Dynamic Control of a Mining Enterprise

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SYNOPSIS

In an earlier paper the author explored the consequences of price-stabilizing effects, on an industry-wide basis, of various production strategies. These ideas have now been applied to an illustrative case of an individual mine. It is shown that the turning of production and financial policies can affect financial performance over a five-year period by as much as 22 per cent.

No generality is claimed for the results and they would differ from mine to mine. It is, however, asserted that the results show that the proper turning of production, reserves and financial policies are more critical determinants of mine performance than has been realised. It is also asserted that the methods of dynamic analysis are the most appropriate means for studying this policy-design problem.

INTRODUCTION

The fluctuations in the price of copper (and other metals) have always been a source of concern to the mining industry. This concern has been expressed at the macro-level in statements of the type 'the industry should do such-and-such in order to stabilize prices' and at the micro-level by severe difficulties in attempting to organize production in such a way as to take advantage of, or provide defences against, price variations.

Problems at both the macro- and the micro-levels ought to be amenable to some form of analysis providing the right questions can be asked in the sense that the questions have to be relevant to significant managerial issues and have to be within the scope of the analytical methods available.

Broadly, there are three classes of managerial question which are likely to be of interest. Put very simply they are:

(i) Should we make this investment?
(ii) Can we forecast the future course of prices?
(iii) Given that we have this industry, or this mine within the industry, how should we operate it to the maximum advantage consistent with a multitude of other considerations?

The first of these questions has been studied extensively and there are many methods available for its solution. However, new mines or major extensions are opened relatively infrequently, particularly by individual companies.

With regard to the second question, it is easy to show that, apart from the short term, the simple forecasting of price by statistical or other procedures is only a small part of the problem. The purpose of forecasting is to provide a guide for action. If a forecast of high prices leads to an increase in production which causes a fall in price, the assessment of the 'accuracy' of the forecast becomes difficult. Clearly, it cannot be done on the basis of some sort of ratio of actual price to forecast price because that would ignore the link between the forecast and the action which led to the forecast being 'wrong'. The only way to judge a forecasting procedure is by its relationship to an overall system. These are complex problems, involving corporate policy, competitive action and many other matters. The matter is so involved that simple price forecasting may actually be misleading.

The third question, that is, what operating policies should be followed, is very important. It affects every mine and company in the industry constantly and can be expected to have a major influence on performance at all levels both now and in the future, because of the way in which present results influence future resources. In an earlier paper, Coyle (1970) discussed the effect which various industry-wide production policies might have on stabilizing prices. In this paper, the ideas and methods of the earlier work are extended to the operation of an individual mine in the face of fluctuating prices.

THE MINE CONTROL PROBLEM

The problem discussed in this paper is that of the operating policies to be followed in a mine faced with fluctuating prices and the effect of alternative policies on the performance of the mine. The main policies are production and financial and these are set against various geological and physical constraints.

The production policies are of the type discussed in Coyle (1970) and are based on whether the production of the mine should or should not be adjusted to reflect price variation. Basically, there are three possibilities, all expressed in terms of the divergence of actual price from some price which is 'normal' for that mine. The three policies are:

Type I — Ignore all price fluctuations and always produce at some 'nominal' capacity.

Type II — Increase production up to some limit (say 20 per cent over nominal capacity) when price is above normal and, conversely, when price is below normal.

Type IA — Increase production for above-normal prices but keep it at nominal capacity when price is less than normal.

The financial policies relate to development expenditure and amount to cutting back on development when cash reserves are low relative to some 'normal' value. Clearly the policy can be varied and may be more or less severe. It has to be emphasized that this policy takes effect in the area of development but it is not a development policy but very strictly a financial control. The linkages between these policies may be seen in Fig. 1. This diagram shows that the basic structure of the problem, conceived from practical considerations, has many closed sequences of interaction (or feedback loops). For example, the production rate affects the cash ratio which influences the actual development rate which alters the developed reserve which in turn reacts upon the production rate.

The performance of a model such as this is influenced by its various feedback loops and is very difficult to assess in general terms. If, however, the model can be related to an actual system then the performance of that system can be studied with the aid of a criterion of performance and a computer simulation model.

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PERFORMANCE CRITERIA

For the purposes of this paper a very simple criterion was used, namely, cumulative earnings over a five-year period. This quantity, referred to as CUMEARN in the computer model and in this paper, is simply the product of metal production and the price ruling at the time of delivery summed over a five-year period. Any other criterion could be used in particular circumstances or a whole range of criteria could be used combined in some way or assessed individually. The computer simulation method is a ready means for producing any desired information about the model. Similarly, contractual relationships of various types could easily be included in the model.

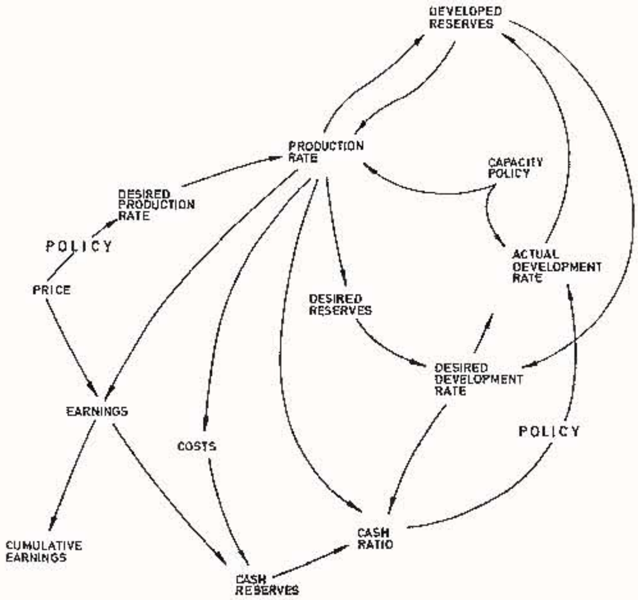


Fig. 1. Principal interactions in the mine control problem.

THE DETAILED MODEL

This section describes the more detailed model which was used to put some flesh onto the bones of Fig. 1. The computer model employs data from an actual mine, but the values have been altered and simplified to give a model more appropriate to a paper of this nature. In order to study policies for an actual mine it would be necessary to build a model several times larger than that discussed here, based on a diagram far more complicated than that in Fig. 1. There is no theoretical or practical difficulty in doing this though the work would be a little tedious. However, since the purpose of this paper is to show that policy affects performance and that the interactions between policy and performance can be examined by dynamic simulation, a simple model will be more appropriate. It is hoped to report a full-scale model at a later date.

The model used, simple as it is, contains a surprising number of complicating factors.

Price

In order to filter out the effect of inflation an artificial price series, having the same general characteristics as the London Metal Exchange price behaviour, was used. The series is shown in Fig. 2. It is not asserted that the values are realistic. They merely show the general type of behaviour which occurs.

Geology

The distribution of the grade of metal in the mine is given in Table I.

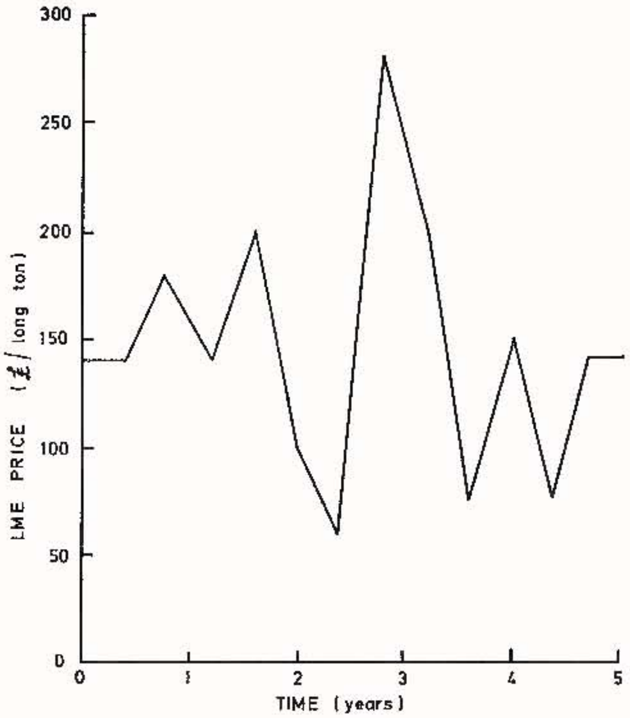


Fig. 2. Price series used in the model.

TABLE I

GRADE DISTRIBUTION

Grade range %	Mid-point %	Relative frequency %
0 – 0.49	0.25	5
0.50 – 0.99	0.75	15
1.00 – 1.50	1.25	70
1.51 – 2.00	1.75	5
2.01 – 3.00	2.50	4
3.01	4.0	1

This distribution is in fact too sharply 'peaked'. With a more realistic distribution the divergence in system performance would be more marked. However, this distribution fitted the other assumptions needed for a simplified model.

Ore reserves

Ore reserves in the model are held in six categories corresponding to the class intervals in the foregoing distribution. It is assumed that developed ore will fall into the categories according to the given frequencies. In practice some selectivity in development would need to be taken into account.

Development policy is taken to be that it is desired to have ore for two years production developed or under development. A desired development rate is calculated on the basis of replenishing the depletion caused by current production and making up any discrepancy between desired and actual reserves over a period of three months. There is a delay before development work is completed.

Cut-off grade

The cut-off grade is calculated on the basis of current price and the parameters of the model have been adjusted so that the lowest two grades of ore are always below the cut-off grade.

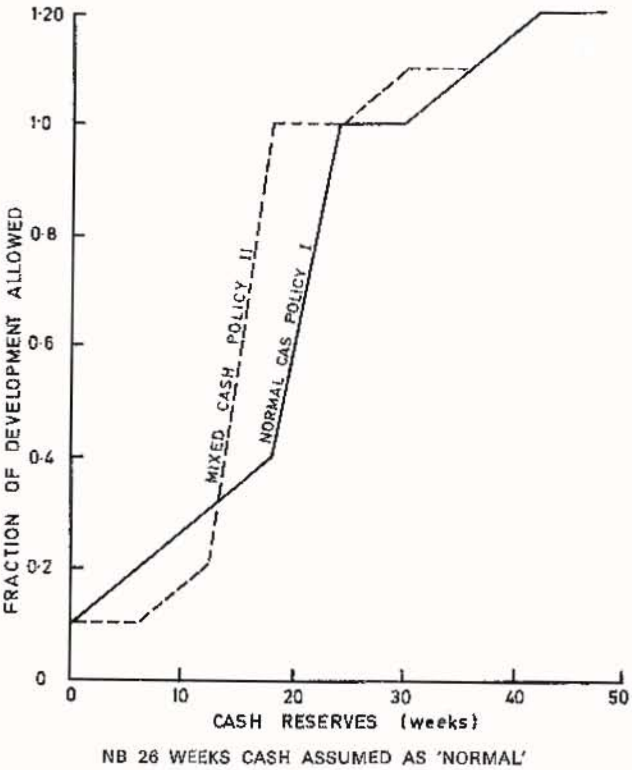
Production policy

The desired production is assessed by taking nominal capacity, scaling it up or down according to the policy type being followed and then apportioning the resultant production between the payable grades on the basis of their developed reserves. A small fraction (0.5 per cent) of the developed reserves in all grades is added to desired production in order to reflect, rather crudely, physical problems caused by intermingling of ore grades.

It is assumed that all ore mined is concentrated.

Cash policy

The desired development rate is scaled up or down according to the cash reserves available. This is shown in Fig. 3 which indicates two of many conceivable policies which could be adopted. The normal policy shows a sharp cut-back when financial reserves fall, the mixed policy is more aggressive for a while but then the cut-back is more severe. Clearly, a more sophisticated model of financial control procedures could be used and experiments may be made with different types of financial control.



NB 26 WEEKS CASH ASSUMED AS 'NORMAL'

Fig. 3. Cash policy curves.

Physical constraints

The resultant target production and desired development are compared with the corresponding maximum capacity and, if necessary, adjusted.

SIMULATION RESULTS

The form of the results from the computer simulation is shown in Fig. 4. Basically, it is a set of graphs of the model variables.

In this case three variables have been selected for illustration. These are the developed reserves, cumulative earnings and net return on investment (this latter is a crude measure of return on the money tied up in cash and developed ore).

Basically, this print-out shows a fairly unsatisfactory situation. There is a steady rise in cumulative earnings to a value of £6 908 $\times$ 10^6 at week 250, but there is a steady decline in developed reserves. This is caused by attempts to raise production at the expense of development when prices are high, coupled with cut-backs in development when a period of depressed prices has reduced cash resources below their 'normal' level. Generally, production was at a high level throughout the period (not highlighted on the graph) but there were three points when there was no production. There were points when the cut-off grade was high. In general, the system state deteriorates over the five-year period despite income of nearly £7 $\times$ 10^6 so that the system's policies (or rather those in the model) are not very satisfactory for coping with fluctuating prices.

The simulation experiments comprised five computer runs (many more could be performed). The characteristics are summarized in Table II.

TABLE II

SUMMARY OF COMPUTER RUNS

Run number	Production policy	Cash policy	Ore reserves desired (years)	CUMEARN at 250 weeks (£ $\times$ 10^3)
1	II	Normal	2	6 908
2	I	Normal	2	6 825
3	IA	Normal	2	6 807
4	II	Normal	1	5 785
5	II	Mixed	2	7 046

Comparison of runs Nos. 1 and 5 shows the effect of changing financial policies and comparison of runs Nos. 2 and 1 shows the result of modifying production patterns.

All runs show the same type of behaviour as illustrated in Fig. 4, with a steadily deteriorating cash position and developed reserves over the five-year period. It may, therefore, be said that the kind of policies modelled here do not deal satisfactorily with the situation arising from sharp variations in price.

However, there are differences in performance amounting to about 22 per cent between the best and worst but there are very small differences of only one or two per cent between the four best policies. There is, in fact, the rather unexpected result that reducing developed reserves leads to lower overall performance. The system has a much better cash performance, as was to be expected, but the attempt to follow a very frugal reserves policy leads to large reserves in the sub-economic grades and very small reserves in those which are payable. When price is low, the result is that the mine is practically closed during most of the last year of the five-year period.

It is interesting that the best performance is obtained with the 'mixed' cash policy described earlier. The difference is small on these figures but would be larger for a mine with more realistic details. This seems to imply that financial policy is more important than production policy, but that result should be treated with some caution until it can be confirmed with a comprehensive case study.

CONCLUSIONS

This paper sets out to demonstrate that the physical and policy interactions in a mining enterprise can be modelled and that the effects of policy on performance can be assessed.

It can certainly be argued that the proposition has been established. The differences in performance amount to about 22 per cent between one plausible policy and others, which could be regarded to be a significant amount. A more com-

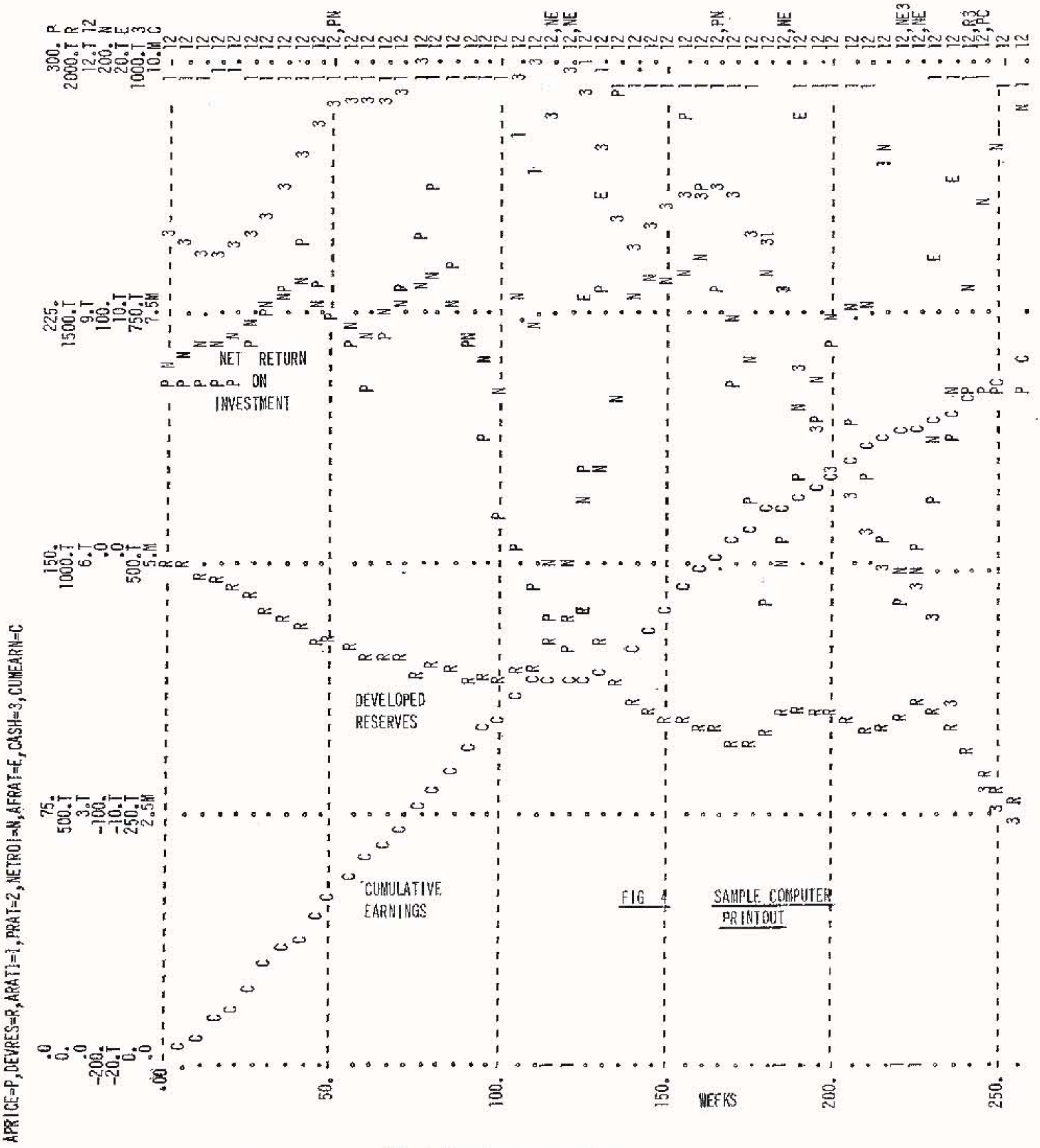


Fig. 4. Sample computer printout.

prehensive model with more realistic data would almost certainly reveal greater differences. It should also be noted that only some of the more obvious policies were analyzed. A detailed examination of the feedback loops shown in Fig. 1 would suggest policy combinations which could be expected to yield improved results. In this way a very refined balance of policies could be achieved. It is evident that the matter is more complex than simply maximizing some measure of performance and that one would wish to do something about the steady and potentially serious deterioration in system condition revealed by Fig. 4.

The conclusions are, therefore, that modelling the dynamics of a mining system presents no real mathematical or computational difficulties, that there are appreciable performance variations between one policy and another and that a comprehensive practical study is much to be desired.

ACKNOWLEDGEMENT

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REFERENCE

Coyle, R. G. (1970). A dynamic model of the copper industry—some preliminary results. *Ninth International Conference on Computers in the Mineral Industry*. June, 1970.