Mine Planning

Chairman: Professor J. ELBROND
Rapporteur: Miss V. E. MARTING

Papers:

Aids to planning production in coal mines by F. H. Deist and M. P. Roberts

Capacity calculations, investment allocation and long-range production scheduling in German coal mines by F. L. Wilke

Ore reserve evaluation and open pit planning by J. M. Marino and J. P. Slama

This session was devoted to the economic aspects of planning and scheduling. After Dr. F. H. Deist had introduced the paper Aids to planning production in coal mines, Dr. T. V. Falkie summarized the following formal contribution prepared jointly with Dr. R. V. Ramani, describing the work that has been done at the Pennsylvania State University in the development of simulation programs for mine planning over the past 15 years:

During the late 50's and early 60's, Monte Carlo simulators were developed to model continuous miner-shuttle car transport systems, track haulage systems, belt conveyor networks, etc. In the mid-60's attention was directed towards deterministic simulation of equipment performance, given the equipment characteristics and the system profile. In the late 60's all these systems (miners, shuttle cars, belts and trains) were integrated together to form a complete coal mine simulator and the program could predict the output potential of the system, given the mining dimensions, method and equipment employed. The actual sequence of coal-cutting operations is entered into the computer through the use of a special programming language which permits any type of mining configuration to be simulated. The simulator is hybrid in nature in that the shuttle cars, trains and belts are simulated deterministically, whereas rate functions with delay frequencies are entered for the continuous mining operations of caving, shearing, shunting, cleaning, etc. With suitable manipulation of the data, the program may be applied to all belt or conventional mining sections. Most of these simulators were developed through the assistance of grants from the Department of Mines and Mineral Industries of the Commonwealth of Pennsylvania and are available from the Coal Research Board of the Commonwealth.

The Pennsylvania State University is presently undertaking the task of building a more comprehensive model for mine planning and operation in which it is proposed that the design of mine workings, roof control, subsidence and ventilation planning models should be included. Other support routines simulating water flow, methane emission, and electrical power consumption are planned. The ultimate aim of this research is to design an overall mining system and to estimate its performance, given information from boreholes drilled in a virgin region, taking all technological, environmental, social and economic factors into consideration. The Pennsylvania State University have had the pleasure of receiving and reviewing some of the work of the Chamber of Mines of South Africa, particularly in the areas of strata control and mine design, for possible application in their simulator. It is believed that simulation will become an increasingly important tool for planning, operations and the control of mines.

Increasing sophistication in modelling and computer techniques and in the development of better computer hardware should facilitate the acceptance and promotion of these tools by mine management. The Pennsylvania State University has received excellent cooperation from all coal mining companies in the United States in permitting these simulators to be evaluated against operating conditions.

Dr. Falkie congratulated the Chamber of Mines on their efforts and acknowledged that their work was amongst the best in the world. He went on further to ask Dr. Deist for his opinion of the validity of a stochastic, as distinct from a deterministic, approach. In reply, Dr. Deist indicated that it was difficult enough to obtain sufficient data to run the existing programs on a deterministic basis; these difficulties would multiply if the mines were asked to make estimates of the distributions.

Dr. Avidan congratulated Dr. Deist and his collaborators and pointed out that one of the attractive features of the system was its ability to extract data on a temporary basis for each simulation run without affecting the permanent contents of the data base. Dr. Avidan questioned the decision to organise the base sequentially on account of the amount of computer time needed to search a very large file, and suggested that a direct access or index sequential file could prove advantageous. He also suggested that certain data that are common to a number of mines could be held separately but referenced from the data base. He also thought that it would be beneficial to check for inconsistencies when creating the data base rather than at the time of extraction. Finally, he enquired about plans for future development.

Dr. Deist acknowledged that the suggestion concerning information common to several mines was perfectly valid. Regarding the retrieval mechanism, Dr. Deist explained that since the first application had been a borehole data file, a sequential access method was selected for simplicity and the low cost of file maintenance. When the simulator operates upon the data base, the relevant data are temporarily restructured for the purpose of the simulation run into a type of direct access file. Apart from this initial interface, the simulator does not access the permanent data base thereafter. Dr. Deist verified that certain edit-type inconsistency checks were performed at the time of creation and updating of the master file, but pointed out that in addition there are inconsistency checks which can be performed only at the time of re-structuring the file or during the course of simulation. For example, it is possible to check only that each haulage block forms part of a continuous chain during the latter phase. He emphasized the statements contained in the concluding paragraph of the paper, namely, that he regarded the existing
A contribution from the user's viewpoint was made by Mr L. F. Duvel, who had been closely associated with the application of the program to the mine mentioned in the paper. He related his comments to certain points made by Mr K. Lane in his keynote address:

(i) **Input should be easy and flexible.** Mr Duvel verified that the file maintenance system made the creation and updating of the data base easy. The primary operations shown in Fig. 4, Block 1, commonly called the **plan commands,** are for the greater part only a sequential listing of the blocks and the operations for each production team indicating their respective movements in time.

(ii) **The program should be flexible.** Mr Duvel described the complex situation at the old colliery mentioned in the paper whose remaining reserves are in widely dispersed remnants of thin and dirty seams. Although the main product is coking coal, certain fractions cannot be absorbed and are disposed of in a number of products of various sizes and quality. The position reflected in the model consists of five sales products and six customers purchasing various mixtures of products. There are three separate seams at each of two mines on a total of nine entrances (adit haulages or incline shafts) and two preparation plants. For the life of mine plan 18 production and nine preparation operations were defined. Major considerations in planning and operating are the sequential extraction of seams from the top downward, coupled with the necessity to mine from different seams in certain ratios in order to obtain a coking coal meeting the required specifications. The Coal Division of General Mining and Finance Corporation Limited, is satisfied that the application of the simulator is sufficiently general since it can handle a situation of this complexity.

(iii) **Output should be flexible and should contain a high degree of selectivity.** Mr Duvel acknowledged that management was able to extract all the desired information by means of the report generators but admitted that they had made the very mistake against which Mr Lane had warned, namely, going into too much detail.

Other user experience was contributed by Mr D. R. Hardman, who said that the Field Investigations Division of the Chamber of Mines Collieries Research Laboratory had used the production planning simulator on a test case on behalf of one of the mining groups. The test case related to a specific situation at an old colliery mentioned in the paper where the outputs were designed which called upon the detailed output: (1) capital expenditure and profit/loss, (2) personnel and equipment requirements, (3) production and productivity, (4) summary of working costs. The total duration of mining was of the order of two years and each report was designed to produce a monthly account and, where relevant, a final summary.

Mr Hardman reminded the audience that a mine had to be planned whether a computer program was used or not, and that the same basic data had to be collected in order to make a reasonable planning assessment. Manual planning restricted the number of alternatives which could be explored because of the lengthiness of the calculations. The advantage of the planning program lay in the relative ease and speed with which various alternatives could be assessed. The planning of a new mine had to be carried out initially with assumed data, or data collected from existing mines, which were replaced by data from the new mine as it became available. When planning was performed with the aid of the program it was easy to update the original, assumed or estimated data, and replace them with more pertinent information, re-run the program and obtain more reliable results.

As distinct from applications experience in the coal mining industry, Mr J. W. Wilson expressed his confidence that the production simulator described in this paper would be used in the production planning of gold, diamond and other mines. The simulator provides mine managers with a means for achieving improvement in the high cost area of production. As an illustration, he mentioned that in a typical medium-grade large-tonnage South African gold mine a one per cent reduction in labour costs and stores would return about R500 000 and R100 000 per annum, respectively, but that a one per cent improvement in the production rate would yield not less than R500 000 per annum. When evaluating the economic implications of long-term planning, very large sums of money, often in the range of tens of millions of rand per annum, are involved on most gold mines. Consequently, small improvements in a planning forecast can provide highly significant savings for a mine.

In the course of introducing Professor F. L. Wilke and his paper Capacity calculations, investment allocation and long-range production scheduling in German coal mines, Professor Elbrod explained how the Technical University of Clausthal has been involved in the dramatic changes in the German coal mining industry, which after experiencing heavy losses for many years now has a rosy future through the merger of coal mines into larger decision-making units. Dr Deist's paper, although treating a problem similar to that of Dr Deist, differed in that an attempt was made to set up a production schedule which may approach an optimal solution. In answer to a series of four questions posed by Mr H. Small, Dr Wilke reaffirmed that the capital investment was not related to the expected profit in later years and that the capital expenditure could not exceed the amount specified in the contract. A change in the capital employed necessitated recomputation. Since the calculations had been completed in 1970 the method had been put into operation in a particular mine as well as for a group of mines in the Ruhr. However, the test group was not always realising the best alternatives since the capital restrictions had been changed since the date of computation. Before the program described in the paper could be used, a fair amount of man-machine interaction had been required to obtain optimization within the blocks and to determine the best way of working individual blocks. Professor Wilke confirmed that the determination of the optimal schedule could not be achieved by mining men alone. The success of the present method could be attributed to the joint collaboration between a team of practical mining men and the staff of the research institute.

An unidentified speaker enquired how the computer program took into account the fluctuations in output, which could vary between 500 and 3000 tons per day, using the same machinery in the longwall system of mining. Because of the disadvantages in stockpiling, that is, the fire hazard and deterioration in quality, the additional output could, in the speaker's experience, prove embarrassing at times. Professor Wilke agreed that the output from a single seam could change very suddenly but since the computer program handled blocks which could comprise several seams, this irregularity was smoothed effectively. Preliminary research is aimed at determining the most suitable method to apply to the various seams and the program permits different methods to be applied to the various seams in a block. Although the output
for the seams could vary from day to day, the output for the block, averaged over a month, could conform to any predefined figure such as the 2 000 tons per day mentioned in the paper.

Dr T. V. Falkie enquired whether Dr Wilke's economic model ever produced a solution which violated good mining practice. He asked, for example, whether it would be possible to obtain a solution which would prescribe the mining of a block in such a manner that it would disturb the ventilation plan or roof support system. Dr Wilke assured him that there were restrictions in the model to prevent a block being mined before the exhaustion of its natural predecessors. The restrictions were established according to normal mining 'commonsense' rules and consequently all production schedules obtained to date have agreed with practical mining methods.

As distinct from the first two papers dealing with the planning of underground mining operations, the third paper in the session represented an amalgamation of various mining and computer techniques to produce a total system for ore reserve valuation, the planning and production scheduling of an open pit mining operation. Mr J. M. Marino presented the paper, written under joint authorship with Mr J. P. Slama, through the medium of 30 slides.

Mr D. A. Phillips enquired whether the authors had given any consideration to the use of cones of different slope in the various parts of the pit. Mr Marino explained that the existing model could not cope with this suggestion since the algorithm employed required that standard cones should be generated at the outset. He pointed out, however, that since the computer time for the generation of cones was insignificant, this could possibly be incorporated in the simulation. Mr Phillips asked for an enlargement upon the philosophy expressed in the paper that a compromise was being adopted 'between rigorous optimization and an acceptable cost' in order to reduce prohibitive computing time. Mr Marino explained that the criteria were not, in fact, very different, otherwise the difference in tonnage would be unacceptable. If the criteria were too different a marginal tonnage would appear in the one case and not in the other. The approximation was governed by two factors, firstly, the generation of multi-cones was restricted to an influence zone of positive generators around the monocone generator and, secondly, the process of re-initiating the problem each time could be by-passed under certain conditions.

Mr J. R. Cutland enquired whether the open pit optimization procedures were used merely to produce guidelines and indicators of the feasibility of a pit or whether it was possible to get operational designs from the program. He asked if only broad guidelines were obtained from the model whether other programs were used for the detailed pit design. In reply, Mr Marino agreed that the sequence of mining was very important and this had to be solved according to management's needs. In their case, management had been able to determine from the shape of the pit produced by their program the sequence of exploitation. For example, they had been able to decide to remove a whole horizontal layer before deepening. However, in the case exhibited, management asked them to generate other open pits within the optimized open pit subject to the simple constraints of providing continuity with the existing operations and with minimum stripping ratio. If the slope had been different they would have taken this into account.

In a second question, Mr Cutland pointed out that some optimization techniques were very sensitive to small changes in the parameter values. He invited the authors to comment on the tests they had performed to establish the robustness of their optimization techniques with reference to the sensitivity of the final design and development sequence to changes in the costs, metal prices, slope angles, etc. Mr Marino pointed out that one of the slides he had shown had illustrated the sensitivity to various economic factors. However, their experience had not been consistent. In some cases the sensitivity was great, while in other cases the slope was hardly affected. He reminded the audience of the theorem that a pit produced under more stringent economic conditions was wholly contained within a pit of more relaxed conditions. He acknowledged that on account of the large amount of expensive computer time involved that this aspect had not been examined exhaustively.

Professor Elbroud congratulated the authors on their work and the documented evidence that their efforts had been well accepted by management. Large areas of their respective mining companies' operations had been covered and in all instances the authors were aware of the necessity for communication with all levels of management. The session could be summarized by a term coined in Australia 'automatic mathematical optimization' as distinct from 'manumatic methods'.