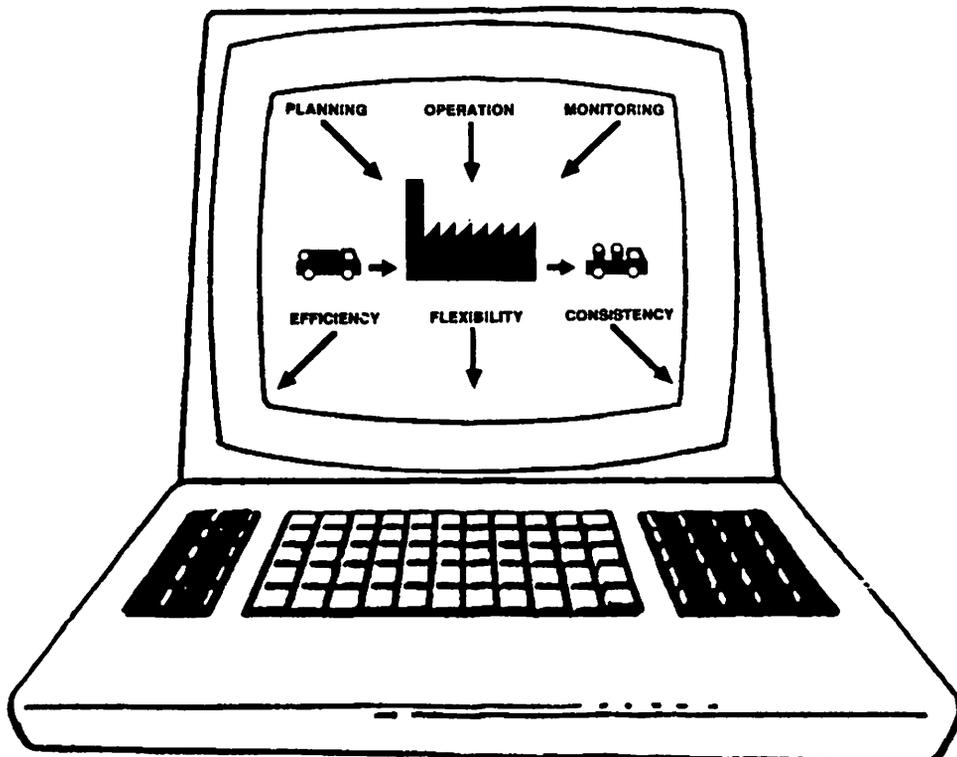


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EXPERT SYSTEM SUPERVISORY CONTROL OF THE WHEAL JANE TIN CONCENTRATOR

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An expert system designed to assist in the control of the Wheal Jane tin concentrator has been developed. The principal objective of the system is as a consultative tool to assist in trouble-shooting and quality control. The system is written in PROLOG and implemented on an IBM compatible PC. The structure of the system, its development and capabilities are discussed.

INTRODUCTION

At first sight, process control within the minerals industry would appear to be no different to that of any other industry, however in practice this is rarely the case. Comprehensive control systems for mineral processing plants have been commercially available for some years, but their installation is still far from widespread. The reason for this is partly financial. They are relatively expensive, particularly to the smaller plants. On top of this, the metals market has been depressed over recent years. This has limited new investments in the sector as a whole. Part of the reason for poor take up, however, is clearly because of technical difficulties (see Tucker (1)). Some important process variables are particularly difficult to measure on-line: for example particle size distributions, particle specific gravities and chemical assays of coarse particles. The technology for on-line assay measurement of slurries is available but its installation is still more the exception than the rule. On plants where it is installed, coverage is rarely sufficiently comprehensive to meet the metallurgical need. Usually the process is monitored by frequent manual sampling; the analysis of these samples subsequently being carried out off-line. The assay results must then be analysed by an experienced metallurgist before any control strategy can be developed and implemented. Consequently a time lag between sampling and control action is inevitable, and considerable pressure is then placed upon plant operators to

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quickly ensure that all is running well. In order to carry out their job effectively, the operators themselves need both in-depth knowledge and experience to understand the plant and how it behaves, for example considering the continual variations in process feed. The necessary skills take time to accumulate and knowledgeable operators are therefore valuable and hard to replace. In the absence of experienced operators, more demands are made on the plant metallurgists to provide control advice. A substantial fraction of the plant metallurgist's time can often be tied up in this one task alone. Any financially feasible technique to help automate the control action would almost certainly relieve pressures on plant personnel, at all levels.

Carnon Consolidated Ltd recognised the above problem at their Wheal Jane tin processing plant in Cornwall, UK. An answer was needed. The routine analysis comprised three main tasks: sample collection and preparation, assay and finally data processing. The sampling and assay procedures could not be improved without considerable financial investment. There was, however, a possibility of streamlining the data processing. This task was being carried out by a plant metallurgist who applied his skill and knowledge to evaluate all the assay data to identify and locate possible problems in the circuit. His way of thinking already proceeded along IF-THEN-ELSE lines and he was confident that all the domain knowledge could be structured in terms of such production rules. On the face of it, it was an ideal application for an expert system.

The principal objective of the system was to provide a consultative tool (i) for trouble-shooting and quality control when a specialist metallurgist was not available or (ii) as an assistant to the specialist to speed up analysis time. The system was designed jointly by Wheal Jane and Warren Spring Laboratory (WSL). The work led on from previous expert system development, by WSL, of trouble-shooting systems for mineral processing plant (Tucker and Lewis (2)).

THE PROBLEM

The Wheal Jane circuit is sampled and assayed, for monitoring purposes, three times per eight hour shift. The plant currently processes two very different tin ores: Wheal Jane and South Crofty. When Wheal Jane is processed fourteen samples are manually taken. When South Crofty is processed there are ten samples. In addition, once every shift, regardless of ore type, one further sample is also taken.

The samples are assayed (off line) by XRF for eight elements: tin, zinc, copper, sulphur, arsenic, calcium, tungsten and iron. These assays must then be scrutinised both individually and collectively to ensure that the circuit is operating to specification. Process knowledge and experience is applied to the data in the form of logical rules. These rules express relationships between different mineral assays at

different sample points and possible problems with the circuit.
For example:

```
IF      high grade concentrate <= 54% tin
AND     high grade concentrate > 0.15% arsenic
THEN    high grade concentrate is low due to sulphide
        contamination.
ACTION  Check tin dressing circuit for pH, reagent additions,
        feed density, pulp levels....
```

A different set of rules are administered to each of the two ores.

In addition to the individual study of each sampling round's assays, it is also necessary to compare the current set of assays with those of previous rounds. This is to ensure early detection of general, but possibly slow, deterioration in circuit performance. This is achieved by applying additional sets of rules to the two data sets.

THE SOLUTION

An expert system has been designed and developed which has much of this specialised knowledge stored as production rules. The knowledge engineering was carried out by the experts themselves, ie. the Wheal Jane metallurgists. They gathered approximately 150 rules, and associated control actions, for the Wheal Jane ore and approximately seventy for South Crofty ore. There are much fewer rules for South Crofty as the mineral processing of that ore is less complicated. Formulation of the logical rules was relatively simple as the knowledge was naturally expressed in the appropriate manner. The compilation, however, proved quite time consuming - though the discipline of doing it was beneficial in its own respect. The available rules ranged from hard fact supported by scientific evidence, through empirical rules (such as those generated via curve fitting of historical data) to local heuristical knowledge.

The system, as mentioned above, was targeted towards the plant operators as well as to the metallurgical staff. After its full validation, the system will be installed in the plant control room where it can be accessed readily by the operators.

The problem employs goal-driven reasoning and has been written in PROLOG. It has been implemented on an IBM PC running under the DOS operating system.

System Design

The expert system has two modes of operation. The first, mode 1, evaluates assay data from a single monitoring round. The second, mode 2, allows two sequential sets of assay data to

be compared. The system structure for both modes is shown in Figure 1a and 1b.

Considerable importance has been placed upon the user interface. It is unlikely that the system users would have had much experience in the use of computers and so it was thought essential that the system should be simple to use. The expert system has been designed to automatically identify which of the two ores are being processed and whether or not the current sampling round has included the extra sample. Keyboard input from the user is kept to a minimum. Additional information relating to circuit operation, is only requested if the inference engine requires this data in order to reach a decision.

Data input to the system for both modes is achieved via ascii data files generated directly by the computer coupled to the XRF spectrometer. Once data has been entered into the expert system, it is displayed in a colour tabular format. Although each sample is assayed for all eight elements, not all of these assays carry the same importance with respect to the different samples. The system highlights the more important assays such that they can be easily identified. Other important values, such as the circuit recoveries, are calculated directly by the software and are also displayed on the initial screen. A typical screen is illustrated in figure 2. If mode 2 is in operation both of the two data files may be displayed in this manner.

Using the knowledge base, the PROLOG inference engine proceeds to identify any circuit errors or inefficiencies. Each production rule is tested sequentially. Once an assay has been found to be "in error", that is outside of the acceptable range the inference engine seeks to identify the cause. In many cases the cause can be determined by other assay values:

```
IF      column concentrate < 37% tin
THEN    FACT - column concentrate is TOO LOW.
IF      column concentrate > 4% sulphur
THEN    CAUSE - due to excessive sulphides.
```

However, sometimes the fault cannot be attributed to a cause without further information about the circuit, unrelated to assay data. In cases such as this the operator is asked to input the necessary data via the keyboard:

```
IF      mill feed > 5% zinc
THEN    FACT - zinc in mill feed is TOO HIGH.
Question:- What is the mill feed throughput in tonnes per hour ?
          <USER INPUT>

IF      tonnage > 14 tph
THEN    mill feed tonnage is TOO HIGH
ACTION  reduce tonnage to less than 14 tph.
ELSE    no action.
```

Occasionally, a unit process may be identified as performing inefficiently but its poor performance cannot be attributed to

any specific cause without visual information. When this happens "Control Actions" are issued to the operator as guide lines on what he should look for and what remedial actions are required:

```
IF      high grade concentrate > 1.1% WO3
THEN    WO3 content of high grade concentrate is TOO HIGH
ACTION  CHECK Wet High Intensity Magnetic separator for:
        1.. Feed screen blockage
        2.. feed pipe wrongly positioned
        3.. wash water addition incorrect
        4.. magnet setting incorrect
```

Once this analysis is complete, if using mode 1, the operator has the choice of report formats; either a screen summary or a full text report. For mode 2 only the full text report is available.

The screen summary has been designed to show the current (disregarding the time lag) plant status at a glance. The assay data is once again displayed in the same format as before but this time only the assays found to be in error are highlighted. Those assays found to be excessively high are shown in flashing red against a white background. Those marginally high are displayed in a stable red. Similarly, those found to be excessively low are shown in flashing blue and those marginally low are in a stable blue colour. Some faults can only be accurately described as "in error" and not necessarily high or low, such as recoveries greater than 100% or obvious assay errors. In these cases, the suspect data is highlighted in green.

The screen summary can not be regarded as a complete picture of what is happening. Some errors can not be displayed in this way. Neither can the probable causes and cures of any identified faults. The full text report option gives a full description of the fault, its probable cause and more importantly how the plant operator can correct it. Paper copies of this report can also be obtained if a permanent record is required.

CONCLUSION

Within the minerals industry, where sensor availability and technical feasibility can often be major hurdles to installing full on-line control, expert systems can play an important role in minimising the time delay between off-line fault diagnosis and the implementation of control action. They can effectively capture much of the knowledge of skilled personnel and so provide "expert" assistance to non-specialised plant operators.

The system described in this paper is currently undergoing validation trials at Wheal Jane. Even at the early stages of these trials, the system has registered successes in picking up circuit faults which the experienced metallurgists have themselves overlooked.

ACKNOWLEDGMENTS

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References

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