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Knowledge in —Money out, redefining mine planning and scheduling standards to improve and stabilize business performance

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Mining professionals recognize the need to continuously evaluate and refine mine planning standards and scheduling. We must examine our current reality, and evaluate the following:

- How well do our planning standards represent the actual mining process?
- To what extent do they support the requirements of the downstream mining activities?
- How we apply them to operational management and control?

In most operations, mine-planning standards are global averages. Little differentiation is made in quantifying key planning variables. Often standards used in the long-term, are applied to the short-term, and the standards and scheduling precedents are only reviewed occasionally. Mine-planning standards applied to production schedules are often only focused on the management of functional mining performance, and play no role in managing the requirements of down stream processing.

Many mining operations are characterized by high levels of fluctuation, and typically incorporate a wide range of factors and adjustments to compensate for deviations from performance targets, in mining operations as well as for the other business areas. *The reason for using global averages is because of a lack of understanding of the causes of deviations that occur through the process, and the impact that they may have on the performance of the business as a whole.*

Average standards and factors are often used to quantify the variability in a system. From these average values, measurement standards and performance targets are derived for the planning and execution environments. During the execution of a plan/schedule there will be deviation in actual performance and the planned 'average' standards. In reality the 'average' conditions seldom occur and the impact of variability and interdependency are seldom constant or predictable. The predictability of variability and interdependency is further complicated by the fact that mining conditions have a role to play in the actual production performance, and they too are variable.

By developing the throughput knowledge of our production systems, we can better understand the nature of variability and the interdependency within the systems as well as the impact of interdependency between the links in our production chains. With this knowledge, planning standards and scheduling precedents can be better defined and sensibly differentiated. This will improve planning and management of ore utilization, mining production and the effectiveness of processing. As a result the business will be more stable and predictable and business performance will be improved.

The purpose of this paper is to describe:

- At a high level, the scope for refining and differentiation in mine planning standards, and incorporating geological and plant parameters into mine scheduling. This will improve planning and scheduling and the overall performance of the mine. Given our current level of scientific knowledge and the technological tools at our disposal we should be able to plan and schedule production so that we can manage pro-actively and improve business performance. In doing so we can also improve reconciliation and value tracking through mining and processing
- The flexibility and functionality of the XPAC planning and scheduling tool that will enable a throughput management approach.

Introduction

Advances in computers, software and new theoretical insights have generated a significant potential increase in a manager's ability to use scientific techniques to plan and manage. Scientific operations tools, planning tools, scheduling tools, linear programming and management approaches should be the key to making improvements in productivity and effectiveness. The 'current reality' within the mining industry is that very advanced applications are used in orebody modelling, geostatistics, mine planning and scheduling, process control for beneficiation etc. As the frequency and reliability of geological information, and the level of detail in terms of optimization in mine schedules increases, it should be getting easier for mining operations to reach their production targets and continuously improve. How much improvement is made on an annual basis is questionable, but it can be said with certainty that mines still deviate from their targets, destroy value and have scope to improve. This paper attempts to address the need for redefining mine planning and scheduling standards so as to assist in improving and stabilizing business performance.

The effectiveness of mine scheduling will influence the long-and short-term performance of a mine. The planning and scheduling must ensure that:

- Sufficient ore is available to be mined
- Ore of the correct quality is available
- Waste is removed so that ore can be accessed in the future.

Being able to ensure that ore is available is not sufficient. There is significant scope to destroy value through the process, and planning and scheduling need to take this into account. For mining to ensure that schedules optimize the run-of-mine (ROM) blend to suit the requirements of processing, mining must ensure that:

- The quality of the ROM blend is consistent.
- The quality of the ROM blend is such that it is aligned to the requirements of plant processing.
- All economically mineable ore is utilized.

To achieve this, mine planning must incorporate throughput variables and plant constraints into their schedules. This requires that geology, mining and the plant collaborate to develop their site-specific throughput logic, as a basis for devising planning standards and scheduling precedents. This will ensure, *ceteris paribus*, that ore utilization and product production is increased.

The current reality

Before we examine how the mining function determines standards and precedences to account for production rate and ROM quality it is necessary to review the stability of the mining process. The mining process is characterized by fluctuation in production rate of ROM and the quality and quantity of the final product. The three primary reasons for these fluctuations are:

- Interdependency which exists between the links/resources of the physical chain or processes and its impact on production rate
- The variability that exists in the system, typically in terms of production rate, the characteristics of the raw material and the impact of the variability on processing
- Non-physical elements such as assumptions and policies, which are implicitly incorporated into the measurements and targets. The measurements and targets that cause certain human behaviours that will also impact the process (which are not discussed in this paper).

The mine planning standards and precedences that are utilized in the scheduling process are simply a quantification of the relationships between interdependent resources (production rate) and the impact of variability (in the raw material) on final product, cost and ROM production rate.

Planning and scheduling

To make sure that:

- Sufficient ore is available to be mined
- Ore of the correct quality is available
- Waste is removed so that ore can be accessed in the future.

...the mine planner will design a layout to access the ore, and the mine scheduler will schedule the loading, hauling and processing of the 'ore' into product using the physical resources (drills, trucks, conveyors, crushers, flotation cells, etc.) that are available. In broad terms this is achieved by using planning standards that quantify the capacity of the resources and the ROM production rate.

Typical planning and scheduling standards are driven by 'Global Averages' and resemble the following for a mine, shaft, etc.:

- Planned mining dilution = 9%
- Planned fines loss = 5%
- Mining production rate = 3000 tons ROM per month
- Tyre consumption = 4 tyres/1000 hours.

The approach of applying these average standards may be considered adequate by some for the long-term planning environment but can't be applied to the short-term production environment. Often the standards used in the long-term environment are factored for reconciliation purposes and may change from time to time. This process is often done subjectively, and lacks logic and transparency. This approach to setting standards is not detailed, accurate or specific enough to align the long-term strategic environment to the operational environment, nor is it suitable for:

- Short-term planning
- Setting of production targets
- Management and control
- Performance measurement.
- Scenario evaluation and to quantify the effect of deviations in plan on the product, income and cost
- Predict the total product, cost, revenue
- Reconciliation and value/material tracking.

Linking the up and downstream processes

There is significant scope to destroy value during beneficiation. Not only must mining ensure that ore is available for processing but that the characteristics of the ore are consistent (as far as possible) and that the ROM blend are aligned to the processing constraints. To increase ore utilization and product production, precedents that enable the following must be incorporated into scheduling:

- Reduce the variability in the ROM blend/feed to the plant
- Manage the quality of the ROM blend such that it is aligned to the requirements of plant processing
- Not waste economically mineable ore.

Limitations

The limitations of current mine planning and scheduling approaches are:

- 'Global averages' are used to quantify key production variables
- There is little scope given to scheduling of income or product tons
- The preferred scheduling target is ROM tons
- The ROM tons target may be independent of ore type
- There is seldom a sensible recovery/yield model built into the mine scheduling tool.

Using average standards

What is the outcome if a planning standard of 3000 tons per month is applied to two sections, where similar equipment is used and the cycle times are the same, but the physical operating conditions are different? Assume one section is characterized by difficult mining conditions (steep dips, thin reef, etc.) and the other characterized by easy mining conditions (flat lying, stable roof, etc.). If a planning standard of 3000 tons per month is applied to both sections, the 'easy mining conditions' section will appear to perform well and the 'difficult mining conditions' section will appear to underperform.

The problem associated with applying average planning standards are firstly that the 'easy' section may not actually be reaching its potential (which may be 3500 tons ROM per month) and the 'difficult' section may be actually performing to its potential. This makes it difficult to manage according to 'real' potential. Secondly if only 'difficult sections', are scheduled for a particular period, then the risk of not reaching the production target is increased.

Differentiation in planning standards must be made according to the influence of ore morphology and orebody morphology on production performance, to make the standards more realistic. This requires knowledge of the geology and input from the geologist. How do variable qualities and quantities of dilution impact processing? This requires knowledge of the geology, and input from the metallurgist.

Average standards do not take the physical and process variability and conditions into account, which may be unique for each mining section. Processing and cost variables must be differentiated and quantified according to conditions. These are:

- Geological conditions
- Mining conditions
- Stockpile reactions
- Variability in the physical and chemical characteristics of the ore
- Plant constraints and process conditions
- Market cycles
- The influence that variables have on each other (dependencies).

The future reality

What is 'optimized' by a typical mine schedule? It should be the value of the final product. Often it is the ROM tons, the utilization of equipment, operational cost, exploitation of a particular ore type, linear advance, tons of metal concentrate, etc. These performance targets normally have very little relationship with optimizing ore utilization and maximizing the final product value. This requires mine schedules to include information pertaining to planned product and its value, production cost and ore utilization.

Developing the knowledge

The process to derive production standards and precedence's (as well as reconciliation, value tracking and predicting the final product) is driven by assumptions, factors and average standards, which are applied to planning and scheduling (and in management and control). The assumptions, factors and average standards are normally invalid and do not reflect the impact of variability of the resource on final product, production rate, processing effectiveness, etc. A change is needed. Looking at the business as a whole can only cause the change. The sources of variability and their impact on the business need to be identified and quantified. This requires the development of the specific throughput knowledge at each mine.

The development of the knowledge will focus on three key areas, namely:

- Physical operating conditions
- Throughput ore classification and plant recovery model
- Plant constraints.

Operating conditions

Mine planning standards need to account for the impact of variability that ore morphology and orebody morphology have on mining and plant performance (Perks *et al.*, 1994). Differentiation needs to account for variability in dip of seam/reef, roof conditions, depth, ground conditions, rock hardness, seam height (and condition of equipment, level of operator skill) etc.

This is depicted by a simple example in Figure 1, (Laurens and Arnesen, 2000) which shows an example of a classification index, based on depth and dip of an orebody. Into each 'index', from numbers 1–15, a planning standard can be assigned to the necessary throughput variables depending on how they influence the physical conditions and mining performance. These are referred to as condition driven standards (CDS) (Arnesen, 2000). This type of differentiation is a departure from the norm of using averages.

Typical production variables that are quantified to each index of the classification include:

- Production rate
- Mining dilution percentage
- Equipment and system availability and utilization
- Planned maintenance schedules according to index code (breakdown maintenance forecast)
- Mining extraction percentage
- Logistics cycle time
- Plant efficiency—linked to mining dilution levels and ROM quality
- Cost variables are awarded to each method
- Mining variable cost—detailed breakdown of all costs
- Maintenance variable cost—detailed breakdown of all costs
- Plant variable cost for different ore types and dilution.

This classification system is the tool to develop understanding, focus and manage the production rate, the ROM blend, production cost, people and equipment performance on a more realistic basis.

Ore classification

Typically, ore is classified according to its mineralogical

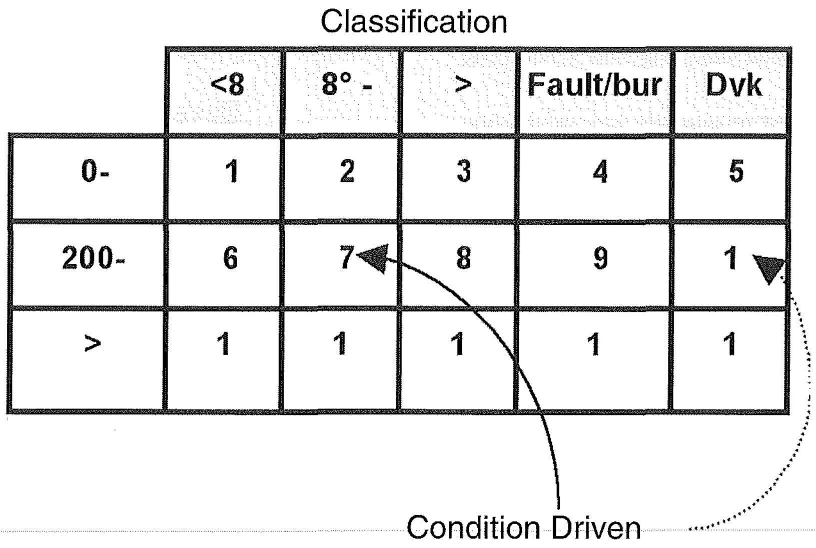

Figure 1. Example of a classification index, based on depth and dip of an orebody (after Perks *et al.*, 1994)

and chemical, and to a lesser extent, its physical characteristics by the geologist. An ore classification should take into account the variability in ore morphology and its impact on mining and processing parameters. Criteria that need to be included into an ore classification include mining parameters, such as the types and levels of dilution, detrimental minerals, hardness, etc., and their impact on processing. This information must be incorporated into a throughput ore classification system.

For example, a lithology with 4% *in situ* zinc, that is fine grained and displays a high level of mineral intergrowth may not have the same liberation potential as a carbonate rock with 4% *in situ* zinc, that is coarse grained and displays a low level of mineral intergrowth. Chemically (and in the mind of the geologist) they may be identical but their product potential is not. Furthermore, *in situ* cut off grades should take beneficiation potential into account, but that is outside of the scope of this text.

The knowledge needs to be developed of the different ore types and their blends to ensure that mixing of different ore types is done on a 'compatibility basis', to maximize processing effectiveness. This will make it possible for the ROM from the different areas to be planned and scheduled accordingly so the characteristics of the plant feed will match the processing design parameters. If we consider the variability in the resource and the limitations of the mine layout this can not be achieved all the time. However, focusing on aligning the plant feed to processing will result in an increase of the raw material utilization and the product production/recovery/yield.

Design of plant recovery models

Typically, average recovery factors are used to predict recovery and the final product. A significant fluctuation in throughput variables will impact on the plant performance and the final product value. Where there are significant fluctuations in throughput variables such as grain size, mineral intergrowth, type of mining dilution, percentage fines, fractional distribution, hardness, etc., an average recovery factor is not sufficient. Plant recovery models need to be incorporated into mine scheduling tools, that take the necessary variables into account.

Using the above logic described for Zn, a sensible model can be designed that will predict the final product for a given ROM (and the compatibility of the different ore types) that will improve the reliability of predictions. Experience has shown that to compile such a model is relatively simple since the variables that influence recovery/yield are known collectively by the metallurgist, mining engineer and geologist.

The physical and chemical properties of the raw material also change while in the production process. These changes need to be understood and accounted for, since they will impact on processing performance and throughput. Examples of mining throughput variables are fractional distributions, actual levels and types of dilution, grade of dilution, the generation of fines, etc. All of these variables may play a role in plant performance and at the same time be easy to incorporate into planning and management and control.

Design capacity and physical constraints

Production schedules need to take plant limitations and capacity constraints into account. The design capacity of the plant will have an influence on the amount of material that is scheduled per period. Different stages in a plant will have different constraints. For example the required/optimal feed rate into a crusher may be dependent on the silica percentage, and the capacity of a flotation cell on the *in situ* feed grade of the ore. For example, plant feed with a low silica percentage and low feed grade may be able to be fed though the beneficiation system at a high tempo, while high silica material with a high feed grade will be best crushed and processed at a low feed rate. The knowledge of the plant constraints needs to be developed and incorporated into schedules. Processing these two different ore types at an average feed tempo will destroy value.

The solution

To expose invalid assumptions, and dispose of the factors and average standards we have grown accustomed to using, we need to truly understand our mining processes. We must map out the production process from resource to point of sale. This must be done in a step by step manner in terms of a holistic throughput-driven approach. The outcome of this is a detailed cause-and-effect map that indicates the sources of variability in the different processes as well as the interdependency between them and the impact they have on the business' performance.

Mining need to compile the logic to describe condition-driven standards, which will differentiate the orebody in terms of a variation in production rate, production cost, impact of non-compatible material and dilution levels on the basis of the variability in the ore and orebody morphology.

Ore classification and the appropriate recovery models are essential so that scheduling can be executed using throughput targets to maximize the rate and value of flow into the selection of mining technique, equipment, mine plan and mine layout.

To develop sensible production standards and schedules, and to maximize throughput of the system as a whole, we must begin with a logical and holistic approach. The first step in this process is for the parties to develop a throughput business analysis, based on the guidelines mentioned.

Throughput drivers can be identified from a throughput business analysis. It cannot be assumed that these fields exist in a geological database or geological model. It is often the case that the important variables are not measured. Initially, the incorporation of these 'missing' throughput drivers into business processes may be difficult because there is little data to describe them. However, intuition and some basic test work are sufficient to achieve levels of accuracy that are useful. In time, with the correct focus the levels of accuracy of the information can be increased.

Application of technology

The process of translating the business logic into a planning and scheduling software application tool is always a challenge. Typically compromises have to me made to accommodate constraints of the chosen application, which are often at the expense of enabling functionality to manage short-term production requirements.

XPAC is an integrated mine planning system that allows the manipulation, analysis and scheduling of mineral resources in the way described by this paper. XPAC has been designed generically and can be configured to suit any type of mineral deposit and any mining method. Users are not forced to adjust their requirements to fit a rigid framework—instead the system is totally customize-able, providing unparalleled flexibility into which the following can be easily built:

- the design capacity of mining and plant
- plant recovery models according to different ore types and blends
- ore classifications relevant to maximizing final product
- differentiation of operating conditions and their impact on production and beneficiation.

The key enablers of this flexibility is the XPAC database (Figure 2) on top of which a very simple yet powerful scripting language can be used to analyse and manipulate all data in the database. This allows the resources data to be manipulated based on site the specific logic. Some of the principal features of the XPAC databases include:

- unlimited number of records, allowing any sized mine to be modelled
- all records are hierarchically organized and are represented by an Explorer-like tree structure so that you can easily gain access to the information
- data is automatically summarized at all hierarchical levels. This allows you to analyse the data at the most appropriate level of detail required
- each record can have an unlimited number of user definable fields (data values such as grades, tonnages, haul distance, costs, beneficiation and cost data, etc.,)
- fields are organized into groups representing the operations that must be performed on each record. A stope can be split into slot raising, drilling, blasting, loading and back fill, for example.

The scheduling system provided within XPAC allows you to generate production schedules that satisfy nominated tonnage and grade target (or any other) during each scheduling period, be it a year or a shift. XPAC supports both 2D and 3D graphics allowing the user to visualize data

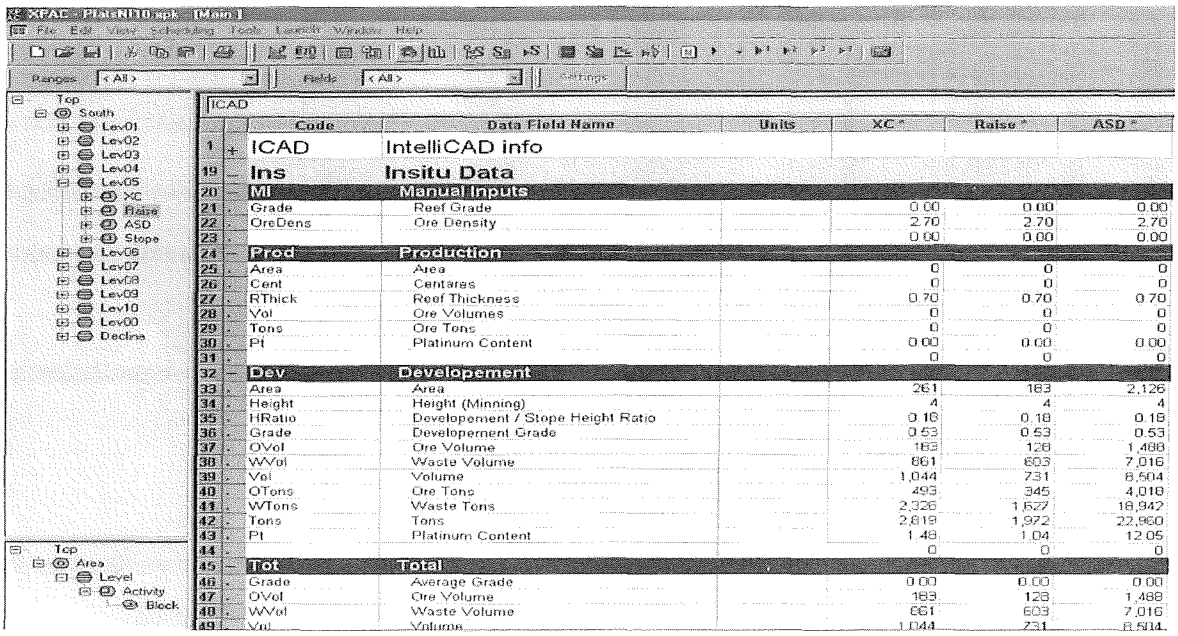

Figure 2. View of XPAC database

graphically (Figures 3 and 4). The calendar database is also used to store data that varies with time, such as targets and production constraints. There are three principal scheduling modes, target scheduling, equipment scheduling and auto scheduling. Together these modes provide a flexible suite of tools catering for the needs of long-medium-and short-term mine planning.

Target scheduling allows the user to nominate production targets for each mining area, activity, or equipment item being scheduled. By assigning a sequence of blocks to each item (using either a tree view or a graphical window), XPAC will allocate each block to a time period. Target scheduling is very simple to set up and is well suited to broad-brush scheduling as well as quick 'what-if' analysis. Quick 'what-if' analysis can be done easily in the short term as the geological or final product requirements are updated and new schedules are run.

The Auto scheduler takes a completely different approach to scheduling than the previous scheduling described. Instead of specifying the sequence of blocks that must be mined, you define the scheduling rules that must be followed, the constraints that must be honoured and the

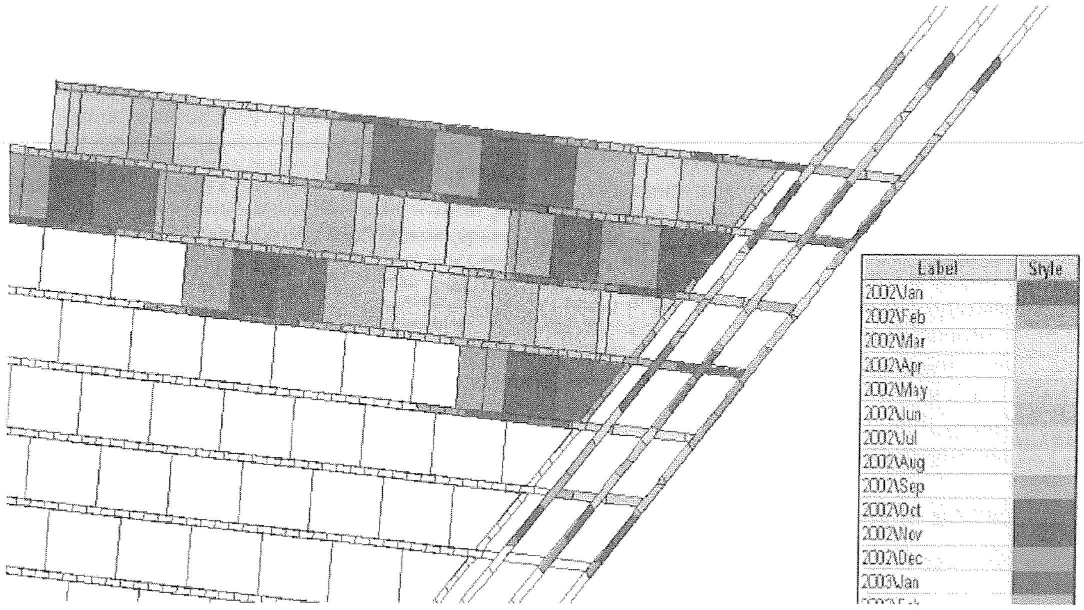

Figure 3. XPAC 2D graphics allowing the user to visualize data graphically. View of XPAC database

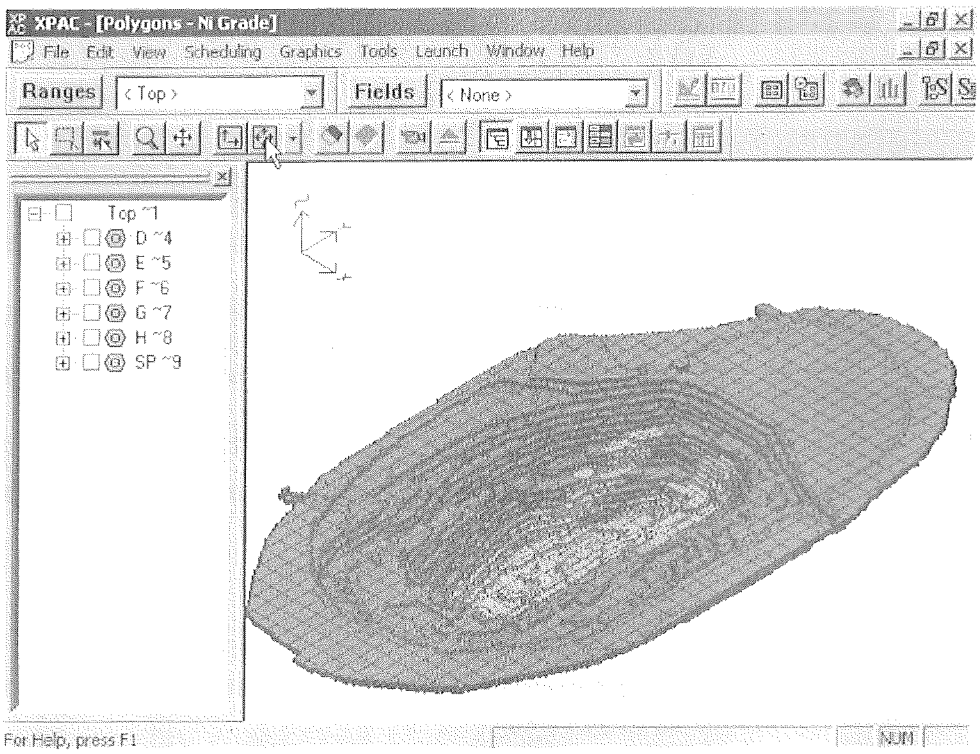

Figure 4. 3D graphics allowing the user to visualize data graphically. View of XPAC database

desired scheduling objectives (tonnage, grade and cost targets for example). The Auto scheduler then generates schedules that will best meet these objectives whilst satisfying all rules and constraints. The value of almost any database field can be maximized, minimized or targeted at a specific value. This can be applied to specific ore types, or beneficiation parameters, etc. The ability to control product quality means that the Auto scheduler is ideally suited to situations where blending or grade control is required to meet product specifications. The most significant advantage of the Auto scheduler's heuristic approach, compared with more traditional approaches such as Linear or Mixed Integer Programming is its speed. In medium-sized deposits with over 20,000 mining blocks, the traditional methods can take days to schedule a single period. The Auto scheduler can perform the same function within minutes. For long-and medium-term schedules, the targets, constraints and objectives can be pre-defined, leaving the Auto scheduler to generate Life-of-Mine Schedules at the click of a mouse. For shorter term scheduling where grade control is more critical, the Auto scheduler can be run from period to period, adjusting its parameters to fine tune the product qualities.

The XPAC system operates under Windows 98/NT and utilizes the latest C++ development environment to produce true 32 bit, multi-threaded Windows code supporting the latest Microsoft standards. It is not an old Unix or DOS programme converted to run in a windows environment. XPAC is also OLE compliant, allowing it to control and provide data to other Windows-based applications, such as Microsoft Excel and Project.

Conclusions

For mining to ensure that the schedule reflects the optimum ROM blend to maximize ore utilization and product production it is important to schedule the:

- Correct quantity of ROM to reach targets of the final product
- Ore is of the correct quality to achieve the required product
- Economically mineable ore is not wasted.

The site specific logic needs to be determined in order to evaluate where value is being destroyed. This will require mine planning to develop a recovery and grade model to predict the final product tons. To enable this, knowledge of the following must be developed:

- Physical operating conditions
- Throughput ore classification and plant recovery model
- Plant constraints.

Knowledge of how the operating conditions, ore classification and plant recovery are related will enable transparency and sharing of information such as:

- Mine planning can inform the plant of the ROM quality and quantity it can expect over a period, particularly with respect to process drivers
- Mining operations can report deviations against the mine plan to mine planning
- Processing can inform geology of deviations/fluctuations in quality, etc.
- Maintenance and mining sequence their schedules according to the throughput targets of the mine and the impact of deviations, variability, capacity constraints etc. (Laurens and Arnesen, 2001).

To enable the effective management of the resource the site specific logic needs to be captured into a planning and scheduling tool without compromising the business requirements. The XPAC software has been found to be highly effective in achieving this.

The challenges to a throughput-driven approach are the obstacles to unlocking this knowledge.

- Do the organizational structure and performance measurement criteria of different departments support the necessary collaboration?
- Do the structure and design of information systems support the necessary information?
- In a facilitation or workshop situation, are there geologists, engineers, metallurgists, etc., who have enough throughput business knowledge of the entire operation to ask the correct questions to lead the management/production team in compiling the necessary throughput logic?

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