Recent Methodological Trends in Operations Research and Computing as Applied to Mining Problems

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The use of operations research techniques and computer models has become entrenched in the mining industry, particularly in the area of mine planning.

The paper considers three major areas where increasing efforts are likely to be directed in the future: the integration of multiple disciplines in a single model; the decentralization of computing capacity within a structured network; and the incorporation of sophisticated techniques such as computer aided design and artificial intelligence.

Introduction

During the last few years operations research methods and computer models have become widely accepted tools and almost standard procedures to tackle techno-economic questions in the mining industry. ‘Computers in mine planning and operations’ was not only one of the main topics at the last (13th) World Mining Congress held at Stockholm/Sweden in June 1987, but in addition a great number of papers given on the other subjects, if not the majority, dealt with computer and O.R. methods. Computers and quantitative methods are playing an important role in both mine planning and operation, and comparing this situation with the first attempts of computing in the mining industry back in the early 1960s the problems can be regarded as being quite considerable.

Looking at the picture methodologically, however, this progress turns out to be not really so marked: Stochastic simulation has been the bread-and-butter method since the very beginning of computerized problem solving in the mining business, and still is except for very rare examples of successful applications of graph-theory, linear and dynamic programming, etc. These (simulation) models grew bigger and became more complicated as time passed (and the easy-to-handle tasks such as ‘optimizing’ transport systems were studied sufficiently), along with the increase in storage capacity and computational speed of the mainframes, from the methodological point of view, however, there was very little new development or breakthrough.

Only very recently have attempts been made to introduce new concepts to problem solving in mining, which trend in my opinion is overdue. There are three different aspects, which deserve even more attention in the future, namely:

- reflecting the complex, multidimensional structure of mining problems by combining different O.R. techniques within one model;
- providing decentralized capacity locally which is simultaneously an integral part of a structured network;
- incorporating CAD/CAM/CIM techniques and elements of Artificial Intelligence.

These emerging ideas inevitably affect the organizational structure of the mine and/or the company; hence it is worthwhile to think about where these developments are heading or where they should lead.

Reflecting the complex, multidimensional structure of mining problems within one model

It is commonplace to state that mining is a complex and multidimensional process, but in effect many of the computerized models used to represent this mining process are linear in nature or only two- or three-dimensional, and mostly cover only one or a few of the different aspects. Many typical mining problems and their respective models could be used as examples to clarify this statement; long-term production scheduling is just one of them.

Regardless whether it is open pit or underground mining, long-term production scheduling always means answering the question: Which part of the deposit should be mined at what period of time in order to reach the economical target as soon as possible? Clearly, scheduling takes into account geological and technical consideration and at the same time pays attention to probabilities – a complex problem, even when considering a very small
Another reason besides the requirement of an oxidator/beneficiation plant - it is needless to mention all of them in detail here.

Completeness still further aspects which may be considered as additional of the mining mined; for there are layers of sequencing problems which have to be looked at three-dimensionally. And there are will influence the sequence in which the blocks may be be considered a third dimension of planning, which has been applied quite frequently in the past, is to let the planning engineer establish this mining sequence by means of his knowledge and experience or by his intuition — thus leaving the bulk-load of the problem to him and restricting the computer to calculating the consequences of this pre-set decision.

It is apparent that a model simulating only one linear sequence at a time through this two-dimensional network will need additional criteria for deciding about the next block to be mined at any node. The most rigid measure to limit the number of branches to a manageable amount, which has been applied quite frequently in the past, is to let the planning engineer establish this mining sequence by means of his knowledge and experience or by his intuition — thus leaving the bulk-load of the problem to him and restricting the computer to calculating the consequences of this pre-set decision.

This is not to say that such 'simulating' models would all be too simple, as the consequences may be very different. For example, the complex issues range from technical questions like machinery requirements, utilization and energy consumption through mining problems like recovery, dilution and subsidence; then there is organizing and scheduling all the different operations in a mine which are influenced by or necessary for the process of winning the mineral, such as ventilation, development work, haulage and transportation; finally, an economic evaluation of this mine-plan has to be established. Such a computer model, if designed to cover all these aspects properly, is in itself a complex system and it will be extremely helpful for the planning engineer. On the other hand, there is no doubt that it is still linear in its underlying principles and hence does not reflect the multidimensionality of the problem of long-term planning.

This expression 'multidimensionality' is justified, because there are more dimensions than just this second one created by branching the sequences of the blocks to form the decision tree. The quantity of material to be extracted from each of the blocks accessible for mining may be considered as a third dimension of planning, which will influence the sequence in which the blocks may be mined; for there are layers of sequencing problems which have to be looked at three-dimensionally. And there are still further aspects which may be considered as additional planning dimensions, such as quality characteristics and requirements of both the deposit (ore grade, chemical and physical properties, recovery, dilution etc. as a function of the mining method applied, and so on), and the concentrator/beneficiation plant — it is needless to mention all of them in detail here.

It is most unlikely that there will ever be a model which completely reflects this multidimensional complexity of production planning in such a general way that it can be applied to any situation in any given mine. It is possible, however, at least to move a little towards this direction of complex multidimensionality, and there are some new attempts which reach for this target by combining different O.R. techniques within one model. Examples for both open pit3 and underground operations4 are available in different mining branches.

Typically, some sort of (stochastic) simulation is applied to model the development of the mine as time progresses. Embedded in this simulation procedure are interacting algorithms to cope with the different problem dimensions mentioned above. A decision tree may be used to represent the many possible sequences of working the blocks, with branching-and-bounding techniques applied for determining the best way through the network, and linear programming used for generating the branches at the nodes and coping with the quality restrictions, while network techniques can handle the problem of ensuring the timeliness of all auxiliary work. All these questions are treated in one and the same model simultaneously, as opposed to those numerous and successful attempts in the past which concentrated on only one of these aspects. Hence these newer models can be regarded as reflecting the true nature of a typical mining problem.

No wonder that such models are very complex and complicated themselves, and therefore require large mainframe computers. This apparently is one of the reasons why they have not been used too frequently in the past. The tremendous growth of storage capacity in the modern computer and its calculating speed, in combination with the decreasing cost/capacity ratio makes these modelling tasks manageable. There is no doubt in my opinion that they can and should be developed and used to tackle mining problems of different types above and beyond long-term production planning.

To develop and apply such complicated, multidimensional models necessitates, however, a well-trained and experienced staff with expert knowledge of these O.R. techniques, computational procedures and mining itself. People of this profile are not too frequent in the mining industry — another reason besides the requirement of an accessible mainframe why development, implementation and utilization of models of this type should be centralized. Other facts which reinforce this suggestion are the costs involved in developing and maintaining models of this complexity, and the comparatively low frequency of utilization which is to be expected — say a long-term production planning algorithm twice or three times a year per mine at the most.

It is quite evident, therefore, that these large, complex computer models do indeed provide the tools for methodological progress and will be most welcome and helpful in improving the mining engineer's problem-solving capacity; but they are not at all the right tool for the equally or even more important task of providing computing capacity to the engineers at the mine site.
Providing decentralized computing capacity as an integral part of a structured network

In the past, one big disadvantage of applying computer and O.R. techniques for problem solving in the mining industry has been the fact that the models were frequently not available at the mine site itself. Quite considerable effort had to be expended and much time was lost in talking to the specialists and experts at the company's computer centre, trying to make them understand the problem, get them interested and involved in selecting or developing a suitable solution program and applying this to solve the problem. Sometimes, the whole procedure was repeated a second time, the other way around: Trying to understand the solution and believe in it, and convincing mine management to give it a practical chance of being tested. This procedure has caused frustration and many misunderstandings which lead to unsuccessful applications, thus blocking further experiments, and possible attempts have never been started owing to these real or anticipated difficulties.

With the availability of comparatively inexpensive, powerful small computers like the PCs these problems do not necessarily exist for the time being and for the future. Computing capacity can and should be locally available for any mining engineer right on the spot, enabling him to do his job more efficiently, and in my opinion they have to become routine tools on the mine captain's and foremen's level too. To maximize the benefit which can be expected from this immediate accessibility of computing capacity, some conditions have to be met, however.

Since all mining engineers cannot be expected to become computer experts, it is most important that all models and procedures implemented on the PCs are as easy to handle and as easy to understand as possible. As a general rule all these models should be self-explanatory and menu-driven in a dialogue mode. In the past perhaps not enough attention has been paid to this aspect of simplifying the use of computer procedures, but in the future this will be as mandatory for the success of any model as the degree of sophistication of the algorithm itself.

Similarly, it will be most important to have all the models and algorithms which are intended for routine application constructed and programmed in such a way that they can really be executed on a PC. It is my firm belief that only immediate availability of computing procedures at the very point where they are needed and at the very moment of demand will ensure their acceptance and really assist the engineering and management staff of the mine in their day-to-day job. This means they have to be run on a small desk-top or personal computer. Many if not most of the models developed in the past have to be stripped and downloaded to a PC. This task, in my view, is equally as urgent as the development of new models and techniques, at least in terms of getting the majority of mining problems solved in due course. If properly used, this availability of local computing capacity can contribute quite a lot towards the routine application of O.R. techniques and models to mining problems. There are, however, some potential problems, which have to be recognized in order to avoid pitfalls.

First of all it has to be ensured that all the individual locally implemented computing capacities and facilities are compatible. As the mining process is a hierarchically structured, multidimensional interacting procedure, there should be an equally interacting system of computer hardware and software for mine planning and operation. This means that the results of one special computerized model, say to solve the production scheduling problem, should at the same time establish the input information for subsequent planning procedures, such as say machinery utilization and allocation, the scheduling of the stripping operations in open pits or of the development work in underground mines.

Furthermore, it has to be ensured that all necessary data for any model are immediately available regardless where and when they have been collected and stored. A tremendous amount of data is needed to plan, operate and control a mine, and it is impossible to store all these data for each of the local PCs separately—not to mention the costs, updating and maintenance difficulties. The only way therefore is to establish one or a limited number of large, comprehensive databases and provide access for any user of the locally distributed computer facilities, perhaps with some limitations corresponding to his duties in order to secure confidentiality. In any case, this information storage and retrieval problem again necessitates a structured network of interacting computer hardware and software.

It should be mentioned here too that this network will also be indispensable when thinking about CIM (Computer Integrated Manufacturing, or Computer Integrated Mining in our case) to ensure the constant flow of information which enables their mutual utilization for planning, scheduling, process control and automation and immediate reaction to any new situation. Finally, this hardware and software network seems to be advisable in a hierarchically structured form in order to provide adequate computing capacity to any potential user in the most economical way: in most cases a comparatively small PC will be sufficient to handle the problems of the engineers at the face, hence a big machine would be uneconomical at this level. It does happen sometimes, however, that more storage capacity and/or computing speed is necessary to tackle a certain complicated problem, and in this case it should be possible to use the PC as an intelligent terminal of a somewhat larger computer on a higher level, say at the company planning department's office.

Any computer network, especially if hierarchically structured and incorporating computers of very different sizes and from different suppliers, creates the problem of how to ensure a full compatibility on both the hardware and software side without losing the flexibility and adaptability of the system which are indispensable for keeping it alive and growing and always meeting the changing needs of the company. In my opinion the best way to reach a good compromise between as free and dynamic development of the system as possible and as frictionless an interaction between all of its necessary components, will be to establish compulsory interfaces both on the hardware and on the software side. These should
be uniform and universal at the same time, so that any part of the system may communicate with any other part without too great a difficulty. This philosophy seems more flexible than to establish fixed, rigid regulations, say programming standards or hardware specifications, to ensure the possibility of component interaction, as it would be impossible to predict all possible conditions, requirements and needs especially with regard to the future.

At Ruhrkohle AG, the largest hard-coal producing company of the Federal Republic of Germany, such a system of standardized interfaces is being developed and introduced, with special emphasis on the aspects of process monitoring, control and automation. In this system a slightly modified version of the ISO-OSI interface, adapted to the special mining conditions, will be utilized. This approach of adapting existing systems from other branches of the industry seems to be more promising than to start a new development from scratch. The existence of such hierarchically structured computer networks outside the mining industry also makes it most likely that they will be applicable here, too, and contribute to improving the economic situation.


Incorporating CAD/CAM/CIM- and AI elements

When successfully implemented, the above-mentioned system of computerized, integrated production monitoring and control in the framework of a partially automated mine could be looked at as being a Computer Integrated Mining (CIM) process. It may be questioned to what extent Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) and Computer Integrated Manufacturing (CIM) will be possible in the mining industry or will be advisable at all, regarding the cost/benefit ratio, but there is no doubt at all in my mind that at least elements of these new emerging techniques will be useful for mining applications. Hence they should be incorporated when developing new computer models and algorithms.

As far as CAD is concerned there are already many recent publications claiming successful application of these techniques - see, for example, the proceedings of the last APCOM symposium or the last World Mining Congress. If taken literally, any computer program used for planning a mining process or a mine layout is computer aided design and has been so from the very beginning of computer utilization in solving mining problems; in this sense it is just a new phrase for an old approach. Perhaps we should be a little bit more hesitant in adopting too quickly such new phraseologies, in order not to provoke grandiose expectations which will lead to frustrations if there is not any real substance behind it.

Taken seriously, there is something new behind CAD, which can be extremely helpful for mining application as well. The idea is to look at a design problem, say for instance the physical and organizational layout of a roadway-heading operation, from a special systems-analytic point of view. In this approach those components of the equipment or elements of the process are combined which optimally fit together and meet the requirements, and which are out of a catalogue or menu in the storage. And there is no necessity indeed when designing, for instance roadway-heading operations, to determine the optimum blasting pattern again and again - this calculation can be done once for each set of special conditions such as rock behaviour, cross-section of the roadway, ventilation and safety requirements etc. and the results stored in the computer as a catalogue and hence be available for any potential user. The problems of selecting the best available roof support, mucking procedure, organizational working pattern etc. can be handled similarly, and if a roadway-planning master program is available which not only combines these elements according to the selection made by the planning engineer but in addition highlights the consequences, uncovers incompatibilities and to a certain degree assists him to arrive at a good or even optimum combination of selected elements, then this may be called a real computer assisted design process. And obviously this type of CAD can be applied to many different tasks in the mining industry, both open pit and underground, regardless which mineral to be extracted.

It has to be admitted, however, that we have not yet reached this goal of routinely applying CAD in the mining industry. Although a considerable amount of research and development is going on already in this direction at different places, it seems to me that even more attention should be focused on these aspects in order to utilize fully the potential advantages offered by CAD.

With regard to CAM/CIM there are already some very encouraging and promising practical applications in different countries; despite the fact that there are additional problems to overcome with regard to the sensor-and remote-control techniques, I do believe that these developments will continue and lead to a very wide field of application; although it is not to be expected that we arrive at a fully automated mine in the foreseeable future, there is ample opportunity for at least a partial automation of mining processes.

Expert systems as a special aspect of the so-called Artificial Intelligence are apparently of extreme interest as a computerized method to solve mining problems; comparing the few papers on this subject given during the last (19th) APCOM symposium at Penn State in 1986 with the attention being paid to this topic right now one could come to the conclusion that this is the most promising new development in the computer application in the mineral industry, if not the only one at all. And indeed we may expect quite considerable progress or even a breakthrough from this technique. Very many mining problems if not their majority are very difficult to describe in quantitative, exact expressions, figures or functions. It is not that difficult, for instance, to describe qualitatively all the factors influencing the drillability of the different rock types, but we do not have an exact figure or function to quantitatively rank say weathered granite against bedded sandstone, and this applies even more especially to such complex questions as which type of infrastructure would best fit the given conditions in an underground

MINING: MINE PLANNING THEORY
RECENT TRENDS IN OPERATIONS RESEARCH AND COMPUTING

coal mine.

Quite obviously, therefore, there is a need for a computerized problem-solving approach suited to this type of task by arriving at a solution through arguing, reasoning and concluding rather than by just counting and calculating, and this is what expert systems are designed for. However, what has been said with regard to CAD seems to be valid here again: We are far from reaching the goal of routine application of expert systems in the mining industry (as is the case in most other industries as well), and we are well advised not to entertain too many expectations for the near future. There is no doubt, however, that we should intensively work along these lines to arrive at this target as quickly as possible.

General conclusions

Obviously there are some more recent developments of computer applications to mining problems which at least deserve to be mentioned here: Computer graphics will definitively play an important role in the planning process and contribute a lot towards speeding it up, cutting its costs and at the same time improve its quality; similarly, there will be an extensive use of geostatistical methods to improve the reliability of databases for all scheduling and planning work. It is not necessary, however, to enter into the details of these developments and some conclusions can be drawn already from the three trends discussed above.

Without any doubt computer and O.R. applications to solve mining problems have been very successful in the past, and will continue to be in the future. To utilize the potential advantages which are offered by the newest developments of both computer hardware and science to the best advantage, it is necessary to cross the borderline of conventional modelling of mining problems and enter into new fields. We must now look at modelling the mining process as the complex multidimensional dynamic system which it is in reality, providing adequate computing facilities locally on all hierarchical levels according to the actual demand and utilizing the most advanced techniques like expert systems and CAD/CAM. These three trends do not all conflict with each other but point in the same direction. What we should aim at is a system of computerized workstations for all the different engineering tasks in the mine, interlinked to each other in a hierarchically structured network, and thus providing to any potential user exactly that amount of computing capacity and access to data which he needs to do his job in the most effective way, with relatively simple and easy-to-use models for the frequent hands-on applications and a highly qualified central staff and installation for the complex and large-scale decision-support systems, all of these working interactively together.

There is still a long way to go to reach this target, but it is a realistic goal — and it is a worthwhile one.

References