Project Design

Chairman: Professor J. C. GRIFFITHS
Rapporteur: Mr J. P. G. PRETORIUS

Papers:

Mine-mill production scheduling by dynamic programming by R. J. Roman
Optimization of a large mining venture by J. C. Paynter, B. K. Loveday and C. G. Robinson
Economic surface mining of multiple seams by T. V. Falkie and W. E. Porter

In introducing his paper, Mr Roman said that whereas in manufacturing plants the yearly production levels were usually chosen to produce the largest annual cash flow, in a mining operation, the raw materials (ore) were exhaustible so that the production had to be scheduled to maximize the total net present worth of the operation. This optimum production schedule could be determined by using dynamic programming. The required information was readily available to management at most mines. The 'possible operating range' of production rates lay between the rate with the highest profit per ton and that with the highest profit per year. The optimum production rate started typically at the top of this range and decreased slowly as the deposit was depleted.

Dynamic programming was used to determine several production schedules for a hypothetical mine-mill complex. The effects of changes in the ore grade estimates, size of deposit and acceptable rate of interest on the production schedule were taken into account. Apart from the fact that the net present worth of the overall profits was larger than that obtained by conventional methods, it appeared from the cases studied that the amount of metal recovered was also greater.

Dr R. P. King commented that this was a very interesting application of dynamic programming. He pointed out, however, that the market price of the metal was likely to vary significantly and randomly during the life of the mine, and he suggested that the problem should, therefore, be reformulated as a stochastic dynamic programming problem.

If the price of the metal rose to abnormally high levels, a much higher than normal production rate could be expected. The results of analyses given in Table 5 showed that the production rate was a function of market price. In his view the stochastic problem could be solved just as easily as the deterministic problem.

In reply to a question by Dr King as to whether the function relating recovery to production rate (Table I) was based on real data, the author replied that it was based on the results of an analysis conducted at the Union Carbide Corporation's Pine Creek tungsten mine in California.

Dr D. M. Hawkins stated that costs were incurred when the production rate was altered, for example, in appointing or laying off staff, and that in practice it may be necessary to take these costs into account in finding the optimum production rate. Mr Roman replied that, while normal administrative costs were accounted for, the additional costs incurred in appointing and laying off staff were not taken into account.

In a comment on Dr King's statement regarding the feasibility of using stochastic dynamic programming, Dr Hawkins said that if stochastic elements were introduced, an extra state variable would have to be introduced for each of these. The work of solving a dynamic program increased exponentially with the number of state variables. A problem involving several state variables might prove to be computationally infeasible.

Mr Roman said that his experience of stochastic modelling was limited to the use of Monte Carlo methods, but he agreed that the amount of computation involved would increase considerably. In reply, Dr King said that the stochastic formulation of the problem would add only one dimension to it and it could, therefore, still be considered to be computationally feasible.

Dr B. L. Joffe asked if the author had considered cases where the maximum production rate occurred below the rate at which curve relating profit per ton to production rate reached its maximum, Fig. 1, and cases where the minimum production rate occurred above the rate with a maximum profit per year. In these cases, which lie outside the 'possible operating range', the optimum would simply be at the upper or lower bounds of the production range.

The author replied that the curves given in Fig. 1 were hypothetical and chosen to have both maxima within the production range. It was conceivable that some mines could be operating in the range where increased production would lower the profit per year. He knew of no cases at the other extreme, however.

Mr C. G. Robinson, who presented the second paper in the session, explained that the work done was an attempt to optimize the design of a processing plant for a large mining venture as distinct from an attempt to optimize the parameters of an existing operating process. Process parameters such as cut-off grade, grind size, process temperature and the different unit operations to be used, were to be decided on for the design phase and a large number of different combinations of operating and design parameters were available which satisfied the required production criteria. The function of the operation was to choose the best set of parameters on which to base the design.

The processing plant was to treat ore from an infinite pit and the output of the mine was contract-limited. The economic criteria to be applied were, therefore, purely dependent on the cost of producing metal at any stage in the process. Marginal costing was used as well as a general-purpose flowsheet in which were incorporated marginal processes, and a search routine was followed to minimize costs as a function of all the variables. Processes with a negative marginal contribution to profit were eliminated automatically and an optimal plant design and control structure were obtained. The total cost per unit of metal was taken as the sum of operating and capital costs, discounted at a given rate. This meant that the design was very sensitive to the rate at which capital was charged.

The various operations comprising the process were modelled mathematically and, where possible, sub-optimizations were carried out and the design was fragmented, only one or two key variables being carried forward from operation to operation.

The effect of variations in cut-off grade on the amount of ore that was mined and milled for the required metal production to be realized, were shown in Fig. 4. Furthermore, the effect of variations in cut-off grade on the total optimum capital costs and the total optimum operating costs were shown in Fig. 5. As the cut-off grade increased, the metal recovery decreased, which had important effects on mining policy. It could be seen that the minimum in the total capital curve did not correspond to the minimum in the curve for total operating costs. The best grade of mill feed would lie somewhere between the two minima and would depend on the rate at which the capital was discounted.

The conclusion was reached that far too much time was spent in mathematical modelling of the constituent unit operations, and it was considered that a more simplified analysis of the type presented would prove adequate in the early design stages.

Commenting on the paper, Dr P. J. D. Lloyd congratulated the authors on obtaining a solution to the complex system they described. He thought, however, that they had not laid sufficient stress on the possible lack of generality of their system, and that this lack of generality had led them to conclusions which were most interesting but possibly open to misinterpretation, particularly in a different context.

In their introduction, the authors identified the physical parameters which controlled the profitability of a mining venture. The venture considered by them was rather unique in that, unlike most ventures undertaken by the mining industry, the ore body was of infinite size, there was a single customer who required a fixed tonnage of metal over a fixed delivery period and, because of the size of the deposit, there was an infinite range of ore grades which had to be considered. In his opinion most mining people would be surprised if it were suggested to them that, against a fixed sales contract, the tonnage mined should increase as the ore grade increased, as shown in Fig. 4 in the paper. Of course, the tonnage milled decreased with increasing ore grade, as expected and as shown in Fig. 4. This implied that more and more low-grade material should be sent to waste as the grade increased, and the overall recovery would decrease markedly with increase in grade, as shown in Fig. 5. This might be called 'wasteful' extraction, and superficially, it seemed justifiable only where an essentially infinite ore body with a wide range of ore grades was available.

Dr Lloyd went on to say that it should be stressed that this most interesting conclusion that the authors had obtained was only a design answer. Plainly, the conclusion might change for an operating plant, particularly under conditions where there was the fixed capital investment in mine and mill, and a change in the market for the product. Under these conditions, which could occur at any time after the initial construction of the plant, the optimum operating conditions might be totally different. It was unfortunate that the authors could not present any data on the effects of such changes, which would have demonstrated that sufficient flexibility had been built into their optimum design to permit such changes without major additional capital or operating costs being incurred.

Referring to the optima shown in Fig. 5, he said that there were plainly wide errors in any design cost analysis, and that the cost curves shown in Fig. 5 should, therefore, had been shown as bands rather than as thin lines. The minima shown were very shallow, and therefore the 'optimum' ore grades determined by this method would be subject to very wide errors. He wanted to know if the authors could perhaps comment on this, and give some indication of the possible relative errors.

Mr Robinson and Dr Loveday replied to different parts of Dr Lloyd's comments. They stated that they found it interesting that his criticisms were directed at the policy of examining the total cost structure as a function of cut-off grade for any given rate of production of metal. This was one of the more obvious ways of determining the cut-off grade in the initial years of operation. The project described in the paper was aimed at determining the minimum total cost curve by considering the interactions of mining cut-off grade, and the upgrading and metallurgical plant design options. They would nevertheless clarify the points as they were raised.

At the design stage of a project, the only major constraints were the total capital and the rate of production of metal, as determined by long-term contracts. In the manual feasibility studies, upon which their data were based, only a few rates of metal production could be considered. With their computer program any metal production rate could be defined on an input variable, thus providing more flexibility. The concept of an infinite ore reserve referred to the situation where the mining company did not wish to operate at a higher unit cost in order to conserve resources. This attitude would prevail when a large marginal grade deposit was mined, especially when future market conditions were uncertain. On the basis of Fig. 5, discount cash flow calculations could be performed to determine the possible benefits of operating to the left of the minimum unit cost, thereby extending the life of the mine.

Figure 4 had been completely misinterpreted, despite a clear statement in the conclusions and in the figure itself. It was well known to operators of open pit mines that, as the cut-off grade (at the mine) was increased, the grade of ore sent to the mill also increased, and hence the tonnage to be milled for a given rate of metal production decreased, but more material had to be mined to achieve the same rate of metal production. The waste-to-ore ratio, of necessity, also increased. This simple statement of ore reserves had nothing to do with day-to-day variations in the grade of ore fed to the mill. The curves in Fig. 5 appeared to be very flat, showing that the change in cost with cut-off grade was a small proportion of the total cost. Nevertheless, this change represented millions of rands. This would be particularly significant in terms of operating cost, which was expressed on a per annum basis.

The question of sensitivity of the total cost curve to individual components became particularly significant when devaluation was announced, but sensitivity studies showed that the position of the minimum was remarkably insensitive. Also, the position of minimum cost changed very little over a wide range of production rates. These phenomena showed that the optimum plant conditions were not likely to be sensitive to changes in labour costs, etc. Changes in the market price affected only profit, but might force the company to operate at the minimum operating cost in lean years.

It was unfortunate that the length allowed for the paper did not permit a more detailed discussion of the design philosophy for large mining ventures, and the authors were grateful to Dr Lloyd for providing an opportunity to elaborate on some points.

Dr Falkie in presenting the last paper in the session said that he had encountered the use of a sophisticated mine economic planning system in phosphate mining and was interested to find out if similar quantitative models could be developed for multiple-seam coal mining which was becoming increasingly important in the United States. The study was conducted in two main stages. The first, which was the subject of the paper, was to develop a preliminary program which would embody a feasibility study. In the second stage the model would be extended to provide daily information on price-cost-production relationships. Throughout the study, the possibility of using the model to study new mining methods which would include land reclamation had to be kept in mind, because of expected future State and Federal land reclamation requirements.

The first part of the model was concerned with decision-making. Physical, chemical and economic variables were taken into account. A strippability factor and effective coal thickness were determined for each block, and thereafter the mining of these seams, within the limits of production requirements, was simulated. This was done incrementally, by first considering one seam only and subsequently including others. The life of the property, annual coal tonnages, etc., were predicted for each seam and combination of seams. Subsequently, costs of, amongst other things, plant supplies, mining supplies and power were calculated and the annual gross profits determined. Lastly, the discounted cash flow return on investment, in which allowance was made for depreciation and variable tax requirements, was calculated and a series of rates of return representing different seam combinations obtained.

Mr Wells said that this paper and many others presented at the symposium exemplified the wide spectrum of knowledge required by the minerals engineer. There was a time when engineers were concerned mainly with technical matters. As time progressed, the financial side of their activities became increasingly important. More recently they had had to acquire knowledge of the use of computers to reduce the tedium of their many calculations. The process started on the technical side, however, and the paper described a good example of the successful marriage between the technical and economic sides of the formulation of a problem. He asked if Dr Falkie could give further details about the output of the system and about his plans to extend the system.

Dr Falkie explained that the paper was based on a lengthy report which had to be condensed to meet the length requirements of papers in the symposium. The output included a listing of strippability factors, coal thickness and overburden thickness for each seam in each block. An operating cost data chart was given, followed by data on capital investment, depletion rate and Federal tax rate. Mining data, such as property life, number of seams being mined, rate of production and block dimensions were then printed, and a list of physical and chemical restrictions such as maximum depth of overburden and maximum ash and sulphur content was given. This was followed by annual production figures, and data on coal overburden and stripping ratios on a yearly basis. The annual profit and loss statements were given and, lastly, the results of the discounted cash flow calculations.

It was hoped to develop models which would relate costs to such items as stripping ratios, depths and volumes. Furthermore, since factors such as price and demand changed, it was hoped to incorporate such dynamic relationships in the model. Lastly, it was planned to extend the model so that it could be used in long- and short-term forecasting.

Mr Hargreaves commented on the mining sequence outlined in Fig. 1. He said that the equipment mixture seemed to be rather random and asked if the maintenance department was consulted in its choice. He added that rehandling took place as a designed procedure which would be expensive, and that the Marion dragline had to operate on a waste heap, which would endanger the undercarriage and also tie up a lot of bulldozer time. He asked whether the possibility of stripping the two upper beds of overburden with the dragline and the lower section with the stripping shovel could be considered. The dragline could be used to make up any leeway on the bottom stripping horizon where necessary. He assumed that it was known from drilling data what variations existed in interseam thickness and that the stripping cycle could be programmed accordingly.

Dr Falkie replied that the mining sequence was determined by the mining company concerned and he would not claim that it was the best possible sequence. At this stage, however, he was not in a position to advise them to change although it was possible that he might do so at a later stage of the project.