A Brief Review of Operations Research in Mining

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Introduction

Mining is an industry in which operational efficiency is key to the feasibility of mine development, particularly with the relatively low ore grades that are being exploited routinely today. From the initial development of the mine, engineers must include quite detailed operational plans in the initial mine design and these must be constantly updated as new information about the ore body and market conditions become available. It is this operational focus that has been behind the successes of operational research in mining.

This article is meant to be a very brief introduction to some of the applications of Operations Research in Mining. It is by no means complete. It is perhaps best thought of as some personal reflections of the author and not as a rigorous review. A lot of material is available. A search on the INFORMS ACI database (http://www.informs.org/Biblio/ACI.html) using the terms mines and mining returns ninety-seven references. Since this is only from the O.R. literature, it is unlikely to represent a very significant fraction of the work in mining. If one consults a journal such as the International Journal of Surface Mining or Mineral Resources Engineering, many more articles will be found.

As we shall see, Canadians have played, and continue to play, a prominent role in some of the development of O.R. techniques in mining. Yet given the importance of the Canadian mining industry it is surprising that even more is not done. To illustrate this economic importance, the following information was gleaned from the World Wide Web (http://www.kmic.ca/English/facts/facts.htm):

> The metals and minerals sector contributed $23 billion to the Canadian economy in 1995, an amount equal to 4.4 per cent of the national gross domestic product (GDP). The sector employs 340,000 Canadians. Every job generated in the mining industry indirectly creates another job in the Canadian economy. Our country is the world's largest producer of potash, uranium and zinc, the second largest producer of nickel and asbestos, and the third largest producer of copper and aluminum metal. It is fifth in the production of gold and lead. Canada is the world's largest exporter of minerals and mineral products. In 1995 these accounted for approximately 15 per cent of Canada's total exports and contributed almost $15 billion to the Canadian trade surplus.

It should also be pointed out that the above calculations omit the tar sands operations in Western Canada. Although these are often thought of as oil projects, in reality they are gigantic open pit mining projects.

Probably few CORS members realize that there is a well established tradition of O.R. in mining. In 1993, Canada hosted the APCOM XXIV in Montreal. This is an international symposium with the acronym standing for "Application of Computers and Operations Research in the Mineral Industries". The first APCOM meeting was held in 1960. A CORS member, Jorgen Elbrond, has been a long time member of the APCOM Council and Chaired the APCOM XXIV in Montreal. The various APCOM Proceedings are excellent sources to consult to find applications of O.R. in mining.

In this article, we touch on a few issues which, although closely related, can perhaps be dealt with separately. The first is that of engineering economic evaluation and the challenges posed by high uncertainty and a cash flow stream that today inevitably includes a large negative cash flow at the

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end of the project lifetime. We then touch on an area that Canadians pioneered, the planning of optimal open pit limits. We go on to mention operational problems of transportation of ore within the mine and problems of blending ores to meet customer specifications. We have chosen to focus on work by Canadians that will be familiar to many CORS members. Our goal in doing so is to indicate to readers of the CORS Bulletin readily accessible people that they might wish to contact. The articles referenced in turn give access to a broader literature.

Economic Evaluation

Few activities are as uncertain as mining. The initial ore body is usually indicated by a number of drill holes whose intersection with the body is used to estimate both the uncertain amount of ore present and its uncertain grade. The initial mine development usually requires a substantial initial investment not only in plant and equipment but also in the initial development of the mine to the point that the ore can begin to be produced. Finally minerals are commodities and as such subject to enormous price fluctuations in the commodity markets. To top this off, most mineral sales are denominated in US dollars and currency fluctuations can have important implications for Canadian mining companies. Together with a regulatory environment that is constantly changing, this results in one of the most challenging decision environments one can imagine.

As a result mining decision makers have tended to rely on conservative economic decision criteria such as payback period or requiring relatively high internal rates of return. However, one of the challenges is that modern mining regulations require a reconfiguration of the mine site to something like its original condition at the end of the mine life. This implies that the investment must be a non-conventional mixed investment. Miroslaw Hajdasinski at Laurentian University is one of the people who has looked carefully at issues of economic evaluation of mine investments.

Mine Planning for Open Pit Mining

A basic problem of open pit mine planning is planning the ultimate contours of the pit. The region to be mined is represented as a set of 3 dimensional blocks where each block has a given ore percentage. Each block has a given objective function value for removal, which can be negative for blocks having low ore values. There is a precedence relationship that specifies which blocks must be removed before a given block can be removed. Typically this requires that at least the block directly above the given block and blocks adjacent to the block above the given block must be removed before that given block can be removed. The classic paper on this problem was written by Lerchs and Grossman. (Jorgen Elbrond informs me that this paper was first presented at a CORS Conference held in Montreal.) They showed that the optimum pit corresponds to a maximal closure in the mine graph which corresponds to the above mentioned precedence relation. Picard showed that this problem could be solved as a maximum flow problem. Picard and Smith have explored this solution concept in more detail.

This classical open pit design problem is essentially static. It does however establish pit limits and to a certain extent indicates the blocks that will not be mined. The next stage is to determine not only which blocks should be mined but when they should be mined. Mill and other capacity constraints limit the amount that can be mined in a period. Dagdaleen developed an integer programming formulation of this problem and developed a solution procedure using Lagrangian relaxation and decomposition. Tachefine, Soumis and Vanderstraten have also developed a Lagrangian relaxation approach and showed that the subproblems can be solved as maximal flow problems.

Operational and Production Planning

Operational planning in mining usually combines some aspects of blending the ore produced to achieve some sort of quality requirement while at the same time attempting to minimize costs of production. These costs of production usually involve not only direct costs of ore removal but also transportation to various processing facilities. Lestage, Mottola, Scherrer and Soumis discuss a situation where a dynamic programming technique is used to look at scheduling drilling and blasting and shovel displacements and utilization. Soumis and Elbrond look at the problem of dispatching trucks to shovels and routing to crushers to both minimize trucking costs and achieve a suitable ore feed to the crushers. Some operational planning problems can involve combining material from several mines. Gunn and Rutherford discuss a combined system of a tactical linear programming production planning model together with a short term operational decision support to plan the allocation of coal from several mines to meet the requirements of several classes of customers.

Capacity Planning

Models of capacity are usually at the upper level of hierarchical planning processes. However, in mining, the capacity determines the rate of extraction and hence exhaustion of the reserve. Thus there is usually an interaction between the capacity decision and the production decisions. Lizotte and Elbrond have looked at the choice of mine-mill capacities using dynamic programming methods. Gunn, Cunningham and Forrester looked at optimal coal mine capacity decisions in the context of the market requirements for various grades of coal products. This dynamic programming approach uses a linear programming subproblem at each node to calculate coal allocation and blending to maximize profit for the given capacity state.

Conclusion

This article has barely touched on a few applications of O.R. in mining. The areas that we have mentioned have quite extensive literature that cannot be treated fairly in the amount of space available here. There is also considerable work using many different types of O.R. techniques that we have not mentioned. It will surprise no one that there are considerable opportunities for simulation of the many aspects of mine operation. Mines consist of many machines and people moving large amounts of material. Simulation models arise in very many different aspects of these systems. Throughput and reliability are often measures that need to be simulated. There are also opportunities to use queueing analysis for throughput estimates of alternative designs at the many points of congestion of a mine system. Although there has been work in this area, I believe that there are lots of opportunities for the development of useful models.

My purpose in writing this article has been to arouse the interest of operational researchers in this important industry. I believe that those who spend the time to become familiar with the industry will be well rewarded with the opportunity for interesting and important O.R. applications. If you want the opportunity to save big money through O.R., it probably makes sense to look where the big money is. In Canada, one of those places is our mining industry.

References:

- Dagdaleen, K. Optimum Multi-Period Open Pit Mine Production Scheduling, Ph.D. Dissertation, Colorado School of Mines, 1985.
- K. Fytas, J. Hadjigeorgiou, J.-L. Collins, "Production Scheduling Optimization in Open Pit Mines", International Journal of Surface Mining & Reclamation, Vol. 7, no 1, 1993, pp. 1-11. Gunn, E. and P. Rutherford, Integration of annual and operational planning in a coal mining enterprise. Proceedings, APCOM XXII, Vol 1., 111-118, 1990.
- Gunn, E., B. Cunningham and D. Forrester, Some results with a capacity planning model in a coal mining enterprise, Proceedings, APCOM XXIV, Vol 2., 529-536, 1993.
- Hajdasinski, M., A generalized true rate of return for a project, Proceedings, APCOM XXIV, Vol 2., 280-287.
- Lerchs, H. And Grossman, I.F., Optimum design of open pit mines, Canadian Mining and Metallurgy Bulletin, Vol. 58, 1965.
- Lestage, P., L. Mottola, R. Scherrer and F. Soumis, A computerized tool for short range production planning at Mount Wright, Proceedings, APCOM XXIV, Vol. 2., 67-74
- Picard, J.C., Maximal closure of a graph and applications to a combinatorial problem, Management Science, 22, 11, 1976.
- Lizotte, Y. And J. Elbrond, Choice of mine-mill capacities and production schedules using open ended dynamic programming, CIM Bulletin, Vol 75, No. 839, 154-163, March 1982.
- Picard, J.C. and B. T Smith, Optimal rate of return in open pit mine design, Proceedings, APCOM XXIV, Vol. 2., 111-118, 1993.

- Soumis, F. and J. Elbrond, Truck dispatching software using mathematical programming implemented on an IBM-PC., Proceedings, APCOM XXII, Vol. 3., 237-246, 1990.
- Tachefine, B. F. Soumis and G. Vanderstraten, A decomposition flow algorithm for the operations planning problem in open pit mines, Proceedings, APCOM XXIV, Vol. 2., 140-147, 1993.