr>
<tr>
<td>Check pH levels are not too low.</td>
<td>Excessively low pH will cause tight froth problems which results in a dark dead looking froth. You may need to increase the lime addition to the circuit.</td>
</tr>
<tr>
<td>Instruction</td>
<td>Reason</td>
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</tr>
<tr>
<td>Decrease the DOW addition rate to the rougher head end.</td>
<td>This action will reduce the froth bed and allow the new froth bed to selectively recover the target minerals. The fast movement of the froth may be caused by an excess of frother which creates too much froth.</td>
</tr>
<tr>
<td>Decrease lime addition rate to the circuit.</td>
<td>To reduce lime stabilizes and strengthens the recovery bubbles. This in turn allows for the development of a supporting froth bed.</td>
</tr>
<tr>
<td>Decrease your PAX addition rates at the scavengers.</td>
<td>Excess of PAX to the scavengers results in a rich dull color froth. The froth will become very tight, collapsed and sluggish. Air may start to spit up in and create the boiling froth condition.</td>
</tr>
<tr>
<td>Decrease Pine Oil addition rate to the ball mill.</td>
<td>Big bubbles indicate too much Pine Oil on the circuit. Because the Pine Oil is cut down at the ball mill, more frother has to be added to the scavengers.</td>
</tr>
<tr>
<td>Decrease Pine Oil addition rate to the ball mill and scavengers.</td>
<td>An excess of Pine Oil may be responsible for the foamyness of the scavenger froth. At this point, we believe that there is enough frother to the circuit so you do not have to increase the DOW levels.</td>
</tr>
<tr>
<td>Decrease Pine Oil addition rate to the ball mill.</td>
<td>Too much Pine Oil may be responsible for the big bubbles at the roughers.</td>
</tr>
<tr>
<td>Decrease your Pine Oil levels to the scavengers.</td>
<td>Excessive Pine Oil may be responsible for the tight froth occurring at the scavenger cells.</td>
</tr>
<tr>
<td>Decrease the air to the rougher cells.</td>
<td>The amount of air which can be dispersed in slurry is limited. This can be improved by addition of frothers, but generally if too much air is added to slurry, bigger bubbles are formed, which are not efficient in picking up copper minerals. Reducing the air supply to the flotation cells will minimize pulp movement and stabilize the froth bed.</td>
</tr>
<tr>
<td>Decrease the air to the scavenger cells.</td>
<td>Too much air to the scavenger cells will create boiling conditions because the agitator will not be able to disperse the air properly and big bubbles will be generated. When these big bubbles reach the surface, they create boiling conditions.</td>
</tr>
<tr>
<td>Decrease the DOW addition rate to the scavengers.</td>
<td>To decrease the Dow should reestablish an optimum froth condition. Other contaminants are not suspected because optimum froth has been identified at the roughers.</td>
</tr>
<tr>
<td>Decrease your PAX level at the ball mil.</td>
<td>Excessive PAX results in a rich dull colored tight froth.</td>
</tr>
<tr>
<td>If NaHS is added to the scavengers, there is nothing you can do.</td>
<td>NaHS usually produces a foamy froth.</td>
</tr>
<tr>
<td>These are the conditions we are trying to maintain.</td>
<td>This froth condition is the one we are trying to maintain.</td>
</tr>
<tr>
<td>Increase the air to the rougher cells.</td>
<td>The reason why the roughers are not pulling hard enough may be that not enough air is fed to the cell so the copper minerals cannot be brought into the froth.</td>
</tr>
<tr>
<td>Increase your DOW addition rate to the roughers.</td>
<td>This will develop a more stable denser froth bed and will also strengthen the walls of the recovery bubbles.</td>
</tr>
<tr>
<td>Increase your DOW addition rates to the scavengers.</td>
<td>More frother will produce finer bubbles and a less tight froth.</td>
</tr>
<tr>
<td>Increase lime addition rate to the circuit.</td>
<td>Lime addition will stabilize the frothing reagents and maintain bubble size. However, too much lime enhance big bubbles froth and create a greyish look. Before changing lime addition check the flotation pH. It should be between 9.0-9.5. Only if the pH is low, increase the lime. Changes to the lime should be considered only a 'band-aid', a temporary solution. It will help improve the froth quality, but not solve the problem which cause the big bubbles.</td>
</tr>
<tr>
<td>Increase your PAX addition rate to the ball mill.</td>
<td>Since no copper is collected at all, maybe you do not add enough collector (PAX) to pick-the copper minerals. If you are adding some PAX, check if the PAX line is plugged up.</td>
</tr>
<tr>
<td>Increase your PAX addition rate to the roughers.</td>
<td>Along with the Dow froth increase, PAX will help reduce the big bubbles back to a normal and optimum size bubble.</td>
</tr>
<tr>
<td>Increase your PAX addition rate to the scavengers...</td>
<td>The reason why the scavenger froth does not collect anything may be caused by insufficient PAX levels to the scavengers. By increasing the PAX addition rate, more material will be collected and will appear in the froth.</td>
</tr>
<tr>
<td>Check rougher pulp levels do not need increasing.</td>
<td>This will remove the partial copper concentrate from the circuit and so reduce the risk of having this concentrate creating a circulating load rich in copper.</td>
</tr>
<tr>
<td>Increase the scavenger cell levels temporarily to off-load the circuit.</td>
<td>To bring back a collapsed froth bed to life necessitates too much reagents. First, get rid of the collapsed froth bed by raising the cell levels. Then, making the recommended reagent changes should bring back an optimum froth. However, one should bear in mind that raising the cell levels is a TEMPORARY measure and that cell levels should be lowered once better froth conditions have been reached.</td>
</tr>
<tr>
<td>Check if rougher cell levels do not need lowering.</td>
<td>The scavenger froth is flowing over the lip steadily. Try to decrease the froth bed a little bit and see if you can build a deeper froth bed that will still be running over the lip but that will be less tight, closer to the optimum froth conditions.</td>
</tr>
<tr>
<td>Check if the rougher and scavenger cell levels do not need lowering.</td>
<td>The froth is flowing over the lip steadily. Try to decrease the froth bed a little bit by decreasing the cell level and see if you can build a deeper froth bed that will still be running over the froth lip but that will be less tight, closer to the optimum froth conditions.</td>
</tr>
<tr>
<td>Check the pulp density at the tailings and lower it if too high.</td>
<td>At higher densities, the agitator disperse less air, which decrease the recovery. The high densities cause the roughers to slow down to the point where no concentrate is pulled off.</td>
</tr>
<tr>
<td>Try lowering the pulp levels and adding frother to the roughers cells.</td>
<td>Lowering the pulp levels and increasing the frother addition rate to the rougher cells will help to build up a deeper froth bed.</td>
</tr>
<tr>
<td>Check if scavenger cell levels do not need lowering.</td>
<td>The scavenger froth is flowing over the lip steadily. Try to decrease the froth bed a little bit and see if you can build a deeper froth bed that will still be running over the lip but that will be less tight, closer to the optimum froth conditions.</td>
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<tr>
<td>Condition</td>
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<tr>
<td>If NaHS is being used, decrease NaHS addition rate.</td>
<td>Too much NaHS can depress copper minerals by making the collector (PAX) inactive, resulting in a foamy froth. Try to decrease the NaHS addition rate. If the tailings grade does not go up, then you know you made a good move.</td>
</tr>
<tr>
<td>If NaHS is being used, decrease PAX addition to the ball mill.</td>
<td>If NaHS is added to the scavenger cells, it will produce a foamy froth at the scavengers and there is nothing you can do for it. Too much PAX to the roughers may be responsible for the collapsed, tight froth. Decreasing the PAX should help to build up an optimum froth bed.</td>
</tr>
<tr>
<td>I would however suggest that you do a PAX test on one of the scavenger banks.</td>
<td>As we are always trying to get better recoveries, it is a good idea to do tests when conditions are stable and recoveries are high. By increasing the PAX on one of the scavenger banks, you will be able to see whether this increases recovery still further or simply indicates reagents are being wasted. Whatever you find out, you will have determined useful information from the test.</td>
</tr>
<tr>
<td>Check for a plugged reagent line to the ball mill or the rougher end.</td>
<td>No reagent, especially no collector or no frother will produce an empty froth. The copper minerals will not be collected in the absence of reagent and therefore, will not show up in the froth.</td>
</tr>
<tr>
<td>You may not be pulling the roughers hard enough.</td>
<td>The heavy build up of copper minerals in the scavenger cells would indicate that this copper is not being recovered in the rougher cells. Try to increase the PAX level at the roughers</td>
</tr>
<tr>
<td>Off-load the circuit by temporary raising the scavenger and rougher cell levels.</td>
<td>To bring back a collapsed froth bed to life necessitates too much reagents. First, get rid of the collapsed froth bed by raising the cell levels. Then, making the recommended reagent changes should bring back an optimum froth. However, one should bear in mind that raising the cell levels is a TEMPORARY measure and that cell levels should be lowered on better froth conditions have been reached.</td>
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