The use of Monte Carlo simulation for operations management decision criteria

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Gold Fields is the world’s fourth largest gold producer with operations in South Africa, Australia, Ghana and South America. All of Gold Fields’ South African Operations are located in the Witwatersrand Basin and are intermediate to deep level underground mines exploiting gold bearing, shallow dipping tabular orebodies, which have collectively produced over 50 kt (1,608 Moz) of gold over a period of more than 100 years.

Although the use of Monte Carlo as a business tool was introduced in 1964, it has only been in the last 30 years that it has gained increasing acceptance within the mining industry. However, the application thereof has been mostly limited to determination of risk in project areas. This paper however, considers the possibility of using Monte Carlo simulations to assess the underlying ‘Root Cause’ criteria critical to the operations management of existing mining operations.

Currently, working operations have a distinct advantage over project areas as they have a wealth of historical information at hand. This, in turn, can be utilized to model distributions and relationships that can be used in Monte Carlo simulations, the results of which can be analysed to determine areas of concern. Projects can then be set up to ameliorate the effects of these and in turn reduce the risk of not achieving the operational targets.

It is here that it must be stated emphatically that it should be the ‘root causes’ and the associated relationships that need to be emplaced within the model in order to achieve results that reflect the true causal relationship.

The paper outlines possible sources of ‘root cause’ relationships and considers the outcomes of these in a case study on a large South African Gold Mine.

Introduction

The basic concept of operational management risk analysis is to determine the root causal factors that contribute to the final product. The distribution of these and subsequent correlations are then modelled and used in an analysis of the causal relationships in order to determine the effect on the final outcome. Once it is determined what the most significant drivers are, processes can then be put in place in order to ameliorate the effect of these.

Operational plans for short to medium term are beset with problems that appear at first glance to be of a random nature. Often tasks are prioritized on a first come first served basis with little cognisance taken of the criteria that have the greatest impact on production. This is not to say that production personnel are amiss in taking their work seriously, on the contrary, there are many mining engineers who consider it their honour bound duty to provide a service that is commensurate with the responsibility bestowed upon them. Nevertheless there are occasions, and these occur on a regular basis, in which the engineer cannot see the woods for the trees. What are the items that require a longer term consistent effort and what are those items that need immediate attention and thereafter can be placed on the back burner? What are the problems that if one resolves will provide the greatest benefit? How does one identify these, and when identified, what do we do to correct them. In other words, what are the root causes for production shortfalls? Once these have been identified, most often the solution becomes abundantly clear.

The root cause analysis

This part of the total analysis is to often skinned over in the eagerness to proceed with the exciting ‘stuff’. However on the other hand, if the team goes into extreme depth the task at hand can become unduly onerous.

So where does one pitch the level of analysis?

Fortunately, we already have the answer to this question. It lies in the subdivisions already existing in most, if not all mining companies, that is, at departmental level. This is not to say that the concept of root cause analysis is a misnomer, quiet the contrary, the author is merely advocating that the analysis be subdivided into sizeable chunks that can be dealt with by the relevant specialist in that field. Consider the following example. The analyst obtains and examines the relationship between the portion of complements at work per working place and the subsequent production statistics, and finds there is a strong relationship between these two variables. Insofar as the analysis for mining personnel is concerned, one of the root causes has been established. It is now up to the human resource department to determine the greatest cause of absenteeism. Suppose that this is found to be due to sickness, and, furthermore, most sick notes relate to disease that can be referred back to dietary requirements. One can now model only these relationships, rather than having to trace every causal effect back to the nth degree.

As intimated by the heading this, analysis identifies the root cause for certain output variables. It does not help to say that ‘our main problem is that we do not achieve our
square metre calls'. This is merely stating the end result of a series of other variables that have contributed to this outcome. These possible root cause variables need to be identified and, then, correlations checked to see if the effect is of a significant nature. Consider the example of square metres planned not being achieved. Here we have a few possible causative variables:

- Temperature within the workings
- Number of boxholes servicing number of panels
- Number of persons at work in crews
- Time taken to workplace, or face time
- Is the area a new raise or a pillar area.

In the case of continuous variables the distribution of say temperatures is modelled initially and then the correlation of temperatures against square metres achieved is modelled. In the case of a binary distribution, the correlation between variables can be modelled.

Another example could be the relationship between MCF and sweepings as well as MCF and fragmentation. Once again the distribution of sweepings and fragmentation sizes are modelled and then the correlation between these and the MCF are modelled.

Using the process flow as a root cause analysis medium

It is in this area that the greatest benefit can be obtained prior to using the Monte Carlo analysis tool. Fortunately, mining is ideally suited to a process flow analysis; this in turn can be used to identify possible root causes for production deficits. Consider the following process flow diagram that indicates only a small portion of the overall process flow and does not include all causative variables. See Figure 1.

As can be seen from Figure 1 some causative relations have in turn there own causative relationships. It goes without saying that without a process flow model, the modeller could become confused and miss necessary effects. It is here that the author must mention that not all relationships can be, or even should be, modelled. Due cognisance needs to be taken in determining cut off points in detail and attempts should not be made to thumb suck parameters if one is unsure of the causal effect. This could lead to undue effort and monies being spent on rectifying parameters which due to the uncertainty on their behaviour produce spurious results.

**Basic principles outlined**

The basic principles to be applied to any risk model can be determined by asking the obvious question of what it is that we require from such modelling? This can be encapsulated within the following few points:

- What are the factors that are the greatest contributors to deviations from the end product
- What can be done about these factors
- What is the effect on the risk profile if alternative scenarios are envisaged
- If controls are emplaced what will this do to the risk profile?

In order to obtain the necessary answers to these questions one needs to follow the following procedure:

- Identify principle components for analysis
- Do analysis of variables and correlations
- Use results of ii for input into risk model
- Run simulation
- Rank principle components in order of effect on output
- Identify 80:20 principles
- Determine actions to minimise effects
- Quantify effects of actions in vii
- Re-run simulation
- Quantify final risk.

The abovementioned process may be of a circular nature in which suggested actions may not necessarily be of a sufficient nature. In which case additional action items may then be identified and the points viii to x re-run.

**Instances where principle components cannot be identified**

In some cases such as in gold price fluctuations, the root cause for the change in variable cannot be identified. All is
not lost in cases such as these. Firstly, the variable is checked for trend and secondly, if a trend exists, the variance around the trend is identified and applied. If no trend exists then the distribution is modelled and applied. Under circumstances were this method is being used, care must be taken to model sufficient data, in order to obtain a trend or distribution that is indicative of the time period under review.

Consider the graphs in Figures 2 and 3.

As can be seen from Figure 2 for the short-term that is operational plan, a relatively simple linear estimate will suffice for a model. When considering the rand to dollar exchange rate, a slightly more sophisticated model may be necessary in order to replicate the periodicity of the variable in question.

It now becomes a simple matter to use the associated variance of the residuals and the models of both rand price and rand dollar exchange rate to generate possible rand per ounce values for ensuing periods. In the examples above the rand gold price estimated for financial year 2010 is R267815 per kilogram with a standard deviation of R1536. Care must be taken to consider enough information to determine trends that are indicative of the period under review. The trend from three months of daily gold prices can hardly be considered an effective indication of trend for a fifteen years life calc.

Running the Monte Carlo analysis

Unlike traditional Monte Carlo analysis, here we are not only considering the distributional characteristics of the variable in question, but also the relationship the independent variable has with the dependant variable, as well as the variability around the modelled relationship. Firstly, we have an independent variable which occurs according to certain distributional criteria. This distribution is sampled randomly and a value selected. The selected value is then emplaced within the model that represents the relationship between the independent and dependent variables and a resultant value for the dependent variable is obtained. However, unless the relationship is a perfect one there is a scatter of residuals around the modelled trend. The distribution of the residuals is modelled and a value randomly selected from this. This, in turn, is used with the estimated value to obtain a final estimate for the individual realisation of the Monte Carlo analysis. As intimated previously, final outcomes from independent variables are emplaced in an ore flow process and then rolled up to final product.

The case study

A shaft on a large Witwatersrand mine was used for a case study in which data for causal analysis was readily available. Data was obtained for a period of 18 months in order to ensure sufficient information for modelling, whilst at the same time, utilizing a short enough period for relevancy of data.

The following variables and the causal effect were modelled.

- Available mineable reserves and the effect on area mined
- Safety incidents not captured within the normal day to day working, as well as accidents and the resultant production delays
- Temperature at the working place related to production
- Number of panels reporting to a single boxhole
- The percentage of the shift spent on the face
- The percentage of crew compliments at work for both stoping and development
- The number of panels working in a raise line
- The number of excessive accumulation reports and subsequent area mined
- The relationship between mining of pillars and area mined
- The relationship between developed metres and panels available to mine.
Table I provides a summary of results of the simulation. Although the preceding table did not provide any surprises, it did provide a means of quantifying were our efforts need to be directed, which in turn leads on to the final phase of any operational management project.

What do we do with our results?

Unlike doing a Monte Carlo analysis for a project, where we start with a project and then determine the risk, operational management risk analysis starts with the risk and ends with a project. One can provide a sterling effort in identifying and modelling risk inherent in an operation, however, if nothing is done about the results, all has been for nothing:

The way forward with identified risk.

- Determine realistic remedial actions
- Create a project outline
- Workshop details timelines and responsible persons
- Clearly document point above
- Attempt quantification of remedial action
- Re-model risk using above point
- Appoint project manager
- Follow up on regular basis on project progress.

Conclusions and recommendations

It is very apparent that Monte Carlo risk analysis for operations management is a tool that provides quantifiable measures of the root causes to production related deficits. These in turn can then be addressed in terms of the individual rankings, in order the minimise the effort expended and effect on meeting of production related targets.

It is recommended that Monte Carlo modelling always be preceded with a process flow model that identifies causal relationships, and followed by a project plan to mitigate these effects.

References


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