HOW TO INCREASE PLANT PERFORMANCE WITH ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS

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Abstract

Expert control of grinding and flotation plants has been successfully used in the minerals industry since the 1970's. The earliest of these systems were written in a hard-coded fashion in FORTRAN, BASIC or Pascal. Second generation systems were built using the first experimental expert system shells that were being developed in the artificial intelligence community. Later systems were deployed in expert system shells designed for real-time processing plants that also included the ability to model the process with neural network models and optimize setpoint selection through the use of genetic algorithms

Significant performance increases have been achieved using these systems, but in general, they suffer from the static nature of their rules and to a degree the process models also. Typical improvements quoted in the literature suggest throughput rate increases of 4 to 8 percent and recovery increases of 1 to 4 percentage points. In over 30 years of designing and installing expert systems we have never seen performance numbers less that these but have often seen numbers in excess of the high values.

However, once the system has been installed and tuned up the performance usually does not improve much thereafter. Granted, the initial increases in throughput rate and recovery are significant but a question always lingers, that is, can the expert strategies be modified further to squeeze a little more improvement out of the system.

The answer to this question is a resounding yes, however a complete understanding of what we do well as designers and operators of expert control systems is required as well as how we can improve upon our best practices is required to move us from the performance plateau we have been on for a number of years to a new higher level of performance.

Why the Performance Plateau?

Regardless of how many improvements and positive changes we see in the world of minerals processing there remains several constants that have contributed significantly to the performance plateau. The list includes:

1. Personnel limitations that include
    - Educational,
    - Experience, and
    - Mobility
2. Static Rules and models,
3. A performance analysis and improvement process that is flawed,
4. Lack of continued management focus and priority, and
5. Lack of corporate coordinating direction.

How the next Plateau will be found?

By in large, our expert systems are more static than they are adaptive. Static rules, taking into account basic and fundamental relationships of grinding and flotation have proven themselves time and time again to be capable of significantly improving average plant performance. However, mineral processing unit operations are generally thought of as being nonlinear and complex. Nonlinear in this context means that the future state of the plant is dependent upon the current state. So if Sag mill bearing pressure is at 600 and the feed rate is increased 50 TPH the dynamic response will be very different than the response if the bearing pressure had been at 700. The concept of *complex* means that once a series of system changes are made reversing those changes does not return you to the same place you originally started from. Clearly this phenomenon, while not understood by many, contributes to the difficulty of controlling and optimizing our typical flow sheets as well as contributing to the performance plateau we're currently on.

The simple answer to overcome our static systems is to data mine the incredible amount of data produced daily by our existing expert systems. Data mining refers to extracting or mining *knowledge* from large amounts of data. The objective is to automatically analyze the data, classify it, and summarize it to discover and characterize trends in it and to automatically flag anomalies.

Clearly, modern process control systems used in the minerals industry both produce and can collect vast amounts of data on a second-by-second basis. Without a doubt, these data contain important information on the operation of our plants and their ultimate optimization. However, analyzing the data continuously, on-line and in real-time, is something that just hasn't happened in a significant way to date. Coupling the information mined from these data with Expert Control Systems will produce more effective control and greater knowledge of the grinding process and the flotation process.

These new methods of systematically taking advantage of the tremendous amount of data produced by the expert system to improve the design, the heuristic rules, the model topologies and the use of the models is at the heart of improving our expert systems.

Introduction to Data Mining

Data mining is all about extracting useful business information from large databases. The key word here is "large." If the database was small discovery technologies is not really needed. In large databases, such as those we can create in minerals plants tools are absolutely needed to discover and extract patterns and relationships that can be exploited to improve plant performance and profitability. In effect we are seeking to gain knowledge from data. This knowledge discovery can be represented as a process as is shown in Figure 1.

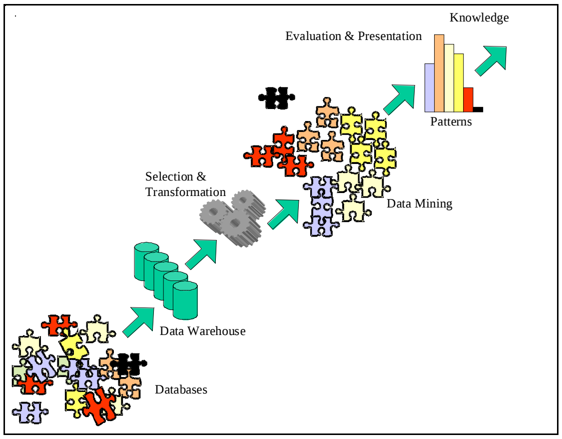

Figure 1. Data Mining is but one step in the process of knowledge discovery.

The steps and processes include:

1) Data cleaning - removing noise, inconsistent data, outliers
2) Data integration - combine data from multiple sources in a time-unifying manner
3) Data transformation – changing according to rules that unify the data or make it suitable for data mining operations
4) Data mining – the process of applying intelligent methods to the data to extract meaningful data patterns
5) Pattern evaluation – sorting through the discovered patterns to identify those that represent knowledge of the underlying processes
6) Knowledge presentation – visualization processes to present the mined knowledge to the user

Simply put, data mining is the mechanized process of identifying or discovering useful structure in data. The objective being the knowledge discovery associated with the process of analyzing large collections of process data, cleaning and filtering the data, organizing the data and then statistically analyzing it to reveal and explore any deep and potentially profitable relationships that were not previously identified or understood.

Data Mining A Sag Mill Circuit

The writer and philosopher, George Santayana, said, “Those who cannot remember the past are condemned to repeat it.” Another axiom that is subtly relevant is “If you don’t measure it, you can’t improve it.” What makes both of these statements interesting is that, to a degree, we measure everything but don’t necessarily improve anything. This seems to be a pretty good description of what goes on in a grinding circuit since throughput rate goes up and goes down as does all the other process variables but what is lacking in general is the definitive relationship between all of process variables and how we can use this information to maximize plant performance.

Universal Question

The following universal question is the question that drives all set point changes in minerals plants regardless of the technologies being used to determine new set points.

> *Given the current physical and mechanical state of the grinding mill, the current process state of the mill, the current feed conditions what set point changes can I make to the independent process variables that will improve my performance five minutes from now?*

The first need in answering this question is to define what the definition of performance is. It is this question that expert rules and predictive models are used to answer. Clearly, because of the well documented improvements achieved by expert systems this universal question is being answered to some degree. As already stated the question is really how effective the answers are and whether or not additional improvements are possible.

Discovery vs. Prediction

Data mining is a process that has at least two aims. They are:

1) *Discovery – tell me something I don’t already know, and*
2) *Prediction – the use of a discovery to predict the future*

Over the years the mathematics of statistical analysis has been applied to the masses of data that have been collected from grinding plants. These analyses have included linear and non-linear step-wise regression, auto-regressive moving averages (ARMA), analysis of variance etc., and correlation analysis in many different forms.

Those who have attempted to, or performed these analysis know how time consuming and difficult the task is. The question of “what is the difference between statistical analysis and data mining” is a good one. The answer is that data mining is statistical analysis that is highly automated and rigorously applied to all available data in a completely exhaustively manner. Additionally, the algorithms used in the statistical analysis are very different and improved from just a few years ago.

Some of the newer components of data mining, as they apply to real-time expert control include:

1) Cluster Analysis
2) Random Forest
3) Support Vector Machine
4) Boosted Decision Trees

To a large degree each of these methodologies are designed to classify data into categories. From a process control standpoint the most basic concept is to understand or dissect the state of our systems into very narrow limits where we then can apply very finely tuned control rules. The axiom here is that one size doesn’t fit all or one rule does not fit all conditions. Ultimately the reason this will produce improved performance over today’s generation of rule-based expert systems is the non-linear and complex nature of our processes.

In grinding, this formal or informal clustering is already present all the time. Plant performance is discussed in terms of 1) ore type, 2) mineralogy, 3) liner life etc. By formalizing the processing of clustering performance in the context of objectives and plant conditions then it may be possible to increase understanding and performance.

Two elements of clustering, then, are 1) discovery of what the clusters are and how they differ from common wisdom and 2) how control within each cluster space can be improved. It is easy to understand that better process models, which is another way of saying better process understanding, can be developed from data sets that are not corrupted by data that belong to another set of conditions or clusters. Ultimately the desire is to be able to cluster objects together where each cluster can be modeled effectively and independently from the other clusters.

Rule Induction

One of the greatest improvements that data mining might bring to expert control is in the area of rule induction. Presently, expert systems typically have several hundred rules that are normally designed to assess the current state of the mill and make set point changes to improve performance in the near term. These rules are often talked about as being heuristic rules, or rules of thumb that have been developed by knowledgeable and experienced people over a long period of time.

What is important to note is that there is little evolution of these rules in the average expert system once the original installation is complete.

A simple example of a typical heuristic rule might be:

> *If the mill bearing pressure has been rising slowly and now is above 800 and the mill power has been decreasing and is now below 2700 then increase the water addition a little and decrease the throughput rate a little*.

Buried in the historical database collected by the expert system is untold numbers of these conditions and actions. Rule induction might be able to discover the supporting data for this rule in terms of:

> *When the throughput rate is decreased a little and the feed water is reduced a little when the mill bearing pressure has been increasing a little and was over 800 and the mill power had been decreasing a little and was below 2700 the mill throughput rate was 2 percent higher a hour later.*

This simple example is actually very complex but it is a good example of the type of knowledge that may be lie hidden in the database.

Empowering and Facilitating Technologies

What may not be intuitive is the vast amount of computing power that must be used to continually analyze the terabytes of data that are available from each expert system. Parallel processing of one form or another will be needed to effectively advance our expert systems from where they are today to where they can be by applying the new technologies introduced here. The newest “cloud” computing methodologies being developed and experimented with will likely be one the enabling technologies needed to provide unlimited computing power at an incremental cost that is economical.

Conclusions

Because of the vast amounts of data produced by expert control systems and the fact that they are somewhat static once they are defined, installed and started-up tightly integrated data mining of the data produced will likely be one of the next advancements explored within our industry. Just as expert control promised improved grinding and flotation performance twenty years ago tightly integrated and focused data mining enhancements to present expert system technologies promise further improvements in the years to come.