Planning of open pit mines on a risk basis

by O.K.H. Steffen*

Synopsis

This paper addresses the methodology of introducing risk into the development of mine plans for open pit mines. Recommendations are put forward for achieving a risk balance between mineral resource estimates and slope design. A design process identifying criteria for different stages of planning is presented. Business risk is separated from geological/geotechnical risk and procedures to address these within the development of mine plans are suggested. It is concluded that a formal design process improves communication between key decision makers and adds value to shareholders, investment.

Introduction

With the development of computer software packages, greater analytical capability has become available to mining engineers with improved computer-aided draughting packages. This paper deals mainly with the analytical processes involved in the planning of open pit mines. Normal planning procedures assume a target price and then develops a mining plan according to specific economic criteria. By definition, such a plan is only 'correct' if the price assumption is correct. For a mine with a reasonable life of say more than 5 years, price projections become highly speculative, and revised plans are generated as the price projections change. This can lead to gross inefficiencies in the mining layouts since the plans are usually sensitive to price. The technical planning function is concerned with the volume and cost of production delivered from the pit, which is the focus of the planning engineer. The result does not usually influence the market price directly, unless it is the major world producer of the commodity, so the price of the product need not be the only key parameter in determining the technical planning process.

Open pit mining becomes most effective for large tonnages due to the high degree of mechanisation that can be achieved, resulting in low unit operating costs making lower grade deposits more viable; high tonnages also imply a higher capital risk off-setting the advantage of low operating cost to some extent; a large producer could also affect the product price cycle. In this paper it is suggested that the risk can be adequately defined by the cost of production and the flexibility incorporated into the mine plan. Fundamental decisions during the course of planning have to be made which define the overall mine plan adopted and these fundamental questions are considered on the basis of a risk assessment. The general planning concepts enumerated in this paper are equally applicable to underground as to open-pit mines. This paper will confine itself specifically to open-pit operations.

Mineral resource estimation

All planning functions commence with an appreciation of the mineral resource estimate. Mineral resource evaluation falls outside the scope of this paper, but since it forms a major component of any risk associated with a deposit, some comments on the interpretation of mineral resources are required.

A tonnage/grade curve is the summary of the grade and tonnage distribution within the mineral resource and is a representation of the asset available for exploitation. Some deposits can not readily be represented in the traditional tonnage grade relationships, for example narrow vein deposits. Nevertheless, applying the principle of understanding that a relationship between tonnage and grade does exist even though it may not be easily quantified will assist the planning engineer in his decision process.

For planning purposes, it is assumed that the mineral resources have been properly categorised into the three main classes, namely measured, indicated, and inferred resources. For ease of reference these categories are referred to as CAT 1, CAT 2 and CAT 3 respectively.

* *Steffen, Robertson & Kirsten, P.O. Box 55291, Northlands 2116.*

These classifications are in effect statements of confidence or 'risk' and need to be clearly defined and included in the tonnage grade curve, as shown in Figure 1. An understanding of the grade distribution and tonnage distribution of the total resource is fundamental in the first step of composing a proper mine plan. Since the planning process is concerned about the physical exposure of ore in given time increments and at specific grades and tonnages, a full understanding of the risks associated with the specific locations of ore tonnages and grades is necessary. No planning should commence prior to a full appreciation and assessment of the tonnage grade curves as shown in Figure 1.

Slope stability

As in the case of mineral resource estimation, the determination of slope angles is dependent on the understanding of geological and geotechnical information and the confidence of design is equally based on the degree of certainty which applies to the data available. Unlike the case of mineral resource estimation, where the exploration is specifically targeted to provide ore reserve information, the requirement for slope design only becomes necessary once a prospective mineral resource has been discovered. Exploration core has usually limited value for slope design purposes as the target areas for slope design are not necessarily the same as for the orebody. Drilling requirements for geotechnical purposes also differ considerably from that for mineral exploration. Hence a limited campaign for geotechnical purposes is usually undertaken in addition to whatever value can be obtained from the original exploration campaign.

It is therefore not uncommon to have a slope design which has a much lower degree of confidence than that pertaining to the mineral resource definition. By definition, the mineable reserves within the resource are determined by applying a mine design which could economically exploit the resource. Within a life of mine plan, resources of different confidence categories will be included, i.e. CAT 1, CAT 2 and CAT 3 resources. By applying the mine planning procedures, these resources will be reclassified as proven, probable and possible reserves respectively, or CAT 1, CAT 2 and CAT 3 reserves respectively.

Maintaining a consistent assessment of confidence would require that the confidence of the slope design should match that of the mineral resource estimation between different categories i.e. CAT 1, CAT 2 and CAT 3 respectively. It is therefore proposed that for open pit designs, the confidence for slope designs should be categorised using the same fundamental approach as that adopted for resource/reserve definitions. This can be illustrated in Figure 2.

Definitions for the classification are suggested as follows:

A *proven slope angle* (CAT 1) requires that the continuity of the stratigraphic and lithological units within the affected rock mass is confirmed in space from adequate intersections. Detailed structural mapping of the rock fabric is implied which can be extrapolated with a high confidence for the affected rock mass and that strength characteristics of the structural features and the *in-situ* rock has been determined by the appropriate testing procedures to allow reliable statistical interpretations to be made. Groundwater pressure distributions within the affected rock mass should have been measured using piezometer installations to allow a high confidence in the groundwater model. Data reliability should be such that an analytical model can be used to carry out the design to a confidence of 85%.

A *probable slope angle* (CAT 2) corresponds to a design based on information which allows a reasonable assumption to be made on the continuity of stratigraphic and lithological units. Some structural mapping will have been carried out utilising estimates of joint frequencies, lengths and conditions. All major features and joint sets should have been identified. A modicum of testing (small sample) for the physical properties of the *in-situ* rock and joint surfaces will have been carried out. Similarly groundwater data will be based on water intersection in exploration holes with very few piezometer installations. Data will be such as to allow

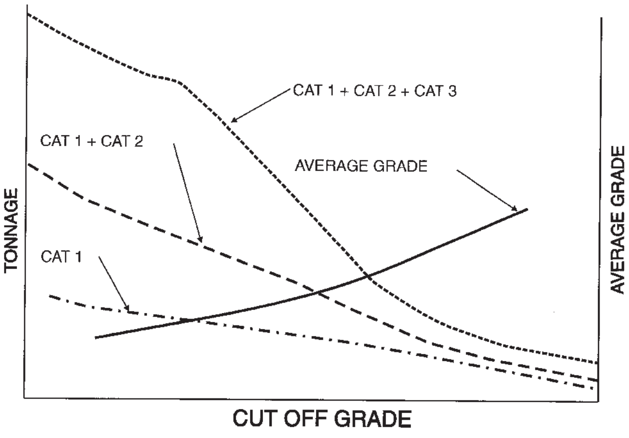

Figure 1—Characterisation of resources/reserves

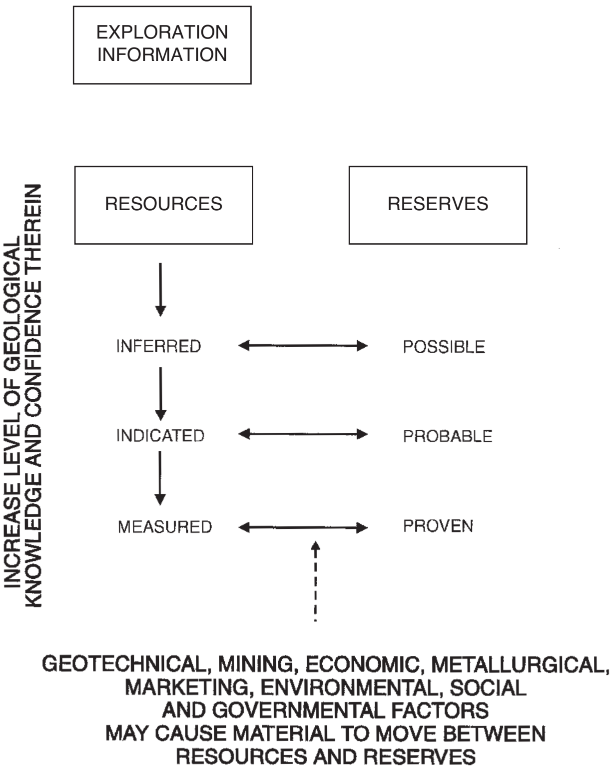

Figure 2—Classification of confidence levels

simplified design models to be developed to allow sensitivity analyses to be carried out.

A *possible slope angle* (CAT 3) corresponds to application of typical slope angles based on experience in similar rocks. Quantification will be on the basis of rock mass classifications and a reasonable inference of the geological conditions within the affected rock mass.

Planning processes

A systematic and disciplined planning process is advocated. Three distinct levels of planning are recognised in developing the reserves:

- ➤ Life-of-mine plan (LOM).
- ➤ Long-term plan (LTP), which follows from the LOM.
- ➤ Short-term planning (STP), which in turn follows from the LTP.

Each of these stages of planning represent different levels of risk and have different objectives. It follows therefore that the planning criteria for each planning phase should be different. Disciplined planning means that each of these steps are closely interlinked; for example, that every activity in the short-term plan benefits the long-term objectives as defined in the life-of-mine plan. This interaction can be illustrated diagrammatically as shown in Figure 3. A systematic planning process ensures that proper participation from all levels of management is able to be communicated to the planning engineer.

Life of mine plan (LOM)

Development of the LOM plan is the first step in the planning process and has the following objectives:

- ➤ define the inventory of ore reserve that is mineable within the assumed economic parameters
- ➤ define the production capacity for the remaining life of mine
- ➤ define the infrastructure requirements
- ➤ determine the fixed capital costs

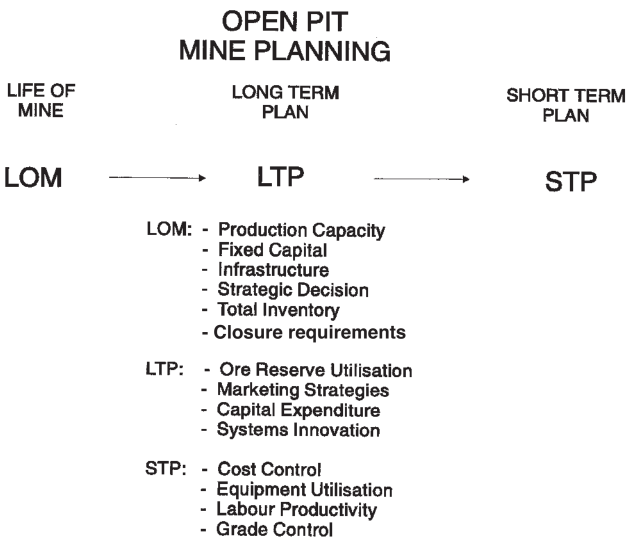

Figure 3—Planning procedure

- ➤ provide information for strategic decision making.

To achieve these objectives, certain planning criteria need to be adopted :

Cut-off cost planning criteria

The life-of-mine open pit represents that outline of the open-pit boundary faces beyond which no further reserves should be recovered by open-pit methods.

This limiting boundary can be defined by:

- ➤ the total ore reserve being exhausted
- ➤ the marginal increment of mining cost exceeds the expected income and that the economic limit of open-pit mining has been reached
- ➤ an underground operation becoming more profitable than the incremental open pits.

But for the first one, the limit in all of these criteria is defined by the increment in mining cost exceeding a specified value. The increment in cost is defined purely by the mining cost, i.e. when the increment in mining cost only is such that the total costs of product are too high. For an accurate definition, therefore, of the open-pit boundary, a criterion that is sensitive to the mining cost component needs to be used in defining this LOM pit limit. For this reason, a cut-off cost criterion is proposed which is the cost of producing the finished product from the final increment.

Typical financial criteria that are in common use, such as net present value (NPV) or internal rate of return (IRR), are insensitive to the boundary limit location. These criteria are most sensitive to the price assumed for the product, the production schedule for mining, as well as the assumed discount rate. Since the mining schedule, i.e. the order in which the ore and waste blocks are removed, is still unknown at this stage, these criteria cannot be used effectively for this purpose. When defining the total inventory available for exploitation, it is important that every block be afforded an equal opportunity to contribute to the profitability.

The cut-off cost criteria can therefore be summarised as follows: The LOM pit limits are such that no ore is mined which will result in the final product having a production cost greater than the cut-off value. The specification of this cut-off cost is related to an acceptable risk.

The first objective of the life-of-mine plan is to determine the maximum inventory of open-pit mineable reserves. The common process, assuming a block model, is to assign revenue and cost values to each block within the model and to use either the floating cone or Lerch-Grossman algorithm in defining the economic boundaries to the number of ore blocks that can be recovered from open-pit methods. The maximum ore reserve available is therefore a function of the value assigned to each of the blocks. Ore blocks will have positive values when revenue exceeds costs, and waste blocks will have negative values.

Consider the marginal ore blocks. The potential of the marginal ore blocks are threefold viz:

- ➤ processed as ore in the normal manner
- ➤ considered as stockpile for treatment by a different process e.g. leaching, or at a later time when cash flow or price variations allow
- ➤ considered as unpay and treated as waste for the evaluation in hand.

Depending upon which of the three potentials are applied to the marginal blocks, three different values will be assigned. Marginal ore blocks with the highest real value would release the greatest number of positive underlying ore blocks. Depending, therefore, upon whether marginal ore is processed or dumped as waste or stockpiled will alter the total inventory available for open-pit mining.

The life-of-mine plan thus provides the outline of the ultimate pit providing the maximum mineable inventory, from which the infrastructure development can be properly located. This prevents expensive relocation at later stages or compromises the ore development programmes, when market conditions change. Compared to the traditional cut-off-grade approach to pit design, the essential difference lies in the emphasis on determining the mining costs, be it either to the ore process point or to a stockpile or waste location. Should there be no difference between the tramming costs to the crusher or the dumping location, then the adoption of a marginal cut-off grade for process only, will result in the same design as the use of the cut-off cost. The procedure suggested here, however, emphasises the decision based on a cost of production rather than a profit which is related to an assumed price. The life-of-mine plan is therefore a definition of the inventory available which then has to be exploited and managed in order to provide the maximum value to shareholders in accordance with corporate policies and philosophies.

Assuming different cut-off costs, the total inventory available in each incremental cost can be calculated and presented on the curve as shown in Figure 4. The average cost of mining to within this cut-off cost is represented by the average cost curve. All figures are presented in present-day value terms and represents the marketability of the ore reserve on the world market in competition to other reserves. Figure 4 can therefore be used in the marketing strategy of the mine which leads to strategic decision making and provides the communication medium between marketing, management and planners.

In this Figure it is assumed that the cost of production represents the minimum in terms of the present technology for operations. The function of the mine planning department is to constantly review the operational methods adopted and to adopt those methods and technology which will see a further reduction in the cost of production. In this manner, as the whole emphasis is based on cost, the efforts from the mine planning staff are directed systematically and purposefully towards the single goal of reducing costs for the purpose of defining the LOM plan.

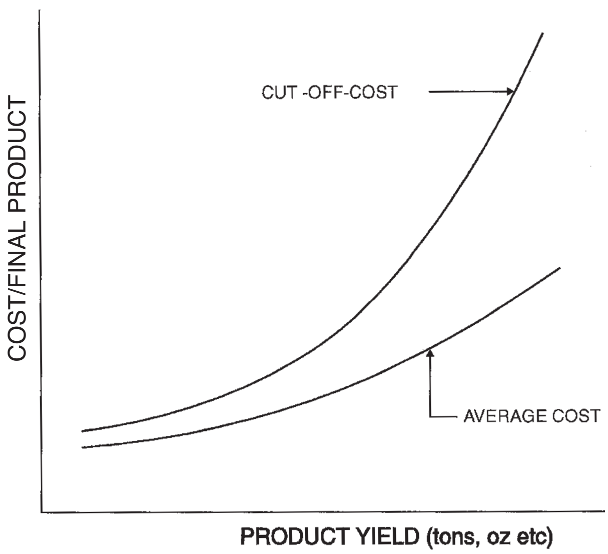

Figure 4—Reserve marketability

Defining an acceptable cut-off cost

Deciding on an acceptable cut-off is a business decision. It reflects the optimism and the risk which the company is prepared to accept in investing in the particular ore reserve. Some guidelines and principles underlying such a decision can, however, be postulated as follows:

Firstly, the tonnage vs cost relationship (Figure 4) for the ore reserve can be a first indicator. Should the relationship indicate an inflection point then this could be taken as a decision on cost limit since the risk of increased cost is not matched with a corresponding increase in product. Since the risk level is largely determined by the ore reserve reliability, this point indicates a natural cut-off point. From previous case studies, not all ore reserves display this inflection point.

Where the inflection point is absent, the next option is to consider the cost in relation to other world producers. Reference to a world producer cost curve is therefore necessary as shown in Figure 5. The relative position of the planned operation on the world producer cost curve is a function of corporate philosophy, e.g. some companies would tolerate only an operation with a limiting incremental cost which falls within the lower 50%, others within the lower two third (66,7%) or others, again, within higher limits e.g. 85%. This decision represents the corporate philosophy on investment risk as well as market image.

It is necessary to distinguish between the cut-off cost and the average operating cost. World producer cost curves represent the average operating costs and not the marginal costs of any particular operation. Since the cut-off cost is at which it is proposed that the operation cease to produce onto the market, the cut-off cost chosen must be based on comparisons with other operations which are likely to have a comparable effect on the world market if they were to cease operations. It also represents the acceptable margin of risk compatible with the company's stated mission and philosophy. The margin of risk acceptable to a life-of-mine definition is also a function of the certainty with which the information is known, e.g. ore reserves and slope angles.

Thirdly, the cut-off cost could be based on the break-even equivalent underground operating cost. These cost comparisons are made on an operating cost basis only, ignoring capital. Clearly, the capital cost for underground development and establishment needs to be included in the total evaluation exercise. The allocation of the boundary ore reserves to underground and open pit operations can readily be incorporated into the Lerchs-Grossman or floating cone algorithm by assigning values to these boundary blocks equal to the difference in value obtained between underground and open-pit operating costs.

Since the OP/UG boundary is not known at the outset, the procedure adopted is as follows:

- develop LOM pit shell on the basis of no underground alternatives; cost of mining equipment capital should be included

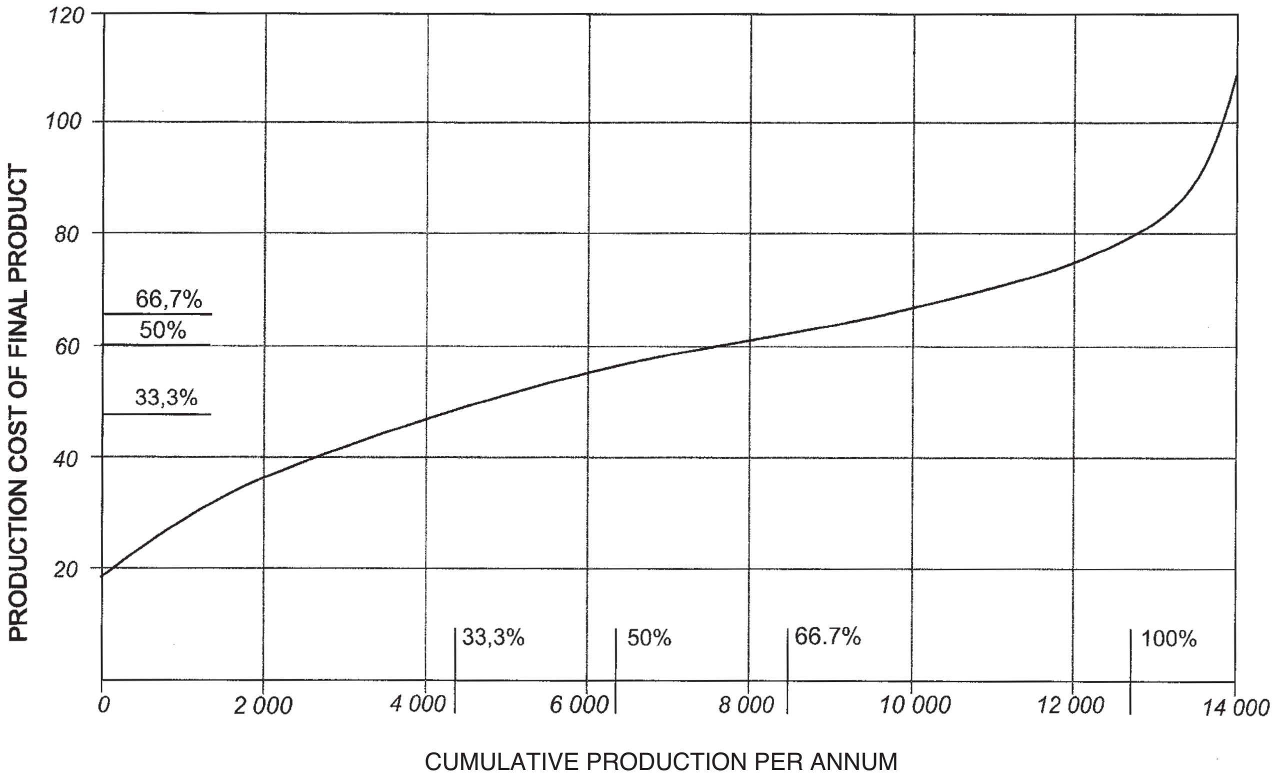

Figure 5—World producer cost curve

- develop an underground mining alternative and assign net values to each ore block; cost of capital should be included
- assign block values equal to the differences between open pit and underground valued blocks in the potential overlap areas
- using these adjusted block values, re-run the pit optimisation algorithms to define the best cut-off limit between open pit and underground.

Based on the appropriate cut-off cost criteria, the final limit can therefore be established and total reserves and inventory determined. This information is then utilised for the establishment of infrastructure requirements and life-of-mine capital investment requirements. Strategic decisions can now be made in regard to production rates.

Long-term planning principles

Having defined the inventory and spatial location of reserves and dumps from the life-of-mine plan, the long-term plan must now devise an operating and mining strategy to achieve the following objectives:

- maximise value for investors
- minimise risk to investors
- maximise life of mine.

These objectives are to some extent contradictory and a maximum NPV cannot correspond to a minimum risk or a maximum life and therefore a suitable compromise must be developed in the long-term plan.

Suggested ranked order of design criteria for the LTP are:

- an acceptable return for shareholders corresponding to the market sector and corporate philosophy
- an acceptable operating cost to final product relative to world producers
- flexibility requirements within plan e.g. upside potential: to increase product volume by 15% within 6 months sustainable for 12 months; downside potential: to reduce unit operating costs of final product by 10% within 3 months sustainable for 24 months
- maximise NPV.

Figure 6 provides a flow diagram illustrating the input, design processes and the outputs of the inter-relationship between the LOM plan and the LTP.

Discounted cash flows are the common basis for evaluating shareholder returns and are expressed in terms of NPV or IRR or similar. Typically a NPV calculation is most sensitive to the following parameters:

- the price of the product
- the discount rate
- the time sequence of the mining schedule
- the cost of production.

The last two parameters are generated by the mine planners while the first two are beyond their control.

Risk on the other hand is sensitive to price fluctuations, flexibility within the plan and management skills.

Life of the mine is sensitive only to the mining strategy or grade utilisation, i.e. the scheduled mill head grade and the development costs.

The need for compromise decisions between maximising a short-term financial return with a longer term acceptable risk can readily be illustrated in a simplified diagram as shown in Figure 7. The minimum cost curve in Figure 7 is the same as that presented in Figure 5, determined in the

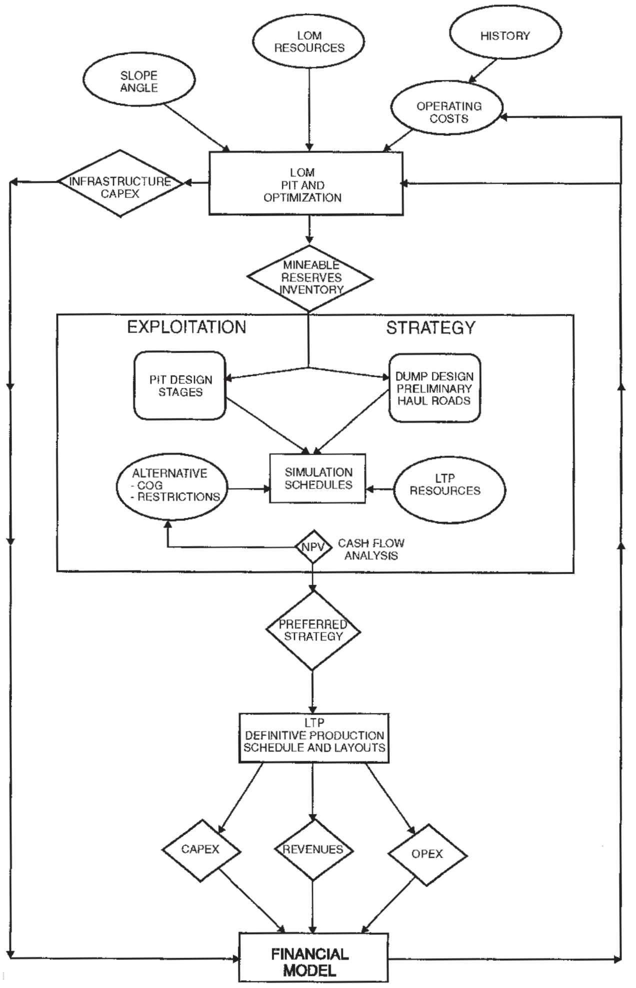

Figure 6—Planning process flow diagram (after Larrain, Thiele)

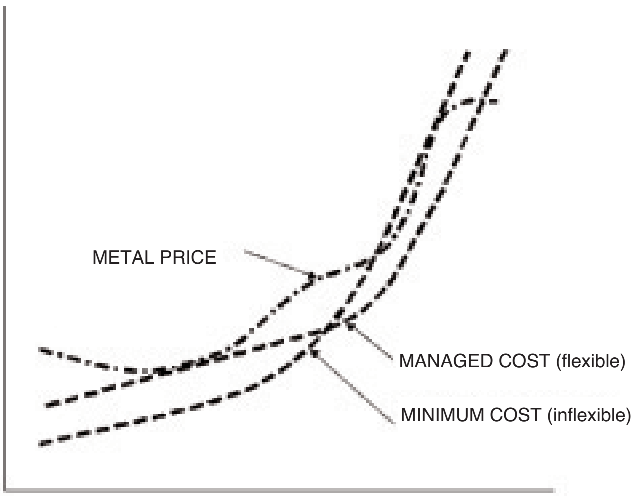

Figure 7—Simplified risk diagram

life-of-mine plan. Should the future price of the product vary as indicated in the diagram, the mine is at risk of premature closure. Since the reserves were developed at a minimum cost in the attempt to maximise the NPV, it implies that there is no flexibility within the system in order to vary the production costs. Therefore the risk associated with maximising the NPV is high. Flexibility, however, has value to the shareholder. This value should be determined using option theory and added to the cash NPV to give a total value, also expressed in NPV terms. The total NPV should be maximised in the planning process.

Should the cost of production be managed differently, e.g. the LTP allows for advanced stripping above that required by the minimum cost curve, then the cost could typically be as represented in the 'managed' cost curve shown in Figure 7. For this case, the total benefit exceeds that of the previous minimum cost case, i.e. a retrospective analysis would show a higher NPV for the latter case due to the introduction of a decision on risk. In Figure 7, the metal price curve is unknown while the other two curves are determinants.

Most large open pit mines in the world operate on this basis by adopting an average stripping ratio over the life of mine. While the waste to ore ratio does define costs of mining to a large extent, it is more appropriate to focus on actual cost of production rather than just one of the parameters contributing to cost of production. Cost should also be based on total cost of final product, not only of the mining operation. It is therefore suggested that the cost of operation for the mine be determined by a management decision having regard to the minimum cost possible but incorporating an assessment of risk while satisfying the return necessary for the investment made. The basis for an assessment of risk is associated with a period of time for which additional development costs are acceptable.

Business risk period (BRP)

In developing the concept of a business risk period, it is necessary to distinguish clearly between the risks associated with business decisions which are time related from those risks which are related to nature, e.g. such as geology, ore reserves, slope angles, weather, etc. The business risk period is one of the most fundamental parameters which need to be defined for any business, and relates to the length of time that is anticipated the business would remain sound. It is also the period over which certain investments are required to produce profits and the investment policy is therefore determined by the business risk period. The BRP is not dissimilar to a payback period. For mines the business risk period is a function of the following parameters:

- new discoveries which create competitive changes in the market
- the time taken for new mines to be brought into production
- changes in technology of geological, metallurgical and mining applications
- the position on the world producer cost curve of the operation
- pay-back requirements on investments, which would include a political risk.

Periods associated with each of these parameters for a fictitious example could typically be as follows:

New discoveries:	1 year
New mines into production:	4 years
Technology changes, metallurgical:	15 years
Technology changes in mining:	10 years
Position on world producer cost curve:	5 years (say)
Pay-back period:	5 years

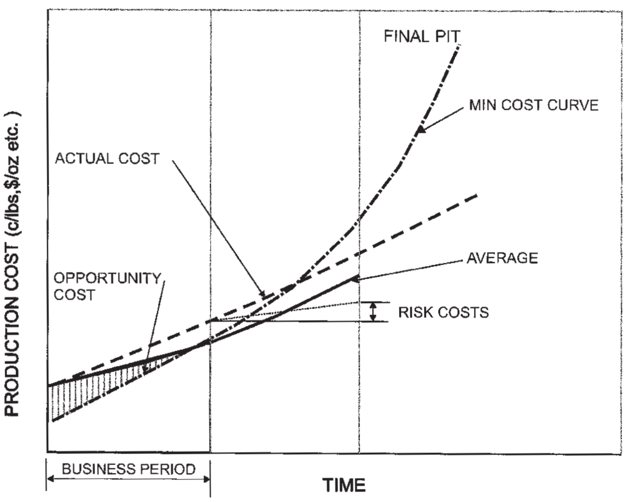

Figure 8—LTP schedule

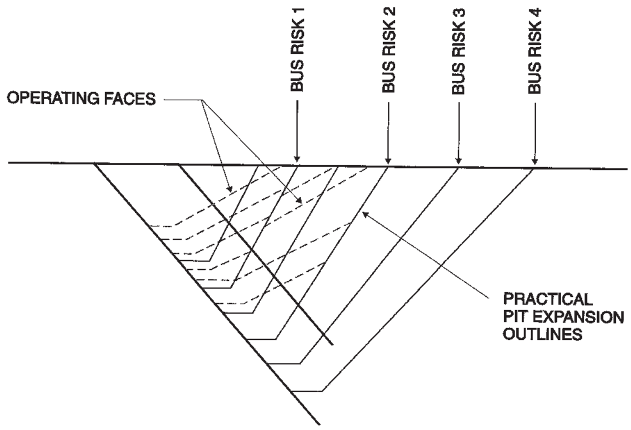

Figure 9—Diagrammatic pit sequence expansions

From the above example, a waited average of approximately 7 to 8 years would result for the business risk period (BRP). Hence the mine would be prepared to make non-recoverable investments for a period of 7 to 8 years, i.e. advanced stripping for a 7 to 8 year ore exposure commitment. The accepted cost of production can then be related to a business period as illustrated in Figure 8.

In the first year of the business period, it is proposed that the average of the minimum cost over the total business period be adopted. The actual cost curve over the life of mine is therefore taken from successive mean averages of 7 or 8 year periods, making the suitable adjustment for investments already made in the prior years. In this way the planned long-term cost curve can be extrapolated over the life of mine, resulting in a maximum risk exposure which is confined to the business risk period at all times.

From this curve, the ore reserve corresponding to the business period can be determined and the outline of the pit corresponding to the end of the first business period can be developed in a normal manner, as shown schematically in Figure 9. All overburden stripping should therefore be confined to within the limit of this pit outline. Should the decision be made for any unforeseen reason to close the pit prematurely, then no stripping outside of a defined risk period would have been undertaken.

Since operating slopes are generally much flatter than the final pit design slopes, the scheduling of overburden stripping will progress to the outline of the business risk final pit profile, until such time as space constraints prevent the achievement of production targets. Stripping is then scheduled to within the boundary of the next business period outlined, as indicated in Figure 9. Each BRP pushback must be designed as if it is a final, pit i.e. incorporating maximum slope angles.

Pushback expansions

Probably the most important planning decision made by the planning engineer, is the width of pushback that needs to be utilised in the development of the mine plan. It is one of the most fundamental decisions required in mine planning and for which very few criteria are available. Most commonly, one of the criteria is to take as little waste for the required ore exposure to maintain ore production given a minimum ore reserve exposure requirement. The just-in-time principle would apply for ore exposure under these planning parameters. This strategy results in another serious difficulty of an inflexible operating slope angle, for any change in the slope angle results in an increased waste stripping requirement for short-term ore exposure. Normal practice is to change the slope angle as experience is gained with mining and the flexibility to change is important in the mining strategy.

The selected pushback width has a number of very important consequences on the operation. Firstly, blasting efficiencies are improved with wider pushbacks, since the number of berms on the outer edge of the bench is minimised for the total volume per unit of strike length advance. Spillage over the edge and into roadways and operating faces below the pushback is therefore minimised. Saving on haul roads on benches can also be realised since the length of access road on the bench per metre of strike advance is reduced. Wider access ways means the equipment moving more freely without any holdups en route. This applies both to truck fleets as well as ancillary fleets.

Shovel operating efficiencies are also lowest at the open edge of the bench and by widening the pushback, the number of open edges per unit strike length are also reduced.

A wide pushback is often interpreted as requiring additional pre-stripping before ore exposure is obtained. This is only true if the strike length is short and the pushback has to be applied to the overall strike length of the pit. Where large orebodies are evaluated, this does not apply since the pushback can be limited in the strike length to conform with the total waste ore ratio as required. Pushbacks that operate on the minimum operating width result in no flexibility of changing the ultimate slope profile from what the current profile is. Therefore, as information on rock slope conditions becomes available, the modification for slope design cannot be easily implemented.

Provided that pushbacks fall within the business limit boundary as defined previously, the pushback width should not have any cost implications to the overall plan except by reducing unit operating costs due to increased efficiencies. The business period limits, therefore, provide a useful criteria for pushback design.

Scheduling

Accepting, therefore, that the mining will proceed along a basis of a defined cost of production in terms of final product, many potential scheduling options now remain. A series of sequential pushbacks can now be planned and ranked in increasing order of cost of production. Inventory that has been defined for each of the pushbacks can now be scheduled in terms of production cost. The only variables that can be managed are the head grade and the stripping ratio, which ultimately determine the operating costs. Scheduling the inventory and the logistics of the design pushbacks can now be undertaken, based on set criteria, e.g. maximum NPV, minimum cost, specified costs etc. (for different combinations of head grade and stripping ratios over the long-term). Comparative schedules can be produced and an optimum selected. See Figure 6. This optimum should be defined in terms of the criteria specified earlier.

Accepting a defined cost has some interesting other consequences in terms of the mine planning requirements. Given that the cost will be fixed, the objective of the mine planning will therefore be to apply this cost in the most beneficial manner. This translates into exposing the maximum reserves for the given cost of operation. Minimising haul distances provides the maximum stripping rate for the same cost and hence the maximum amount of exposed reserves. The additional cost incurred over and above the minimum cost is therefore being invested into exposed reserves, providing additional flexibility and reducing risk.

Cost modelling

Accurate cost modelling forms an essential part of this particular process. Different cost models apply to the different planning phases. Cost components can be isolated in the following manner:

- Fixed costs: non-discretionary/discretionary
- Variable costs: non-discretionary/discretionary.

In the case of the LOM plan, the cost model should include total mining costs, i.e. fixed costs, variable costs and all mining equipment capital costs discounted into the unit mining operating cost. In the case of the LTP only variable unit costs are included as all capital items can be accommodated into the cash flow analysis. At actual pit closure, ultimate costs will comprise only variable costs with fixed and discretionary costs minimised.

Many mining simulation software packages are available which can produce a realistic schedule of production costs over the long term. Projections of cost in the long term rely on a knowledge of escalation of different components of cost.

It is convenient to separate out the cost components in the following manner:

- energy costs
- maintenance costs
- labour costs
- capital costs.

Each of these cost components can be escalated at a different rate to determine the project-sensitive parameters. Since cost escalations are generally more reliable than the prediction of future prices of any product, the risk evaluation of alternative project strategies are often determined by comparing the net present value of the life of mine costs only. When comparing it to other operations on the world cost curve, it should be assumed that all operations present a minimum cost of production. Since Figure 6 is a window of present production costs on a worldwide basis, the best comparative figure to use is the present-day value of the average operating costs.

Short-term planning

From a defined long-term plan, short-term planning now applies to a one year period within a single business cycle. Short-term planning has as its major objectives:

- grade control
- cost control
- equipment utilisation
- capital productivity
- labour productivity.

The short-term planning process is therefore concerned primarily with the day-to-day scheduling of feed grade to the mill and stripping requirements for the first 12 to 18 months of the LTP. Equipment utilisation includes the planning for equipment replacement, repurchase and manning schedules for determining labour productivities. Short-term planning must ensure that the long-term planning goals are achieved on a daily, weekly and monthly basis.

Planning risks

Risks associated with planning are related to the confidence which applies to the mineral resource (geology and grade distribution), the mining plan (geotechnical) and the business assumptions (price fluctuations). These risks can be addressed by upgrading information in the case of the first two and by providing flexibility within the plan in the case of the latter. In all these cases risks can be reduced by incurring more expenditure but can never be eliminated. Accepted risk levels will vary from company to company. Fault /Event tree analyses provide a formalised way of adjudicating the value added by additional information. A typical example for an underground gold operation is presented in Figure 10.

Frequently options are compared on a DCF basis only, even though they represent very different risks of achievability, or in some cases are combined with a subjective assessment of risks applicable to each option. A formalised risk evaluation as proposed, provides the opportunity of determining the relative costs to equalise the risk for each option and therefore makes the DCF comparisons valid.

In the fault tree, contributing elements to the Top fault of producing too few ounces, are analysed to the most fundamental parameters. At this level, the reliability of information can be reasonably estimated, as well as the cost associated with improving the reliability. In applying the branch network of the fault tree, the combined impact of all the elements can be summoned to result in a probability of the Top fault happening. This procedure is therefore useful to identify the critical areas requiring additional expenditure.

Ultimately the technical planning risks can be presented as shown in Figure 11. Categories 1, 2 and 3 reserves represent the different confidences of mineable reserves, i.e. after the application of ore reserve and geotechnical

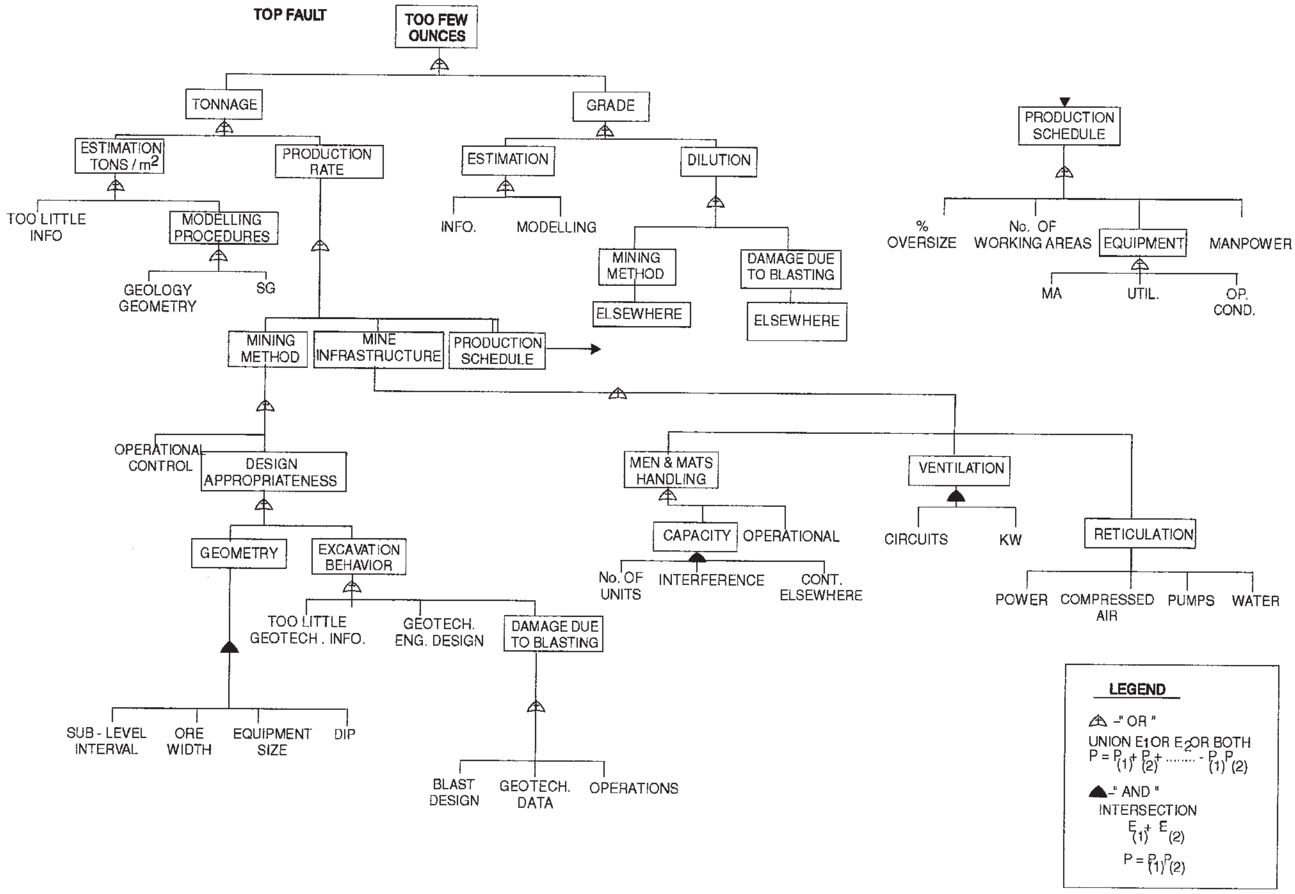

Figure 10—Typical fault tree risk analysis

confidences to the mine plans. It should be noted that 'reserve' in this context is not only the primary grade data but all the information that may impact on the marketability of the product e.g. contaminants, particle size etc.

Figure 11 suggests that a decreasing confidence should be incorporated with the increase in the planning time scale. The rationale behind the concept being that the exploration program for mineral resource definition should be closely tied with the planning process to achieve maximum benefit for the exploration dollars. In this context the exploration includes orebody definition drilling and geotechnical information gathering, but excludes any greenfields exploration for new resources.

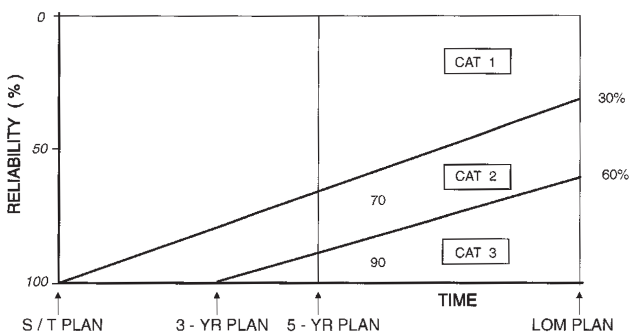

Figure 11—Ore reserve reliability by category

Conclusions

Integration of the three planning levels from life-of-mine, to long-term, to short-term planning, provides a robust planning procedure which allows for good communication between all levels of concerned personnel. That is, from the planning engineer through management to marketing departments.

The cut-off cost criteria for planning is a practical and a more useful means than the normal price estimate or cut-off grade approach; reduces the amount of work involved and concentrates the efforts and skills of the planning team on those issues which they can contribute most to, i.e. improvement of the mine plan. The application of the cost-based long-term planning scheduling means that risks can be properly assessed in terms of a business risk period and the best solution obtained between return on investment and risk of operation. The end result of the planning process is a maximum exposed ore reserve for a given cost of production.

The difference between the proposed procedure and that which is commonly in use today, is that the planning process is driven by the competitiveness of the ore reserve on the world market. Management participate actively in planning decisions and determine the planning criteria. These concern the expected rate of return for shareholders, the risk levels acceptable to the company, the flexibility required in the operation and the acceptable cost of operation.

Conscious decisions need to be taken about certain fundamental parameters, such as the period of risk defined as the business risk period, as well as the pushback size.

Experience has shown that the improvement in communication and understanding of decision-making between management and planning engineer has added considerably to the growth in shareholder's value.

Bibliography

Australian Code for Reporting of Identified Mineral Resources and Ore Reserves: Report of the Joint Committee of the IMM, Australia Institute of Geoscientists and Mineral Council of Australia (JORC). July 1996.

Ore Reserves and Resources—Colloquium SAIMM. July 1995.

JANISCH P. 'Classification of South African Mineral Resources and Reserves within the International Framework', note prepared for 15th CMMI Congress, Sun City. 1994.

MISKELLY N. 'A Comparison of International Definitions for Reporting of Mineral Resources' *IMM Bulletin,* no 4, July 1994.

SRK Internal Reports.

LANE K.F., 'The Economic Definition of Ore', Mining Journal Books. 1991.

BRENNAN M.J. and SCHWARTZ E.S., 'A New Approach to Evaluating Natural Resource Investments', Stern J.M. and Chew D.H., (eds). *The Revolution in Corporate Finance,* Basil Blackwell, 1986, pp. 78–87.

BLACK F. and SCHOLES M. 'The Pricing of Options and Corporate Liabilities', *Journal of Political Economy,* LXXXI (1973), pp. 637–654.

BRENNAN M.J. and SCHWARTZ E.S. 'Evaluating Natural Resource Investments', *Journal of Business 58.* pp. 135–157, 1985.

PINDYCK R.S. 'Irreversibility, Uncertainty and Investment', *Journal of Economic Literature,* vol. 29, no. 3. September 1991.

TRIGEORGIS L. and MASON S.P. 'Valuing Managerial Flexibility'. *Midland Corporate Financial Journal,* vol. 5, no. 1. Spring 1987.

ANG A.H.S. and TANG W.H. *'Probability Concepts in Engineering Planning and Design',* Wiley J., vol. no. 1, N.Y. 1975.

ANG A.H.S. and TANG W.H. *'Decision Risk and Reliability',* Wiley J., vol. no. 2, N.Y. 1975.

LORRAIN M. and THIELE C. Anaconda, Chile. Private Correspondence. ◆

Dr Diane Hildebrandt wins Meiring Naudé Medal*

The Royal Society of South Africa, the oldest multidisciplinary science-based society in the country, has awarded the Meiring Naudé Medal to Dr Diane Hildebrandt of the University of the Witwatersrand's School of Process and Materials Engineering.

The Meiring Naudé Medal is awarded annually to a candidate who has made an outstanding contribution to science in Southern Africa and is less than 35 years of age in the year of nomination.

This is just one of the many accolades which are proving Dr Hildebrandt to be among the country's, and potentially the world's, most promising young researchers. Last year she won the FRD's prestigious President's Award for young researchers showing exceptional potential.

Dr Hildebrandt is the first engineering candidate to win the Royal Society's Meiring Naudé Medal since its inception 13 years ago. This is the fourth time a researcher at Wits University has received the award. Two of the previous Wits winners were in the physics field and the third was from the Department of Mathematics.

The citation to Dr Hildebrandt for the 1996 award read that she was 'a young enthusiastic researcher who has gained an international reputation for her work on the geometric approach to chemical reactor optimization'.

She has developed these ideas together with Professor David Glasser at Wits University. Together they have attracted a large number of students from South Africa and abroad to their Centre for Process Modelling and Optimization. Their novel approach to process synthesis has enabled them to find answers to previously unsolved problems and has excited researchers worldwide. In particular researchers from the UK, Norway and the USA are incorporating the results of this research into their own work.

Dr Hildebrandt is now extending the theoretical basis of this work in collaboration with Professor Marty Feinberg of the University of Rochester, USA. She is also extending the research into new areas such as the synthesis of systems involving separation heat exchange as well as reaction. This will enable the method to be used for problems of industrial importance. In fact industry, both locally and internationally, has already begun to show an interest in the work. ◆

* *Issued by: Lynne Hancock Communications, P.O. Box 180 Witkoppen,* 2068.