Economic Modelling and Optimisation Application in the Mining Industry

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ABSTRACT

Cyest Corporation has been involved in economic modelling and optimisation with various mining clients within South Africa, and internationally, for the past 5 years.

In the mining industry in particular, the relationships between variables that are controllable, and those that are not, and the physical and economic outcomes are complex and often non-linear. These relationships constitute an economic system. In the mining context, although many of the relationships can be accurately quantified on a ‘single variable to single variable’ basis, such simplistic relationships will not suffice in order to understand the dynamics of an entire mine. One has to specify and quantify the relationships between hundreds, if not thousands, of variables. Furthermore, in reality, these relationships change over time. This is the role of an economic model where all the relevant cause-effect relationships, within pertinent constraints, are accurately represented. Models that are used for optimisation must therefore capture the dynamics of the economic system in question as well as anticipate changes to the relationships between these variables.

An accurate economic model is a prerequisite for successful optimisation. Optimisation entails the allocation or configuration of resources, within control of management, which will maximise (or minimise) a desired objective function. An optimal configuration (implying trade-off) of controllable variables therefore exists for a given set of assumptions that will yield a maximised objective function.

Due to the multi-variant trade-offs required for optimisation, the concept of the ‘Economic Surface’ or ‘Hill of Value’ has been used to represent these optimisation outcomes and to discern the route to an optimal configuration. A good example of this is the volume versus cut-off grade trade-off that yields an optimal value for a particular shaft with its unique geological and economic assumptions.

More recently, Cyest has extended these economic models to incorporate risk associated with variance in assumptions and inputs. This is termed DFA (dynamic financial analysis) and incorporates stochastic modelling and some of the latest actuarial techniques around modelling global assumptions (such as pricing and exchange rate).

This paper will cover the theory around mine optimisation through some example case studies, and also explain the latest thinking regarding incorporating DFA.

1. INTRODUCTION

Cyest Corporation has been involved in developing economic models for mining clients both in South Africa and internationally for the past five years. These economic models have allowed mining clients within platinum, gold, diamonds, coal, and more recently copper, to answer complex questions relating to their operations.

The application of economic modelling has extended from high level strategic planning issues around portfolio optimisation, to detailed operational optimisations relating to the paylimit versus volume trade-off at shaft level, half level optimisation in the platinum industry, optimal product, OPEX modelling for new and existing operations, and optimisation of the complete value chain from mine to mill. The common thread through all these examples is that a representative economic model of the operation is required for this work to be undertaken.

These models have been built in a variety of modelling technologies over the past five years, each characterised by their unique challenges. Some of these challenges are speed of calculation, robustness as an enterprise wide solution, transparency of modelling logic, ability for a business analyst to build the model without the need for a developer, object oriented design allowing replication of entities and many other technical challenges. This has lead Cyest to develop a proprietary multidimensional modelling engine called ***CarbonL***, which addresses all the requirements of a sustainable enterprise wide solution.

This paper is an extension of the work presented in the paper at AUSIMM in November 2004 by Ballington, Bondi, Hudson, Lane and Symanowitz entitled '*A Practical Application on an Economic Model in an Underground Mining Environment*' and the paper at SAIMM in September 2006 by Lane, Hudson and Bondi entitled '*Implementation of an Economic Model at Gold Fields Limited*'

This latest paper will cover some practical examples of how economic modelling has been applied in the mining industry and some of the latest developments which are now being applied.

2. What is Economic Modelling

An economic model is a mathematical representation of the real world. In the mining context it is an enumeration of the complete business, operation or shaft and integrates all production, labour and financial metrics into a holistic representation. The model also includes all the rules and relationships around constraints such as hoisting, tramming, ventilation and cooling for example.

A model consists of three fundamentals, namely an input driver, a behaviour or relationship rule and an output. The example below in *Figure 1* is a very simplified example to explain the concept for refrigeration cost. The input driver is "square metres stoped" at a given depth, the relationship rule is a cost curve depending on depth due to virgin rock temperature (VRT), and the output is the refrigeration cost per square metre for that depth.

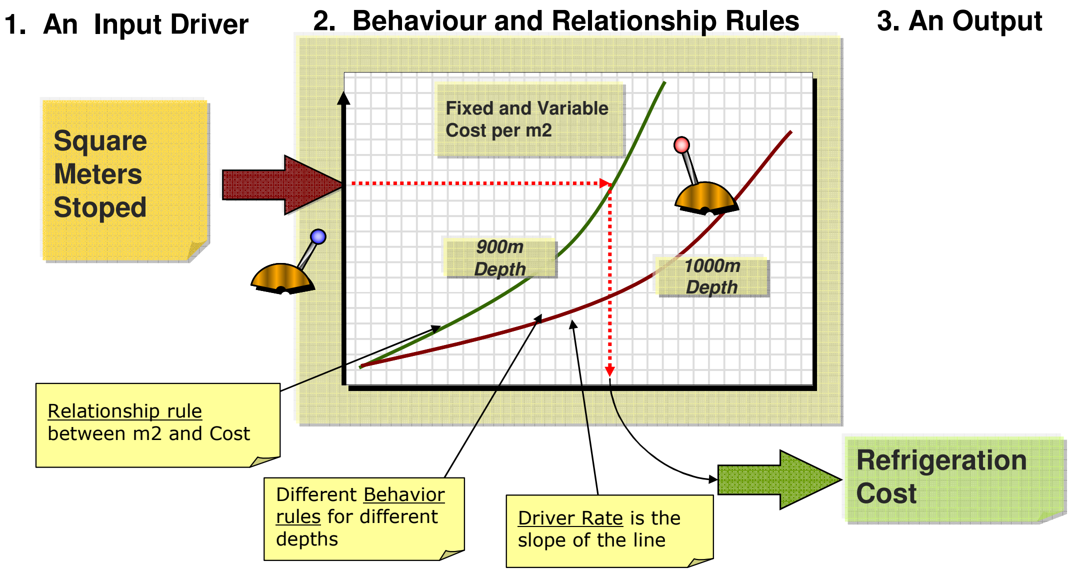


Figure 1 – A model consists of three things

In this way an economic model of a mine is built up of thousands of such relationships. Some are empirical relationships provided by the engineers, others are relationships contained within the basic mining equations (BME) and some are derived from historical data mining.

Therefore a representative economic model can generate all the operating costs, full labour complement and financial metrics for a given production schedule, and at the same time, flag any constraint breaches around hoisting, tramming, ventilation and cooling for example.

In some instances the economic models built have incorporated all strategic planning polygons and the associated grade tonnage curves. This allows different production strategies to be quickly tested without the need for detailed mine planning. The chosen strategy can then be planned in detail in the general mining planning system to verify that it is achievable.

It is important to understand that modelling and forecasting are different concepts. Forecasting is about taking a given output such as stores cost and forecasting it into the future using a factor such as inflation. Modelling is about understanding what drives stores cost for a particular activity and modelling the relationship between that cost and its driver. Therefore costs can only be adjusted by understanding the levers management have under their control as represented in *Figure 2* below.

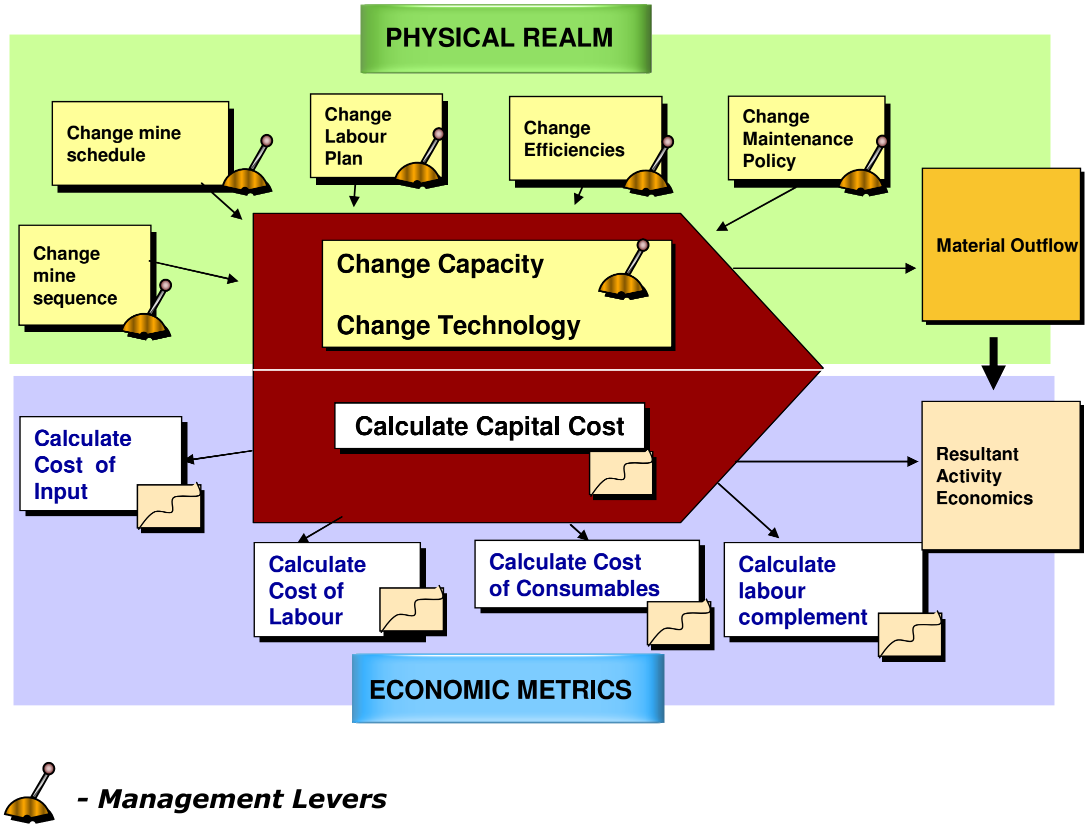


Figure 2 – Economic Model and Management Levers

2.1 Optimisation Theory

Optimisation entails the allocation or configuration of resources, that are within the control of management, to maximise (or minimise) a specific objective function. There is an optimal configuration of controllable variables (e.g. mining rate, cut-off grade, capital expenditure, capacity, ore mix etc) for a given set of external uncontrollable variables (e.g. geology, external market conditions, commodity prices etc). Optimisation requires a precise understanding of how changes in one (or more) of these variables or drivers will impact a single outcome or desired metric.

Optimisation generally implies a trade-off; there are often two (or more) opposing effects or consequences of changing any two variables. Thus mine planners are often faced with contradictory objectives. Typically, planning implies optimisation even if it is not explicitly understood, as the planners have to make trade-offs in their planning process.

Typically, planning will attempt to balance maximum extraction of the resource with maximum value from its exploitation. These two objectives often work counter to one another as full extraction is invariably achieved with a low margin and long life, whilst value maximisation is generally focused on larger margins and a somewhat shortened life of the operation.

Figure 3 below demonstrates the typical trade-off between volume and paylimit (or cut-off grade). If management use the volume lever then as volume increases the unit cost of production should typically reduce through the leveraging of fixed costs. This in turn results in one being able to mine at a lower paylimit and therefore yielding a lower average revenue per tonne mined. Conversely, management can make an explicit decision to mine at a higher paylimit. This will increase the average revenue per tonne mined, but significant additional development is required to open up more areas so as to allow for more selectivity in order to achieve this higher paylimit.

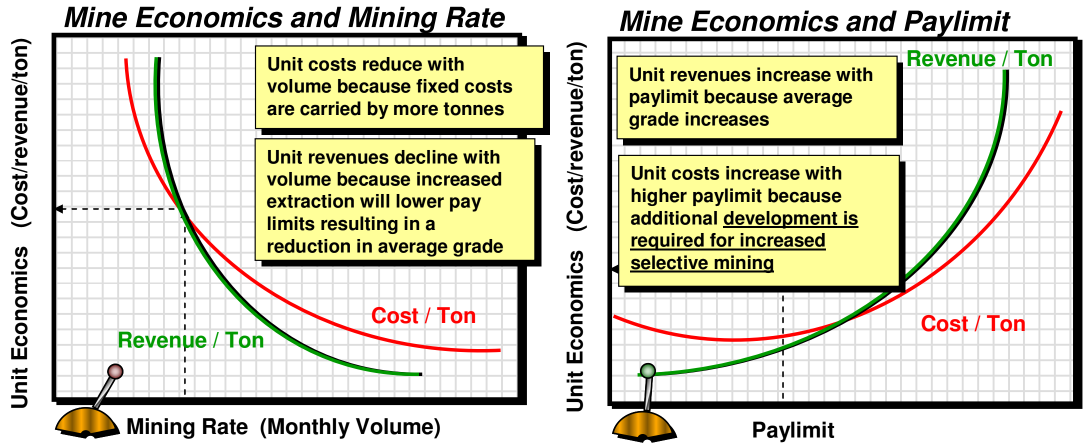
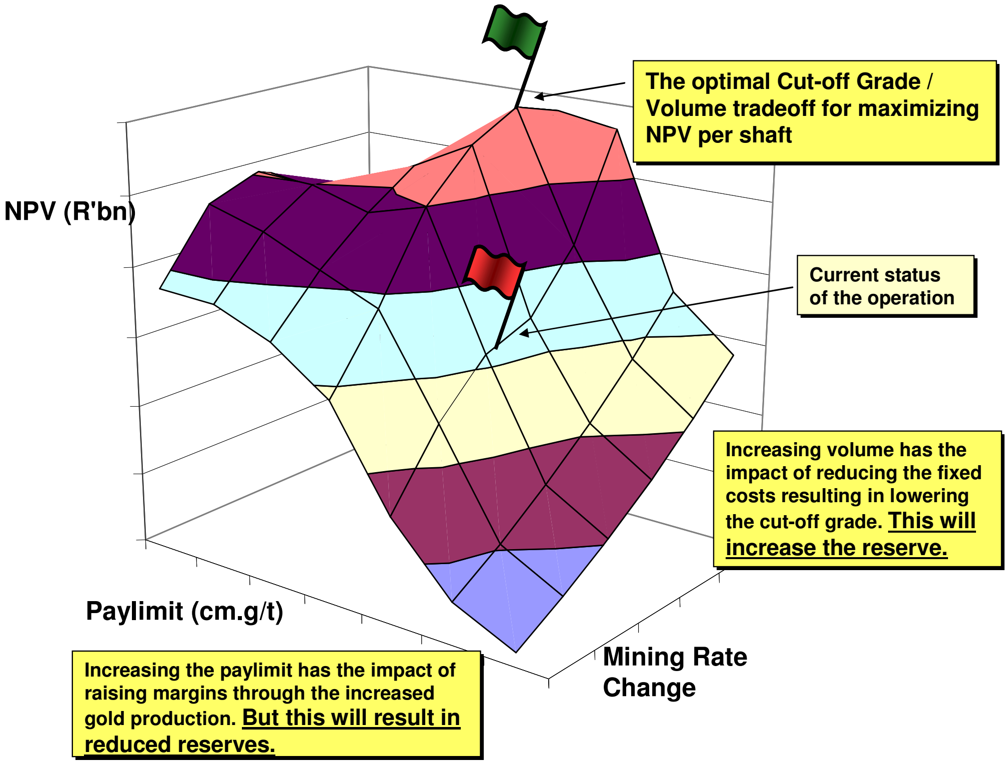


Figure 3 – An Example of the Volume versus Paylimit Trade-off

The only way to reasonably depict this trade-off is through what is termed the 'Hill of Value' (Hall 2003). This economic surface in *Figure 4* below, depicts the paylimit on one axis, the volume on the second axis, and, in this instance, shaft NPV (the objective function) on the vertical axis. Each combination of paylimit and volume is a unique scenario generated in a detailed economic model and takes all constraints, capex and costs into consideration to mine at that specific configuration. This 'Hill of Value' depicts the path to potential increased value for the shaft. Detailed geological and production planning – for example in CADSmine^{tm} – will still be required to confirm what is practically achievable.



The optimal Cut-off Grade / Volume tradeoff for maximizing NPV per shaft

Current status of the operation

Increasing volume has the impact of reducing the fixed costs resulting in lowering the cut-off grade. <u>This will increase the reserve.</u>

Increasing the paylimit has the impact of raising margins through the increased gold production. <u>But this will result in reduced reserves.</u>

Figure 4 – A 'Hill of Value' for the Volume versus Paylimit Trade-off for a specific set of assumptions

The additional challenge that executives face in the mining industry is that the objective function in itself is a trade-off. Depending on where in its life the mine is, what the prevailing market conditions are and what shareholders are expecting, the objective function may vary. A strategy that yields the greatest NPV for the life of mine may not be viable under tough economic conditions where analysts and shareholders are still expecting short-term profitability which requires possibly mining at a higher paylimit at the expense of long term value. Capital yield criteria may omit projects that could potentially yield significant value for the operation.

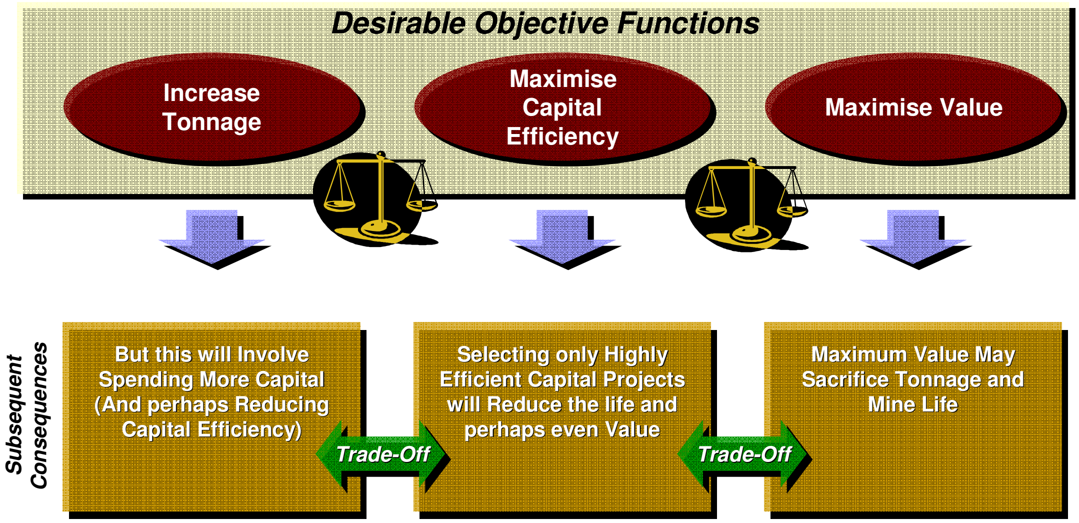


Figure 5 – Mining Executive Dilemma

This challenge goes one step further in that maximising the value of each individual component of the business may not yield the maximum value for the group. For example maximising the value of each individual shaft, versus maximising the value from the concentrators, versus maximum value from the smelters, may not yield the maximum group value due to the individual component characteristics, down stream constraints and non-linear recovery grade relationships.

The maximum group value may require some shafts to plan below maximum capacity and therefore not maximise value. Rather, they may be required to route their material to lower recovery concentrators so as to yield more value from a high grade shaft. Therefore sub optimal individual components of the business may be required to maximise the whole businesses value. *Figure 6* below indicates the complete challenge faced between trade-offs on inputs, desirable outcomes (objective function) and between components in the business.

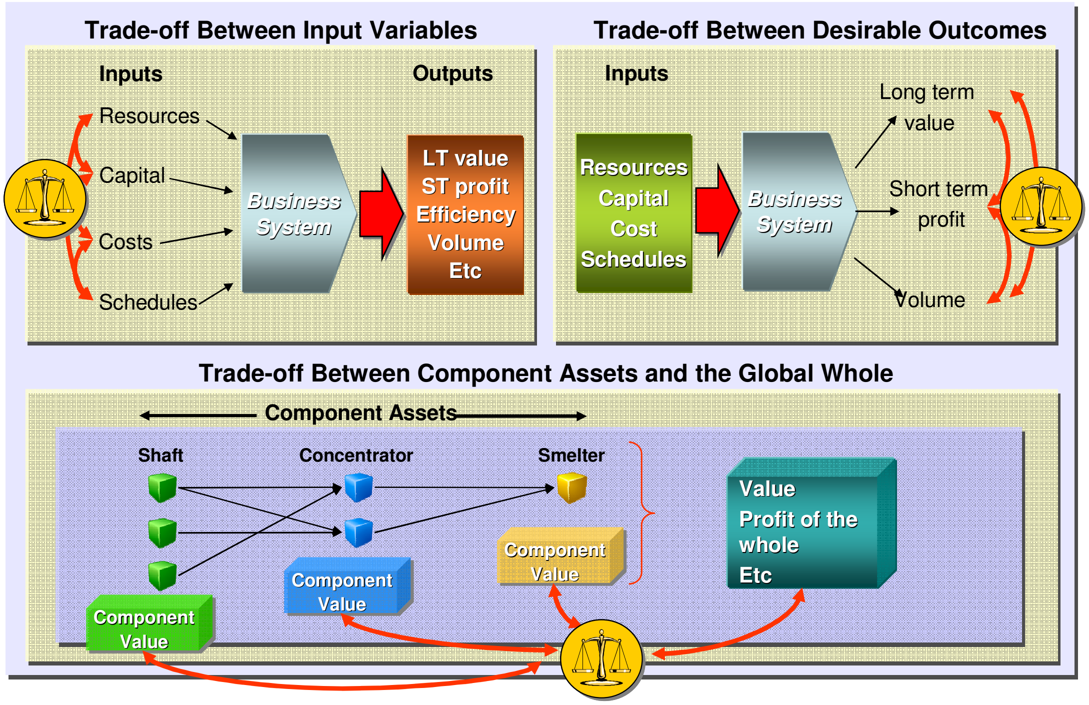


Figure 6 – Three levels of trade-off

3. THE APPLICATION OF ECONOMIC MODELLING AND OPTIMISATION

Economic modelling, and in most instances incorporating some type of optimisation, has been designed and successfully deployed extensively by Cyest over the past 5 years. The section that follows gives some short case studies on some of these applications.

3.1 Optimising the Production Sequence and Schedule

An economic model was built that integrated the costs, labour, processing and all the engineering rules around hoisting, tramming, ventilation and cooling, compressed air, electricity and pumping for a complete mining operation that consisted of twelve shafts. In addition, a very detailed production module that integrated strategic planning polygons (areas of ground) and the respective grade tonnage curves was incorporated which allowed paylimit to be applied.

This economic model allowed the mine planners to test different production strategies around sequencing and scheduling of the operation. This also included the timing around access to the polygon from different shafts which allowed an optimal total operation schedule to be derived.

For example, a certain polygon could be accessed six years earlier through shaft x as opposed to through shaft y, but with a capital expenditure for development required. In this way these options could be assessed and the optimal trade-off derived (again – given an agreed objective function that the client wanted to maximise in this instance).

The model also allowed management to test different strategies around possible foot print reductions to reduce the shaft fixed costs on the operation.

The selected strategies were then tested by detailed mine planning and scheduling in a general mine planning system for their viability.

3.2 Optimising the Paylimit versus Volume for each Shaft

The economic model developed for the above application was extended to allow the optimal combination of the volume and paylimit for each shaft so as to maximise the shaft value. This involved running a minimum of forty nine scenarios with different paylimits and volumes, and plotting these on the 'Hills of Value' mentioned earlier in the paper. Each of these scenarios was generated within the constraints of the shaft and took all costs and capital into consideration for that particular paylimit and volume.

Workshops were held with each shaft manager to discuss the viability of achieving the new volume and paylimit and the plan going forward.

This is an ongoing process as the optimal configuration changes depending on commodity price changes and as additional information regarding the ore body becomes available as drilling is extended.

This will be extended in the future to incorporate level based activity based costing and therefore level specific paylimits.

3.3 Half Level Optimisation

This application was for a platinum mine where planning is done at a half level. A half level is the portion of level each side of the apex where the haulage from the shaft intersects the reef horizon. Therefore, if a level is mining Merensky and UG2 reef, then that level will consist of 4 half levels.

An economic model was constructed based on activity based costing which incorporated all the production activities on a half level. This allowed different half level production strategies to be tested with reference to labour structure, efficiencies, teams per half level and foot wall drive advance rates. In addition, this model allowed the individual half levels to be sequenced and scheduled within the context of the shaft in order to derive the optimal schedule within shaft and ventilation constraints that resulted in the maximised objective function.

The original prototype model was built in Excel and is currently being converted into a robust enterprise wide system using Cyest's ***CarbonL*** modelling platform. This system will be integral to the overall mine planning system to assist with deriving an optimal production schedule.

This final system will also be used by projects to assist with deriving the optimal mine design and production schedule.

3.4 Life of Mine Economics

First principle activity based costing has been developed for a number of mines to derive the labour complement and OPEX costs for a given production schedule.

In some instances the model has been integrated into the transactional systems to get the actual historical performance data which can be used to derive the costs-production relationships for costs going forward.

The same approach has been used to derive the OPEX costs for the different approval stages of a project (pre-feasibility, feasibility etc). It has been found that project teams spend significant time deriving an accurate capital estimate for the project and then erroneously assume an average unit cost for production. In this way different shaft configurations and production schedules are fed into the economic model and the OPEX costs calculated so that project options can be compared.

3.5 Budgeting

Due to the fact that ***CarbonL*** can accommodate large amounts of detail down to first principles, the economic models have been extended to do budgeting. The same rules and relationships apply except that more detailed information is required. For example an activity such as stoping may have a cost item called stores, which in turn is made up of 150 individual line items. Some of these may be fixed whilst others may be variable, each with their own cost driver (for example stope width may drive support costs).

The economic model integrated into the transactional system allows the budget to be loaded into the budget template for performance monitoring.

This now allows 'rolling budgeting' to be performed as the production schedule is updated on a monthly or quarterly basis.

3.6 Mine to Mill Optimisation

A detailed economic model that incorporates the metrics around drilling and blasting, loading and hauling, and processing allows trade-offs and optimisation to be done through the complete mine value chain. For example, changing the drill hole spacing or detonation type may increase drilling and blasting costs, but this in turn may change the fragmentation that improves digability, increases bucket fill factors which reduces hauling costs and may also increase mill throughput. The increased value to the operation may negate any additional drilling and blasting cost.

4. INCORPORATING RISK INTO ECONOMIC MODELLING

Recently risk modelling has been incorporated into the economic modelling so as to be able to deal more accurately with the uncertainty that is typically associated with a large number of input variables. The technique used is called DFA (Dynamic Financial Analysis) and is explained below.

4.1 Where did DFA originate?

Having stemmed from military scenario modelling principles during the Second World War, Dynamic Financial Analysis [DFA] has evolved to become an established actuarial valuation methodology used to quantify value, risk as well as value at risk.

A simplified application of early DFA principles was deployed to great effect by the famed scenario modelling unit of the Shell Petroleum Company in the late 1970's (the influence that this unit had on strategic decision making has been regarded as a major driver of Shell's success from 16th largest petroleum firm to 2nd).

More recently (in the last 2 years), a more sophisticated (and accurate) iteration of DFA has been successfully used by large corporations for the valuation of large capital investments; it is this latest iteration of DFA that Cyest has begun implementing for its client base. We have no doubt that this proposed methodology will be the most advanced evaluation of project risk and value applied within the mining industry, and that more importantly, it will provide decision makers with insight that will result in a project configuration that will yield the highest value for the lowest risk.

4.2 What is DFA?

Simply put, DFA is a stochastic methodology that provides a probabilistic range (or distribution) of values, as opposed to a single 'crisp' or discrete value such as a single NPV, or IRR, or ROI. DFA does this by allowing for different inputs to a scenario (be they external factors such as exchange rate, commodity prices etc. or internal factors such as estimated efficiencies, capital cost, etc.) to be entered as a distribution.

The distributions of different inputs are derived from rigorous regression and stochastic analyses of the historical values demonstrated by those input variables, (or by a credible proxy). The DFA methodology then weights the impact of each input distribution accordingly. In other words DFA provides a means of calculating a distribution of overall value based on the weighted distribution of each input variable or assumption. For example if the exchange rate has a wide distribution spread (e.g. it is unpredictable and high risk), but because of the limited dependence on foreign purchases for a given project, the net impact of exchange rate on the value distribution will be low.

Finally the DFA methodology goes one step further in that it allows for the probabilistic modelling of the dynamics between the different input variables. For example – historical analysis may show that there is a relationship between exchange rate, gold price and inflation or between scale of the operation and efficiencies achievable. The use of ‘copulas’ quantifies the relationship between different variables and as such results in more accurate risk and value modelling.

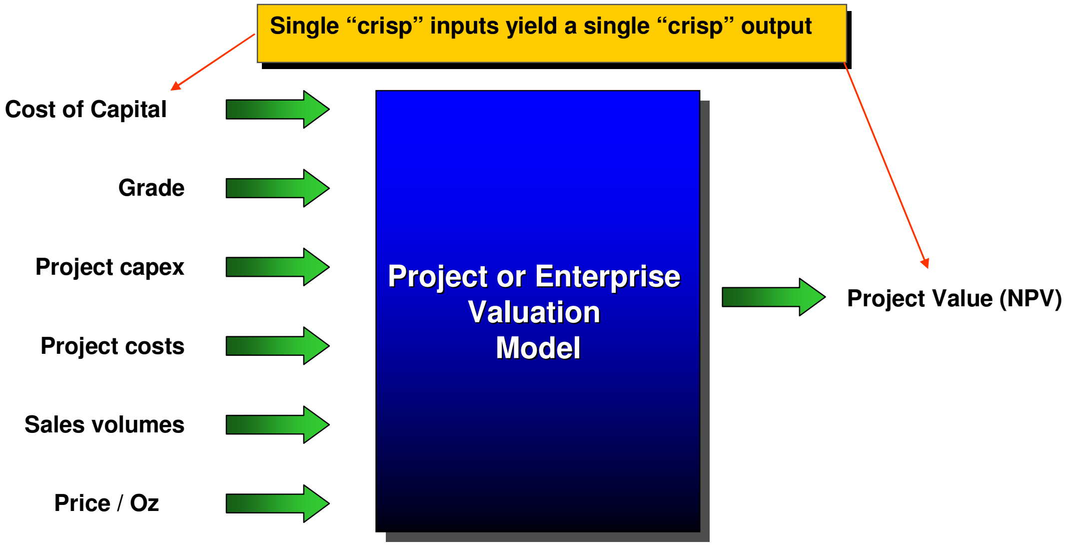


Figure 7 – Traditional Valuation Methodology using Crisp Inputs

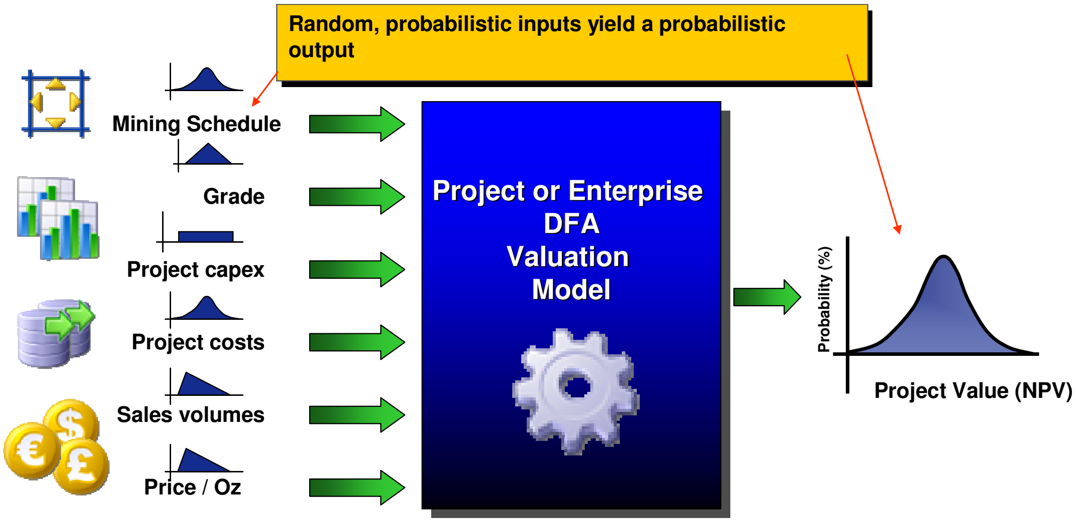


Figure 8 – DFA Modelling Methodology

4.3 How is DFA used in the Enterprise Arena?

DFA, applied to the valuation and risk quantification of large capital projects, is not used to simply decide if a project is a 'go' or 'no go'; Simple static or crisp scenario modelling will achieve this. Rather DFA will show how a project can best be configured to yield a ratio of the highest return profile for the lowest risk profile.

Project configuration in this context can refer to amongst others – sequencing of events or project milestones, funding configuration (cash vs. debt vs. equity) and the timing of funds, the introduction of hedging instruments (and other risk mitigation strategies) and the introduction of different engineering options.

DFA does this by allowing a scenario modeller to quantify different risk and value profiles that will result from different configurations as illustrated graphically in *figure 9* below. In this real example below, the cumulative frequency distribution chart indicates that project option 1 has a mean NPV of 9.0 but has a probability of failure (i.e. NPV<0) of 30%, whereas project option 2 has a mean NPV of 5.0 but only a 10% chance of failure. In this real case example, option 2 applied some risk mitigation strategies that involved spending additional capital. This reduced the mean NPV for the project but reduced the variance of the NPV and therefore reduced the project down-side risk.

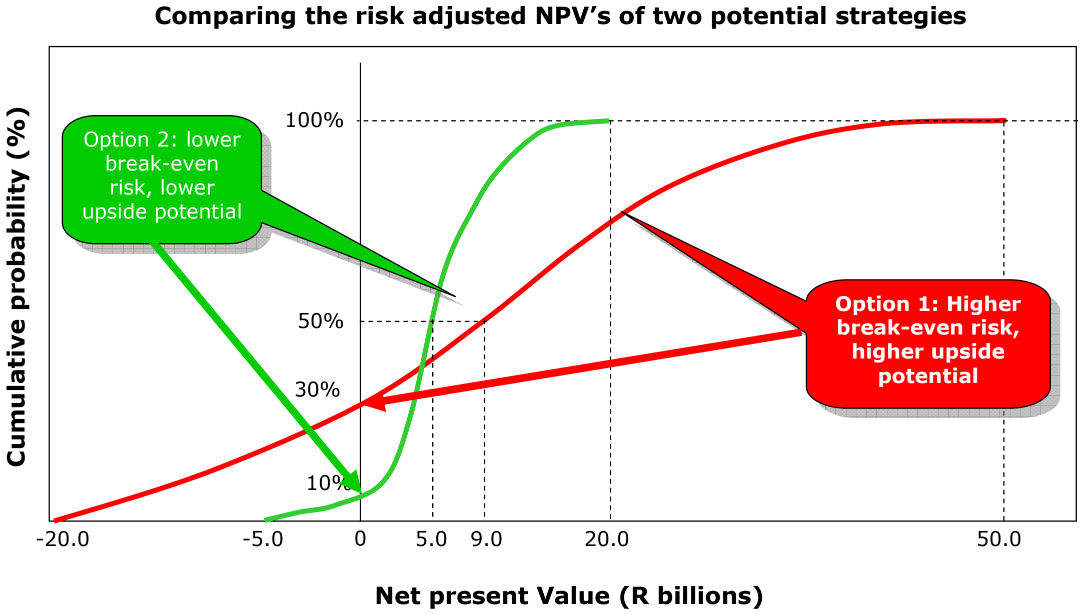


Figure 9 – Cumulative Frequency Distribution

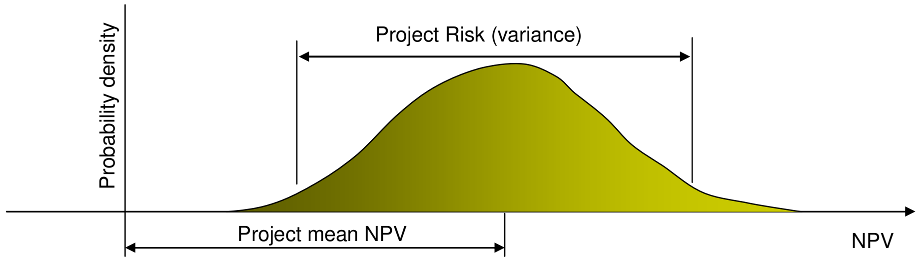
4.4 Risk Attribution

Risk attribution is another output of DFA, and this clearly indicates where the areas of highest risk are, and in so doing indicates where the greatest management attention must be focussed as shown in the schematic in *figure 10* below.

Risk attribution differs from sensitivity analyses where each variable is tested in isolation in order to assess their impact on the mean NPV. Often, the fact that NPV is exceptionally sensitive to changes in a specified variable is not always relevant to the analysis, if that variable is highly predictable and exhibits little variation. For example, if material costs are fixed contractually, the fact that the NPV would fluctuate wildly if these increased is of little relevance – as it is extremely unlikely that this would occur and is low risk.

Risk Attribution is a measure of 'how much' that variable contributes to the total risk (variance) of the NPV distribution, relative to the exposure of the other considered risks. Therefore, in the example below in *figure 10*, the sum of the risk attributions from each variable adds up to 100%, i.e. if only a single input variable had a variance distribution and all other inputs were deterministic inputs (100% probability) then that variable will contribute 100% to the risk attribution of the variance on the NPV – implying that all project risk is from that single variable.

The risk attribution graph (*Figure 10*) allows users to quickly identify inputs that contribute highly to the risk of the project, and apply mitigation strategies (such as hedges or operational measures) to reduce these. This would have to be done with due consideration to the cost-benefit of the proposed change as the riskiest component of NPV does not necessarily have the highest impact on ultimate profitability.



The Risk contribution analysis chart explains the percentage contribution of the various variables to project risk.

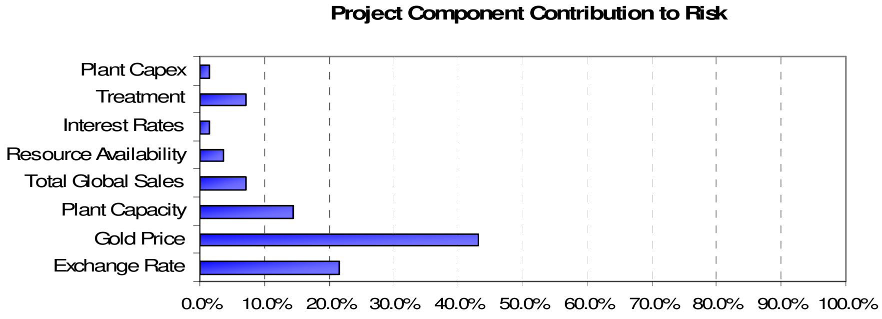


Figure 10 – Risk Attribution

5. CONCLUSION

An economic model is a mathematical representation of reality and allows management to test 'what if' scenarios to see the impact on the company, operation, mine or shaft. It allows strategies to be very quickly and easily tested.

Economic models are not intended to 'make decisions':- they are complex tools with intricate intelligence and substantial processing power, that allow management to quantify decisions and give them the confidence to make more informed decisions. These models will certainly not replace management, and will not necessarily make management's life easier, as decisions may become more complex and frequent – but they will provide the means with which to accurately and rapidly make decisions in an ever increasingly complex world.

An economic model that is an accurate mathematical representation of the business (with all relevant causal relationships and constraints represented) is a prerequisite to be able to run an optimisation on the business. The interaction between production, costs, capital and financial metrics is highly complex and changes over time, but needs to be accurately modelled so as to provide for insights around optimal configurations of that business.

Cyest has developed a multidimensional modelling environment called ***CarbonL*** that allows enterprise wide modelling solutions to be developed that give transparency of business rules and relationships (to overcome the black box approach), the ability for a business analyst to build the model, are Sarbanes-Oxley compliant and the use of templates to allow fast replication of similar entities within a business.

Economic modelling is advancing to the stage that in the future most companies will have detailed economic models of their businesses, which will drive rapid and informed decision making around complex questions, and allow for much improved budgeting.

The incorporation of risk into economic modelling will provide management with a better means to deal with uncertainty (which of course is representative of the reality out there), and in the identification and quantification of those factors that most contribute to risk and then allowing mitigation strategies to be tested.

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