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Application of a PC-based Network Analysis Program to Mine Scheduling

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Scheduling the extraction and rates of production for an underground mining operation is a common task carried out during the life of a mine, from the initial feasibility study through to the final production phase. The scheduling process can be complex when several requirements have to be satisfied, for example, match mill capacity and maximize net present value while constrained by mining sequence and availability of resources.

Many mines have computer programs relevant to their operation but because they are site-specific they need considerable reprogramming to be adapted to other operations. Other methods currently in use also suffer drawbacks: manual spreadsheets are laborious, computerized spreadsheets cannot handle sufficient constraints, and operations research techniques require a complex mathematical model to be set up.

The use of network analysis techniques has been proposed previously but the unavailability, until recently, of easily used computer programs has not allowed this approach to be developed. There are now many programs which can be used; however, the particular program which has been adapted to mine scheduling is Metier's 'Artemis-PC' running on IBM-XT or compatible machine.

The use of network analysis offers many advantages, including the use of a logical mining sequence; activities can be as detailed as required; related activities can be readily incorporated, and costs can be easily extracted. A heuristic approach is necessary to optimize the schedule, but the ease and speed of program execution enables this to be readily achieved, while leaving the mining engineer in full control.

The paper discusses the problems encountered in mine scheduling and current solutions. It then details the use of network analysis techniques and the application of the Artemis-PC program to solve mine scheduling problems.

Introduction

Scheduling the extraction and rates of production for an underground mining operation is a common task carried out during the life of a mine from the preliminary feasibility study through to the final production phase.

The starting point in such an exercise is a geological model of the ore deposit giving the tonnage and grade of each block contained in the in-situ reserve. The objective of the exercise is to attain a production rate at a grade which satisfies the mining company's requirements. This requirement may range from:

- matching mine output to mill capacity, to,
- maximize the return on investment.

The result of the exercise is a statement of tons and grade by time period which the mine is expected to produce, in order to obtain this the mining engineer must take cognizance of a variety of constraints which may be imposed. Some examples of typical constraints are given below, their order of importance depending upon the nature of the deposit, mining methods, the mine plan and capacity of ore handling systems.

- Produce from higher grade stopes first.
- Balance grades or mineralogical types for optimum metallurgical recovery.
- Timing of completion of major mine development such as a haulage access to a particular area of the mine.
- Mining sequence such as that imposed by the method employed, typically a requirement to complete one cut, stope or block before commencing that adjacent to, above or below it.
- The capacity of the mine's hoisting system.
- Availability of resources such as men and equipment; and in backfilled stopes, fill material.

From the foregoing it is seen that mine scheduling can be a complex task. Many methods have been tried to solve the problem of mine scheduling, and the following section refers to some of these methods.

Scheduling methods

The spreadsheet approach

Most mining engineers have at some time taken a piece of paper and worked out a schedule, using a calculator and their own expertise to obtain a solution. Such solutions are probably the best that can be obtained, but limitations are many:

- it is a laborious task, involving a lot of time and effort, and any changes in data or logic require considerable recalculation;
- only a few constraints can be applied, typically tonnage (output), grade and the logic inherent in the stoping sequencing.

In part some assistance is given by the use of computerized spreadsheets to ease the problem of manipulation of data and recalculation. Spreadsheet programs, such as 'Lotus 1-2-3', running on microcomputers are increasingly part of the mining engineer's working tools, their advantages being:

- ease of calculation, especially with changing data, and
- ability to incorporate some basic logic.

Much use can be made of this technique, particularly in the feasibility study stage of a mine. However as the number of constraints increases the problem becomes more complex and the spreadsheet approach becomes limited in its use.

Operations research techniques

Many engineers have adopted operations research techniques for mine scheduling.

Linear programming is one such technique which is normally utilized to solve the problem of how best to use limited resources. In linear programming, however, only one factor or objective can be optimized, and this objective must be expressed as a linear function. Limiting this objective function is a set of equalities or inequalities. In the case of mine scheduling, the result is a complex mathematical model with limited use because the correlation between simple linear assumptions and reality is poor.

Transportation theory has also been used, but it only allows for optimization of costs; it is also difficult to impose precedence relationships and as such it cannot fully simulate real activities.

In general, because mine scheduling is a dependent process with a specific activity sequence, operations research techniques become complex and solutions are difficult to obtain within reasonable time and effort.

Mine-specific and ober computerized methods

Many mines have devised their own computerized scheduling methods with much success. However, it is generally difficult to adopt these methods to other mining operations. The programs themselves are usually site specific, the documentation may be either poor or non-existent and the mining company may be reluctant to be drawn into the software business.

Several software packages have become available in recent years to solve the problem of mine scheduling, however in most cases they require at least a mini-computer and are relatively expensive.

Network analysis

The use of network analysis techniques to solve mine scheduling problems has been proposed previously, [1] but the unavailability, until recently, of easily used computer programs has not allowed this approach to be developed fully.

The advent of powerful microcomputers coupled with the development of appropriate programs has now enabled a scheduling method to be devised. The following section discusses the way in which network analysis can be applied to mine scheduling.

Network analysis applied to mine scheduling

Network analysis techniques are applied to mine scheduling in two ways.

The interdependence of one activity to another is known together with an estimate of the duration of the activities. This becomes the basis for scheduling and is best demonstrated by the following example. Figure 1 represents, in long section, blocks or stopes in a mine which require scheduling.

The mining sequence or logic is:

- A is mined first.
- B and C developed after A .
- B C and D can only be mined when A is mined and filled.
- D can only commence after a particular date.
- Each stope requires developing, drilling, stoping and filling.

Figure 2 shows how the above can be represented by a network. In order that a network can be analyzed (determine dates for the start and

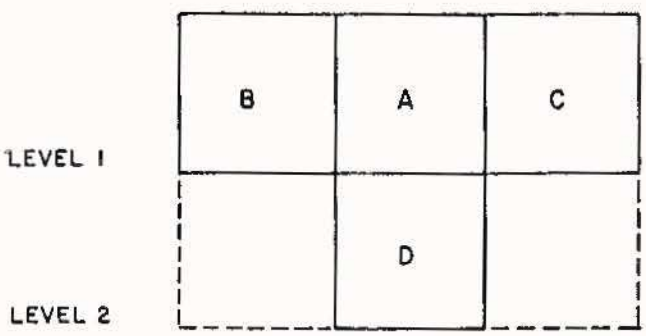

FIGURE 1. Long section showing location of stopes

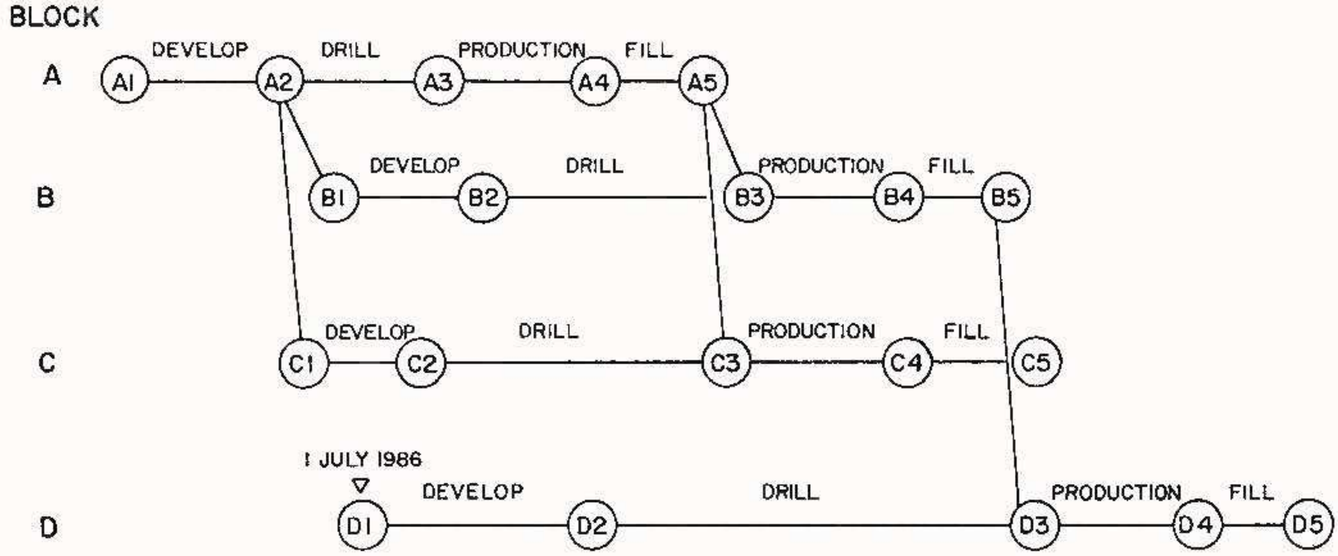

FIGURE 2. Network diagram of activities

completion of activities, calculate float etc.) durations have to be set for each activity. In the context of mine scheduling this is readily calculated by dividing the particular task, (meters to be developed, meters of drilling and stope tons) by the relevant rate (development advance, drilling rate and extraction rate).

After the time analysis, each activity has a start and finish date assigned to it. The results of the analysis are best shown in the form of a barchart, see Figure 3.

The primary usefullness of network analysis to mine scheduling, and the main concept of this paper, is in the treatment of mining parameters, such as tonnage and grade, as resources. This enables two powerful features of a network analysis program to be utilized, resource aggregation and resource leveling.

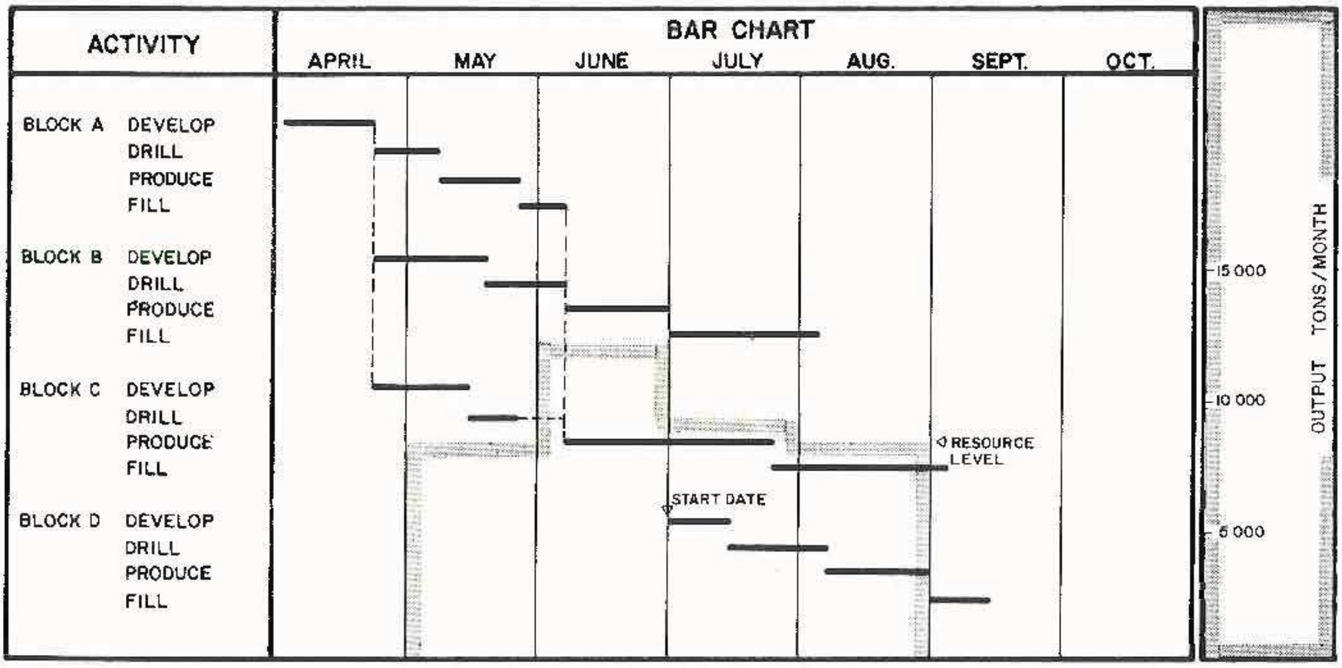

FIGURE 3. Barchart of activities with histogram of production

Aggregation

By aggregating the resources associated with each activity (scheduled in unit time such as days or shifts) it is possible to obtain the output for any period, whether weeks or years, while taking into account work patterns (regular days-off, holidays and vacation).

Leveling

By carring out resource leveling any activity in which the aggregated resources would exceed a set level means that ' specific activity is delayed.

Again these points are best demonstrated in an example. Taking the schedule generated previously and assuming a uniform stope extraction rate of 250 tons/day then the results of aggregation would be as in the output histogram shown superimposed on the barchart (Figure 3). Note that the aggregation is based on unit time such that production from stopes which cease in, say, mid-month is reflected in the aggregated total.

By then setting the total resources (tonnage) at say 10 000 tons/day the program is forced to delay an activity in order to level out the resource.

Where there is an option between activities, one of which must be delayed, then this choice can be programmed on one or more criteria such as:

- grade of stope (highest grade mined first);
- duration of activity (longest activity implemented first);
- amount of float (most critical activity first).

In the example shown in Figure 4, the production from block B has been delayed in favor of that from block C.

Another example of the use of setting resource levels is the case where backfill material is only available at a certain rate (possibly as a proportion of the mill input), then the availability of the resource (backfill) is set at that level. In the schedule the demand by the stopes

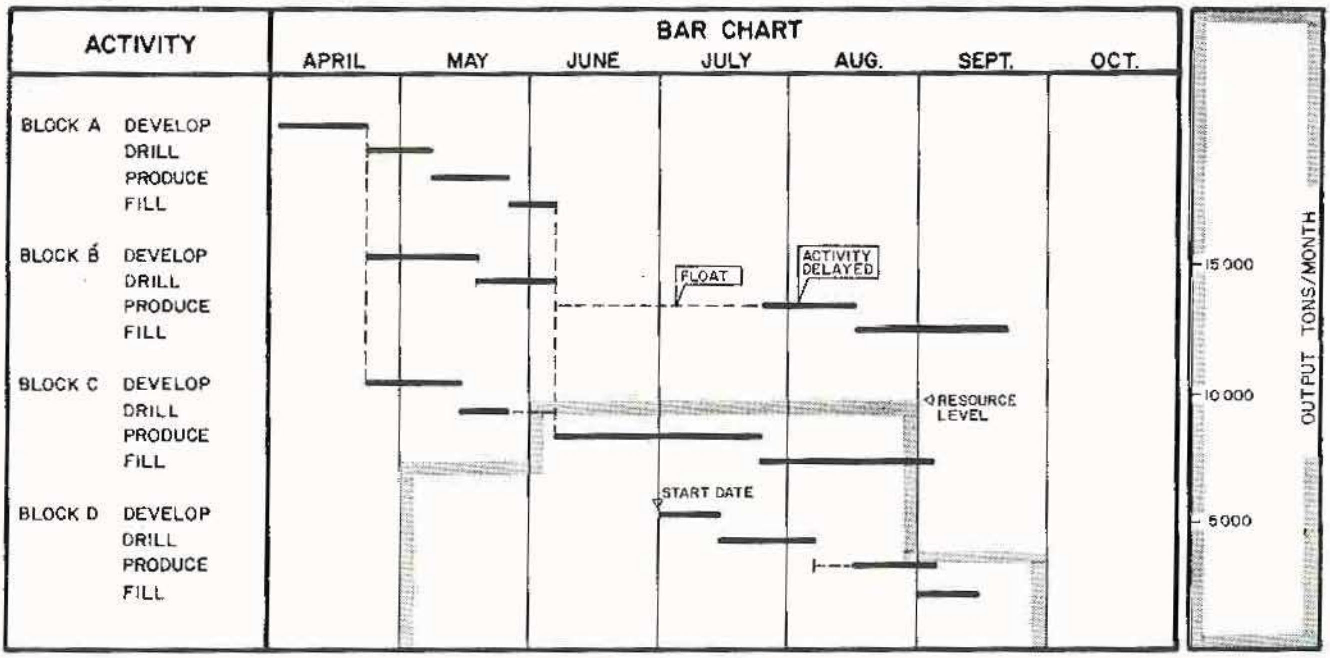

FIGURE 4. Barchart and histogram following resource leveling

for backfill will be met until the resource is consumed, at which point the filling activity for a stope will be delayed until the total demand falls below the pre-set level.

An important point in both these examples is that a schedule has been obtained which reflects what would actually occur in a mining situation: stopes will not commence production unless the mill has the spare capacity, and a stope cannot be backfilled if there is no fill available (which then means that the stopes adjacent cannot be brought into production).

In the above discussion, two resources were mentioned but the number of resources which can be assigned to activities and the use to which they can be put is almost limitless.

Grade

Grade is handled a little differently in that to treat it as a resource it is converted into metal by multiplying by the daily or unit production rate. Average weekly or monthly grades are then obtained by dividing the weekly or monthly metal output by the weekly or monthly tons (obtained after aggregation). In many cases there will be no need to put a limit on grade unless there is a metallurgical constraint.

A good example of this is where it is required to minimize the levels of impurities; for example bismuth in copper, mercury in zinc,in the mined output. In such cases the grade of the impurity is set as a resource (in, say, the stoping or extraction activity) and the availability set at the maximum level allowable. The effect on the mine schedule is that it will not bring into production a stope if by so doing that pre-set level of impurity is exceeded, the stope will be delayed and possibly a lower grade or lower tonnage stope may be brought into production instead.

Men and equipment

These are the usual resources allocated to an activity, and it can be seen that a schedule can be readily developed in which the number of men, LHDs, trucks, drill jumbos and so on is limited.

As a corollary, the effect of increasing resources can be examined, the result of additional resources being the subject of a 'what-if' type of analysis.

Costs

Costs can be assigned to an activity in a similar way to other resources. Costs calculated on a unit basis are thus amenable to aggregation, giving total costs over the specified time period. Any budget constraint can then be extended as the availability of that resource and a schedule produced which will not exceed the budget.

Other uses of network analysis related to mine scheduling

Major or capital development

In many cases the start-up of a particular stope is related to the development of an access. By including these activities in the network it is possible to see either the effects of a delay in completion or assess whether such development is critical to the mine schedule.

Degree of detail

Activities in a network can either be broken down into smaller, detailed activities or combined. In mine scheduling this means that detail can be provided for the more immediate planning, and subsequent planning can be on a broad-brush approach. Taking the previous case as an example, 'development' could be detailed as:

- develop sub-level A
- develop sub-level B
- develop slot raise A-B

and activities 'develop, drill, produce, fill' can be combined tc 'mine block A' for the broad-brush planning.

Continuity through mine planning phases

Network analysis provides the means for a common planning tool to be used throughout the life of a mine. The broad-brush approach can be applied to the feasibility stage, and this can be followed by detailing the initial two years and then detailing even further the first six months for the production stage. Once the mine is in operation, the network can be continuously updated as activities are completed and new activities formulated.

Critical activities

A network analysis provides an indication of which activities are critical.

The mining engineer, by examining the critical activities, can decide whether to allocate more resources to the activity to reduce its duration or conceive a plan which will eliminate the criticality of the activity.

The listing of critical activities also serves to focus the attention of the mining engineer so that the most important activities are dealt with first.

A production tool

When a mine is in production, there are many activities which have to be coordinated and managed. By using a sort facility it is possible to extract only those activities in the network which relate to a particular area or function. It is thus possible to produce both a bar chart of all activities in, say, a shift boss's section for the following month (Figure 5), and produce a listing of all backfilling operations for the next quarter for the foreman in charge of that operation (Figure 6).

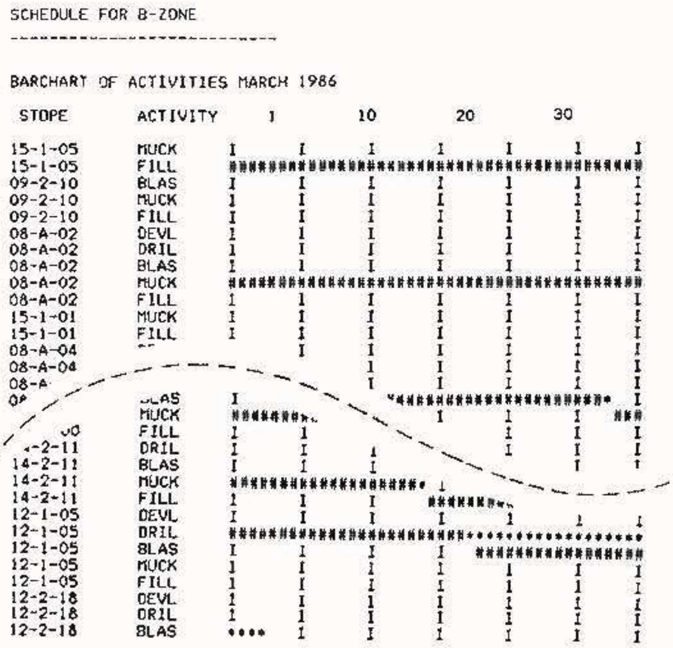

FIGURE 5. Example of a general short-term schedule

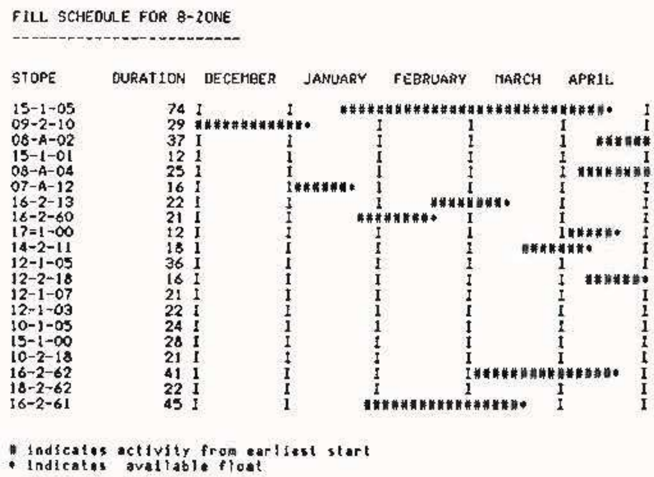

FIGURE 6. Example of a specialized long-term schedule

Network analysis in practice

One of the main problems encountered in practice has been the instance where a critical stope, scheduled to produce at a certain rate, is not brought into production because in doing so the total output would exceed the set level. The consequence of this is that either a shortfall in output is obtained or less critical stopes with smaller rates of production are scheduled. If there are a relatively few number of stopes the engineer may observe this happening and elect to manually reduce the output of the stope to that of the shortfall for the period involved. However if there are a large number of stopes in production either he may not observe this or the task may be onerous, especially if adjustments are necessary on subsequent runs. One solution that has been proposed for this problem but, as yet, untried in practice, is to set the resource levels higher, such that on aggregation, over say a month, the desired output is obtained. This, in effect, simulates the use of ore passes and storage pockets to even out mine production.

Network analysis will not give the best schedule at the first or second attempt. A heuristic approach is necessary in order to obtain the optimum solution and it is here that the mining engineer can use his skills together with the computational facilities inherent in the network analysis program. The solving process in network analysis is logical and does not require the use of any 'black-boxes' which may provide a result but not the means by which that result was obtained.

Network analysis programs

There are a number of software packages for network analysis which have been developed recently on microcomputers, and the basic principle of using network analysis for mine scheduling could be applied, in some form, to most of these programs.

The program which has been adapted to mine scheduling is Metier's 'Artemis-PC', the main reasons being:

- it is a powerful program both in terms of the data it can manipulate and flexibility;
- its user-friendly, menu-driven system;
- data can be transferred to and from other packages such as Symphony and dBase III;
- its excellent report and graphics generation.

Features which are of particular reference to mine scheduling include:

- with data held in datasets it is possible to perform calculations between fields, so converting, for example, stope or block geologic reserve data into mineable reserve data prior to scheduling;
- datasets can be linked so that a dataset holding reconciliation factors for various mining methods can carry out the calculation mentioned above where a particular mining method was assigned to a stope or block;
- the menus presented to the user can be tailor-made to the application so reducing the skill required to input data and obtain results.

Other features relevant to its use:

- it runs on IBM-XT or compatible system with all the advantages of cost, ease of use, transportability etc. that it brings;

- it allows up to 2000 activities in each project, up to 64 fields in each dataset and up to 64 resources for each activity;
- it holds up to four different work calendars with each calendar having different work patterns.

The benefits of taking an 'off-the-shelf' software package, such as Artemis-PC, and adapting it to mine scheduling, rather than developing specific program, are many:

- the program, hopefully, is completely debugged;
- the costs are considerably less as general programs have a wider sales appeal;
- the program is updated on a regular basis;

In practice the program has been found to be relatively easy to operate and can be put to use in straightforward scheduling without any difficulty. Some experence, however, is required to manipulate datasets so as to deal with grade. With more experience it is possible to completely customise data entry, dataset manipulation and reporting for a particular application. The Artemis-PC command language is structured with english statements and, in use, has the benefit of on-screen selection of commands.

Future developments

One future development envisaged is the use of a digitizer, or other device, to select, from a plan or long section, the order in which stopes or blocks are to be mined. The subsequent generation of a plan or long section showing the analyzed stoping schedule would give the engineer a visual means to check and monitor the scheduling process.

Another development would be, by the process of updating the schedule on a regular basis, to create a historical database. It would than be possible to compare actual against forecasted and monitor (revising as necessary) recovery and dilution factors.

Conclusion

The use of network analysis techniques goes a long way in solving the many problems encountered in mine scheduling: it maintains the logic inherent in a mining operation: the effects of availability of resources can be readily seen: activities can be as detailed as needed, and related activities can be easily incorporated.

The use of a microcomputer based network analysis software, such as Artemis-PC, provides a low-cost solution for mine scheduling. The flexibility and ease of use of such a package should enable mine scheduling to be carried out by the mining engineer more easily and better than ever before.

Acknowledgement

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Reference

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