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The Application of Probabilistic Logic to

Identify, Quantify and Mitigate

the uncertainty inherent to

a Large Surface Mining Budget

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by

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SYNOPSIS

Title: The Application of Probabilistic Logic to Identify, Quantify and
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Mining is a hugely expensive process and unlike manufacturing is based on an ever diminishing resource. It requires a continuous infusion of capital to sustain production. A myriad of factors, from the volatility of the markets to the surety that the minerals are really there, "plagues" both management and investors. The budget tries to predict or forecast future profits and acts as a roadmap to all stakeholders. Unfortunately, most of the time the budget of a mine degenerates to the extent of a collapse, sometimes very soon into the new budget period. This problem plagues both small and large mines indiscriminately. The budget is dictated in absolutes, and little or no variability is allowed.

This thesis aims at developing a process to predict the probability of failure or success through the application of probabilistic logic to the simulation of the budget. To achieve this, a very detailed modelling tool is required. The model must replicate the actual mining process both in time and actual spatial representation.

Enabling technology was developed over a period of five years, primarily based on the Runge Software Suite. The use of activity based costing enabled the budget to be simulated and expressed as a probability distribution. A Pareto analysis was done on the main cost drivers to extract the most important elements – or key drivers - that need to be manipulated. These distributions were mapped against real data and approximated with the use of the three parameter Weibull distribution.

Simulation using Xeras® (Runge) proved to be impossible. This is due to the time needed for setup and processing. The budget was described as an empirical function of the production tonnages split according to the Pareto analyses. These functions were then utilised in Arena® to build a stochastic simulation model. The individual distributions are being modelled to supply the stochastic drivers for the budget distribution. Income, based on the sales, was added to the model in order for the Nett profit to be reflected as a distribution. This is analysed to determine the probability of meeting the budget.

The underlying analysis of an open pit mining process clearly reflects that there are primary variables that may be controlled to trigger major changes in the production process. The most important parameter is the hauling cycle, because the haul trucks are the nexus of the production operation. It is further shown that the budget is primarily influenced by either FTE's (full time employees, i.e. bodies) or funds (Capex or Opex) or a combination of both.

The model uses probabilistic logic and ultimately culminates in the decision of how much money is needed and where it should be applied. This ensures that the probability of achieving the budget is increased in a rational and demonstrable way.

The logical question that arises is: "Can something be done to utilise this knowledge and change behaviour of the operators?" This led to (IOPA – Intelligent Operator Performance Analyses) – where the performance or lack thereof is measured on a shift by shift basis. This is evaluated and communicated through automated feedback to the supervisors and operators and is being implemented. Early results and feedback are hugely positive.

The last step is prove where capital (or any additional money spend) that is applied to the budget will give the most benefit or have the biggest positive influence on the achievement thereof.

The strength of the model application lies therein that it combines stochastic simulation, probability theory, financial budgeting and practical mine schedule to predict (or describe) the event of budget achievement as a probability distribution. The main contribution is a new level of understanding financial risk and or constraints in the budget of a large (open pit) mine.

Acronyms

CAD – Computer Aided Drafting

force majeure – Act of God, i.e. unforeseen and uncontrollable

LOM – Life of mine, could be a plan or a schedule

Murphy – Refers to Murphy's Law, an adage typically stated as "Anything that can go wrong will go wrong"

Pit-shell - The term pit-shell was first used and popularised by Whittle. Currently pit-shell is used to delineate that portion of the resource that is converted to a reserve by use of technical and economic factors.

ROM – Run of mine, tons mined

SAP® - Enterprise software used in the mining industry

Table 600 – A generic budget summary used in SAP®

Xeras® - Software from the Rung suite to cost schedules

XPAC® – Scheduling software from the Runge suite, widely used in mine planning

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INTRODUCTION

1 INTRODUCTION

1.1 Background

The extraction of minerals is a hugely expensive endeavour and unlike a factory process, is based on an ever dwindling resource that gets depleted as each production year goes by. Mining requires a continuous infusion of capital to enable optimum production. Capital can be sub-divided into Sustaining, Responsibility, Improvement and Expansion Capital. This capital is spent mainly on replacement off equipment. Second on the list is normally Expansion capital. This may be due to Geographic expansion or growth, i.e. brown-fields expansion projects. Improvement Capital is capital projects of a nature to optimise or better performance standards. Responsibility capital is capital required mostly from a legal nature, i.e. rehabilitation, environmental or special safety issues. It would probably be correct to think of it as capital required to protect the mine's licence to operate. There is a myriad of factors, from the volatility of the markets to the surety that the minerals are really there, that plagues both management and investors. The standard procedure to help combat this "unsure" environment is the budget process. It should be noted, that the total budget of a large mine easily runs into billions of rand.

The biggest question confronting senior management of a mine is:

"*Why does the budget of a mine degenerate to the extent that it is totally worthless, sometimes in so short a period as a quarter?"*

This question seems to plague both small and large mines indiscriminately.

One may really wonder why management, sometimes with years of experience and a barrage of sophisticated tools still fail, and more importantly, keep on failing to budget with any real confidence?

The budget is *the singular most important* document that regulates the production of a mine. All efforts are made to achieve, or deliver what has been promised in this document. Management and its actions are constantly judged and measured against this document, both by Head Office and Investors.

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It seems that the standard process for a budget is to be measured against last year's performance – and if this is a better budget – i.e. "more satisfying" being the operational concept here – everybody is "HAPPY". The fact that last year's budget was never, and will never be met, has very little to do with the current "happiness".

The budget is depicted in absolutes and all deviations are just that, an Act of God, whether it is a strike or a rainy season. Sometimes an attempt is made to consider changes in physical standards – but they are seen as independent, fixed influences. Standard procedure is to average all fluctuations and treat it as a singular event, that is even periodic predictions are treated as a deterministic point that will occur exactly or precisely. Interdependency and accompanying risk is largely, if not totally ignored (Hudak & Maxwell 2007).

Funding needed for the budget, especially the capital part of it, is normally secured up-front and at a cost. This leads to added pressure to get the budget low enough. The dichotomy is: that a budget that is over achieved is too lenient, with too much fat in it and one that is not met was done by incompetent people.

The budget of a large mine, is an enormously complex process, taking detail inputs of every department over a period of up to six months before it is finally compiled. The rest of the time is spent forecasting for the remaining period how far the deviation will be, i.e. if this is for example the 7th month, the forecast will be 7 + 5. So although Management do measure the budget very carefully, it is only reactive – i.e. the fact is only known after the budget failed, either negative or positive – and the nature of the autopsy then turns into finding a scapegoat to blame.

Secondly, the decision of the application of scarce capital sometimes appear to be somewhat arbitrary – mostly a case of "***the baby that cries the loudest gets the most milk***"

The importance of increasing the confidence of achieving the budget, while simultaneously giving the assurance that the budget is accurate and "strict" enough cannot be over emphasised.

This thesis aims at developing a methodology to predict the probability of failure or success through the application of probabilistic logic to the budget.

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To achieve this, a very detailed modelling tool is required, that will allow the mining schedule (based on a mine plan) to be directly translated into a budget. The specific modelling tool was developed over a five year period and had to conform to very exact prescriptions. The model must be able to replicate the actual mining both in time and actual spatial translation - i.e. travelling distances and specific physical attributes must be coupled to the mine layout and assets utilised, taking cognisance of the particular equipment fleet and uniqueness of the beneficiation process, as well as the specific geological factors that govern the resource. The model must be able to replicate the budget from first principles to within 1% accuracy and do this within a very short timeframe so as to enable changes to be simulated quickly and accurately.

1.2 DESCRIPTION OF MODELING TOOL

The Runge Suite was selected to do the modelling and comprises of Talpac®, Xpac® and Xeras®. These three pieces of software were combined to form the modelling tool. The total process is shown in **Figure 1** The Mine Planning Methodology.

1.2.1 TALPAC®

TALPAC® is an industry standard and broadly used. It is used independently from the scheduling tool, Xpac and the costing tool Xeras. The main aim of the TALPAC® simulations are to determine cycle times and the accompanying productivity for sets of equipment under different mining conditions. Within TALPAC®, the haul route for the truck can be specified, the truck type selected from the TALPAC® database and operating limitations, including speed limits to be adhered to, as well as rolling resistance for different road surfaces. TALPAC® is flexible in allowing each user to determine loading strategy, material characteristics and work roster applicable to the fleet that is being simulated. Once the TALPAC® simulations have been completed, it is vital to calibrate these answers against real data. Real data is obtained by accessing the Dispatch (a Modular program used to monitor and allocate trucks dynamically) Sequel Database. Trucks are positionally logged every 30 seconds,

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thus giving a very accurate indication of travelling speeds on different road segments, which is used to calibrate the different TALPAC® scenarios.

One of the prime considerations in choosing this suite for the modelling tool was the fact that all reports are fully Microsoft compatible, i.e. all reports can be viewed as .csv files in Excel. For more detail refer to Appendix B.

1.2.2 XPAC®

XPAC® mine scheduling software is a business focused application, designed specifically for reserve modelling, production forecasting and scenario analysis. It is a completely customisable reserve database that suits all mining methods and commodities. XPAC® has been in use since 1980 to model minable reserves, generate production schedules and evaluate alternative scenarios. XPAC® is utilised to identify where to dig, where to move and store waste material and how much equipment will be needed to meet production targets. XPAC® Graphics creates a visual representation of the mining schedule and gives credible insight to the mining plan. XPAC® uses advanced 3-D graphics rendering, combined with detailed spatial data, to accurately represent the complex shapes within the mine layout. The mining processes can be easily visualised with the following graphical output options:

- Database plots give an accurate representation of the deposit at any point in the schedule. Colour code by quality, quantity or any other attribute.
- Period progress and mine status plots show the progression of the schedule over time.
- Animations show how the mine develops over time.

[Source: http://www.runge.com/mining-software/Xpac®]

XPAC® is the primary scheduling tool. The strength of this tool lies in the fact that it runs in a 4D environment, thus incorporating both time and space. The primary language is Cypress, a propriety language but interfaces effortlessly with Visual Basic. XCM's, or scripting algorithms may be run prior, during or after scheduling. The main database allows for a "very large" quantity of attributes to be assigned to each mining block.

A mining block is typical the bench height x length (100m) x width (45m). Attributes include all geological data, wash-curve data and production data, i.e. distance, routes, cycle time, fuel required, explosives, drill meters etc. The schedule is target

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driven and the blocks are mined in a practical extraction sequence, pre-scribed by strict rules, called dependency rules that adhere to practical mining protocol. The standards and attribute parameters are extracted when a specific block is mined in time, resulting in a very accurate mining schedule. Algorithms that replicate the beneficiation process are run to give the most accurate production plan that is possible within the known parameters. XPAX® also incorporates an Auto-Scheduler, a module that runs on a heuristic "engine", allowing automated optimisation based on the parameters in the database. The final schedule is dumped in a flat file (.csv) that is read into Xeras®. This methodology allows several schedules to be run quickly, compared and changed.

For more detail refer to Appendix C.

1.2.3 XERAS®

XERAS® is a total budgeting and strategic planning solution has been used in the mining industry for a financial modelling solution for nearly twenty years. XERAS® has been designed specifically for the resource sector and is suitable for any capital-intensive industry. "First principles" of financial planning underpin all XERAS functions and its meaningful and logical structure ensures rigorous financial discipline. Each solution's rules-based models make it easy to adjust variables such as mine production options, mining method and equipment specifics. Because the model is built from first principles, forecasting multiple mining scenarios quickly and effectively is very easy.

[Source: http://www.runge.com/mining-software/xeras]

The power in the application of this suite, lies in the seamless integration between the mining schedule and the costing thereof. For a large mine, the budget may take up to 3 months to complete and in some cases as long as 6 months. This means that it is virtually impossible to link the budget to the mine planning, as the exterior factors imposes changes more quickly than they can be accommodated.

XERAS® is an activity based costing (ABC) modelling environment. All costs are linked to their activities. The most relevant costs are actual production costs, incurred as and when and to the level that it happens. (Note – happens in the schedule, assumed the schedule translates to reality). Cognisance of production

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hours available, pieces of equipment with their LCC (Life Cycle Costs) and replacement strategies, fuel consumption, tyres, GET (Ground Engaging Tools) etc. all goes into the final model. The initial estimate was to get within 5% of budget, but because of strict security capabilities in XERAS®, real salaries and selling prices may be used, allowing the model to get within 0,5% of the budget. For more detail refer to Appendix D.

1.3 Modelling of the Mine Plan and Budgeting

The modelling of the mining scheduling process can be outlined as follows and the process is depicted in **Figure 1** The Mine Planning Methodology

- Convert and incorporate all geological and spatial data in a block-model environment.
- Validate and add expert design parameters to finalise the mine design inclusive of the exploitation strategy i.e. from where and in what sequence will it be mined.
- Reserve and translate to the Xpac® database through a CAD environment.
- Add elements of the equipment strategy through Talpac® simulations and PAM (Physical Asset Management) to both Xpac® and Xeras®.
- Run scheduling and plant scripting algorithms in Xpac® to complete the database for scheduling.
- Utilise the heuristic capabilities of the auto-scheduler to find a optimum solution.
- Cost all activities in Xeras®.
- Evaluate the scenarios through delta cash flow, NPV analyses and other cost parameters.
- Rerun the process by incorporating lessons learned from the previous schedule until it is clear that no further progress will be achieved, or all objectives are met.

It should be noted that this process facilitates seamless integration from the geological database right through to a "costed" (budgeted) mine plan, the so called "*Cradle to Grave concept*". It therefore enables simulation of the budget directly linked to the mining activities.

Interaction within Mining Processes' Methodology
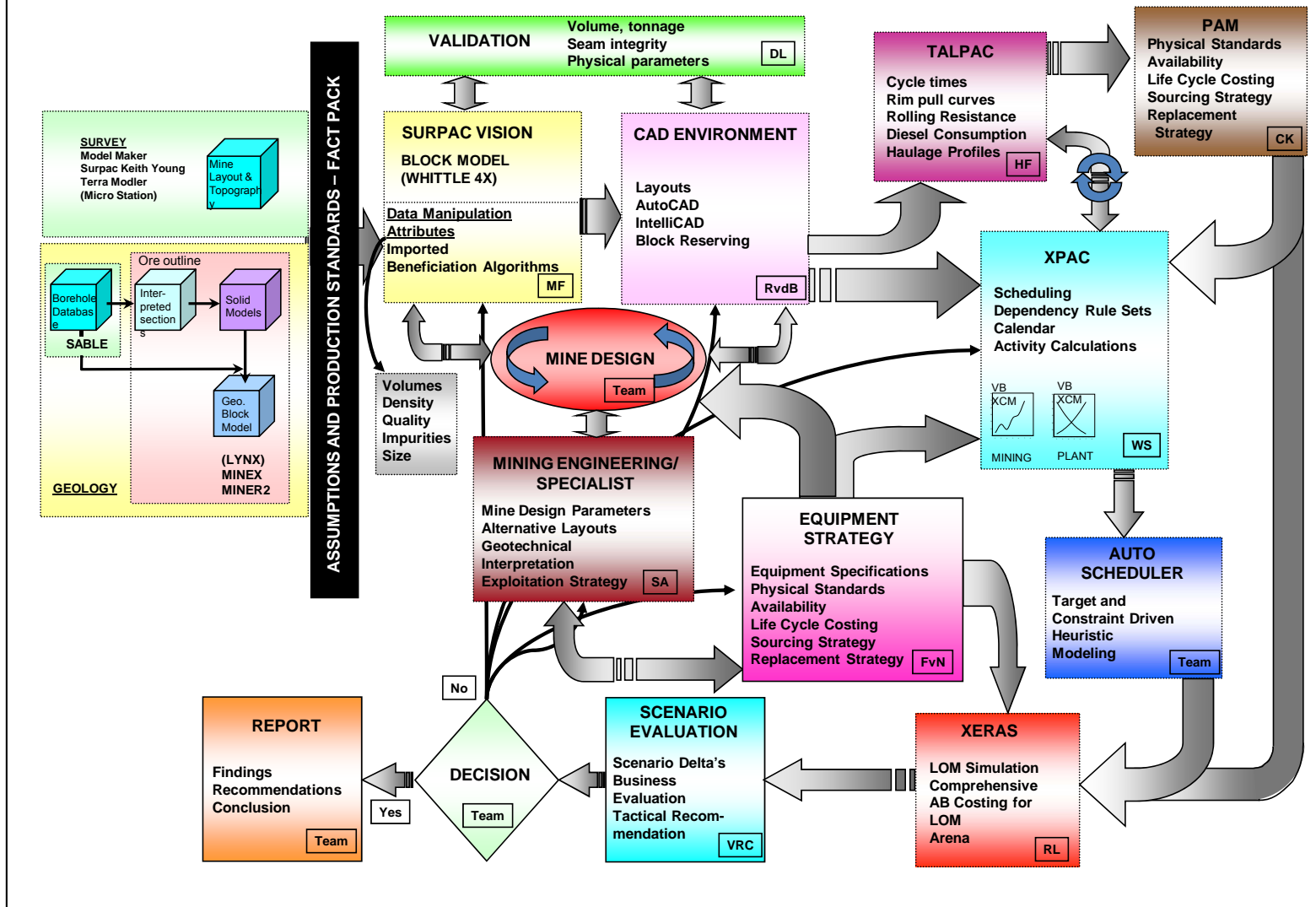
Figure 1 The Mine Planning Methodology

1.4 Productivity and Bonuses in the Budget

To get a better understanding of the complexity surrounding the compilation of a budget for a large surface mine, it is necessary to investigate the roles of productivity and bonuses in the budget process.

The following describes the "side" issues influencing the budget process and demonstrates the complexity surrounding the budget. Top management is often desirous to motivate the mine to achieve its budget in the best way possible, and this is where productivity, or rather the measurement thereof comes in.

To motivate the mine, a bonus scheme is normally proposed. This scheme often rests on a singular measurement, i.e. the achievement of the budget. The achievement of the budget is in all probability the "single coin flip" measurement that everyone is looking for, but as will be demonstrated shortly, is much easier said than done.

The first problem in considering whether a budget has been achieved, or not for bonus purposes, is that the results must be normalised, before it may be compared against the original budget. This means that all extra-ordinary or unforeseen influences must be taken into account. If this is not done, the playfield is not level and either the bonus payer or the receiver will be advantaged. External factors such as exchange rates, abnormal price fluctuations that could not have been normally foreseen, for example electricity, diesel explosives and price hikes, must be removed before any comparison could be attempted.

Unfortunately it is rarely that straightforward, as will be demonstrated because the budget in the mining environment is left open to manipulation in various ways.

The following is but a few examples thereof:

- **Stripping:** Any mine normally has a waste to ore ratio. The larger this ratio is, the bigger the influence, and therefore the easier it can be manipulated. For example, it is easy to see that in a specific year, under-stripping or the delay in waste production will obviously benefit the "budget".
- **Pit room:** To optimally produce, and especially to mitigate risk, a mine needs pit room, which readily translates into floor stocks. Here ore is ready for transport to the plant, but still at the face.

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- **Measurement date:** The budget closes on an exact date. Measurement and re-conciliation in the mining environment is done through surveying the production faces and stockpiles. This is a complicated process and for a large mine may take up to a week to finalise. Although not so obvious with modern technology, this may still have a reasonable influence on the achievement (or the manipulation) of production targets.

- **Maintenance:** This is a favourite, especially where a pro-active strategy, with replacement schedules are being followed. Unfortunately some of the effects of these strategies are not readily apparent, as most of the theory is based on probabilistic logic. It will be extremely difficult to prove or disprove manipulation. In a lot of instances the replacement or decision is based on physical inspection and practical experience. The manipulation of these strategies is unfortunately a two-edged sword, as it allows for achieving the budget in the short term, but will cause havoc later on. As the reliability of the production units goes down, they will consume money and other resources to a larger extend than planned, while simultaneously inhibiting the production due to lower than planned availability.

- **Spares and other "stores":** Mines have large "capital" expenses and have to carry a large amount of spares. In hard times these can be drawn down to facilitate cash flow. Spares or the cost there of, can also be manipulated by moving it "out of stock" into consignment stock (where the supplier carries the stock). This strategy is often viewed as advantageous, but there is no "free lunch", and the mine will incur the cost at some time in the future.

- **HR Compliment:** Another short term strategy for budget achievement is the manipulation of the personnel compliment. This is where "over budgeting" occurs, i.e. positions are budgeted and not filled, hence showing a saving against budget. Control in this area is extremely difficult as people move around, skills shortages, etc suddenly occur and contractors must be used, to name but a few problematic areas.

- **Final product stockpiles:** The mine will argue that its mandate is to produce. Therefore the level of the final product stockpiles that was brought onto the books at the beginning and end of the budget period plays a huge role in budget achievement, especially with high value products. Sometimes product

may be out of specification and has to be written off, or penalised. The declaration of this, i.e. just prior to month end or just after month end will have a huge impact on perceived budget achievement.

The list is nearly endless and the combinations legion. It is therefore quite accurate to state that the idea of a single "coin flip" measurement is a fallacy that can never be achieved. The original questions that faced top management are still there: i.e.

- Why do they fail to consistently achieve the budget

- Where do they need to spend hard earned capital to improve the achievement of the budget? (i.e. where will you get the "biggest bang for your buck")

- Is there a better way to approach this process? – instead of continuously striving to improve the accuracy of the measurement

Taking cognisance of the above implies that a strong case may be argued that budget achievement should rather be expressed in terms of a probability distribution.

Prior to investigating the application of stochastic techniques, it is necessary to have an overview of the budgeting process as applicable to large surface mines. The following is a brief explanation of the budgeting process for a large open pit mine.

Chapter 2

THE BUDGETING PROCESS

2 THE BUDGETING PROCESS – OPEN PIT MINE

2.1 Overview of the Process

The budget is the singular most important document that regulates the production of a mine. Management and its actions are continually measured against what has been "promised" in the budget.

The main inputs to any mining budget are derived primarily from the past namely:

- Historical costs
- Historical performance
- Strategy with regards to exploitation, stripping, equipment replacement and marketing

Normally, the mine will have a "Life of Mine Pitt Shell", which will delineate the mining boundaries. Within these limits, the mine will then schedule production - using a 2 to 3 year window so as to ensure that the original stripping / mining strategy is honoured.

The most important driver of the schedule and hence the budget is the Market Forecast. It is of no or very little use to produce product that cannot be sold. Constraints imposed by infrastructure, such as rail or harbour capacity is normally viewed as part of the overall Market plan. A huge amount of time is spend on price forecasts – for the very obvious reason that it is imperative to know what prices will be realised.

The next step is to marry the Market Plan to the production constraints – or bottle neck, normally the plant capacity. The Beneficiation Plant is usually the largest capital investment, and has a fixed production ceiling that limits the total that may be produced.

The Schedule is then broken down into its base components.

- 1^{stly}, the ROM tonnages from the different benches are determined and allocated to different beneficiation plants, honouring the spatial constraints.
- 2^{ndly}, the specific metallurgical characteristics for the material as will be delivered to the plants are calculated – namely yield, plant efficiency and other modifying factors like misplaced coal, etc.

The main calculation is based on

- physical standards
- norms

[The Merriam-Webster dictionary defines:

- " Standard: something set up and established by authority as a rule for the measure of quantity, weight, extent, value, or quality "
- "Norm: a set standard of development or achievement usually derived from the average or median achievement of a large group"]

The base assumption is that physical standards are changeable and can be influenced by the amount of money available – or invested, whereas norms are a given, for example:

- Availability is non-linear and for example can be upgraded by spending money, i.e. it will take a 20% increase in the maintenance budget to improve availability of shovels from 60% to 90%, but it will take 80% of the budget to go from 90% to 95% (based on the law of diminishing returns)
- Norms are things that are fixed irrespective of money spend – For example a certain plant design gives a fixed magnetite consumption, or tyre life related to km.ton/hour for specific pieces of equipment

Utilisation through shift rosters and the number of operators employed is then added to the equation. Broadly speaking, the budget may be divided into two distinct parts namely:

CAPEX (Sustainable) and other (as explained earlier)

- Replacements
- Refurbishments
- Fleet changes   (etc)

and OPEX

- Salaries
- Electricity
- GET (Ground Engaging Tools)
- Oils & Lubes

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- Petroleum

- Explosives

- Conveyer Belting

- Magnetite Consumption

- Tires

- Other Miscellaneous Items

The correct way to cost a schedule is to link the tonnages to the activities, called activity based costing (as previously indicated in the scheduling methodology – refer **Figure 1** The Mine Planning Methodology). This is achieved by using XERAS® and is commonly referred to as ABC – Activity Based Costing.

This results in a budget that tries to reflect reality, however the shortcoming is that it is based on **fixed** events – i.e. events that are supposed to occur. No exceptions are allowed for. This is of course not true. In the mining production environment nothing is absolutely fixed as is apparent in the intricate and highly complex environment of a large mine.

The only way to address this is to have a different approach, and this leads to the introduction of risk and uncertainty. The concept of risk and uncertainty is by their very nature not deterministic, but can only be reflected through probability theory. This then logically leads to the use of stochastic modelling of the budget to reflect uncertainty in the predicted cash flow.

The budget process is graphically shown in **Figure 2** Diagram of Planning and Budgeting Process. The assurance part inclusive of CI (Continuous improvement) is also included in the picture for completeness.
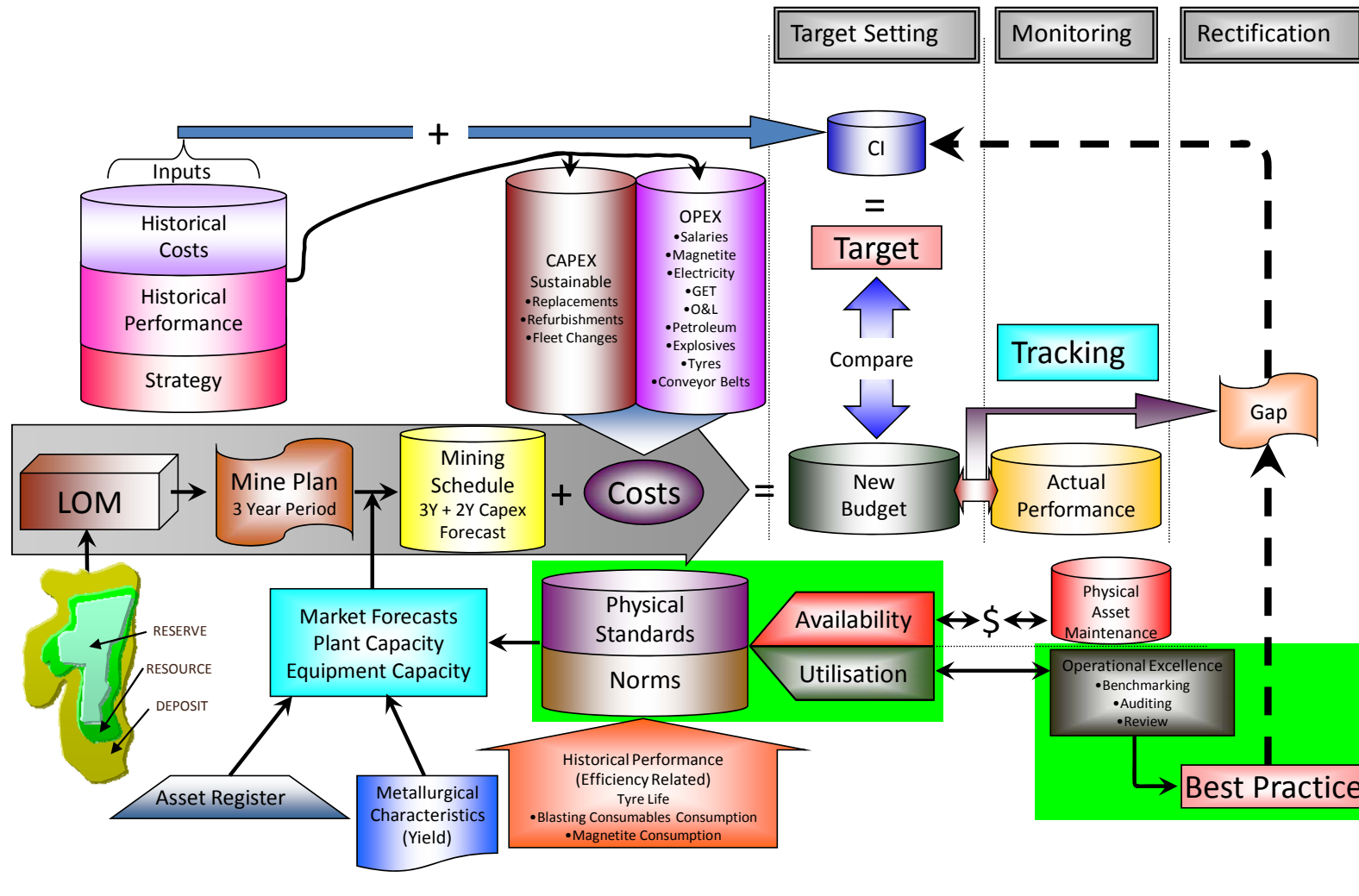
Figure 2 Diagram of Planning and Budgeting Process

2.2 Basic Measurements of the Budget

Once the detail modelling tool is in place and calibrated, the key drivers of the budget can be determined. These are the drivers that have the largest influence on the budget, and also have the largest variance. To find the most important (key) drivers of the budget, a classic Pareto analysis (Reviews 2012) was done.

Table 600 is a SAP expression that is generally used to summarise the budget in its main cost buckets. **Table 1**: Pareto Analyses (Reviews 2012), shows the main cost buckets that were extracted from Table 600. (Budget figures normalised, not real).

Table 1: Pareto Analyses

Patero Analyses Category	Total Term R	FC R	VC R	ROM Tons	Function VC Factor R	Makeup %
Other	497,524,211	199,009,684	298,514,526	81,472,040	3.66	29%
Salaries	277,166,335	203,756,430	73,409,906	81,472,040	0.90	7%
Energy	159,002,391	53,000,797	106,001,594	81,472,040	1.30	10%
Diesel	202,737,144	12,671,071	190,066,072	81,472,040	2.33	19%
Plant Maintenance	184,945,530	-	184,945,530	81,472,040	2.27	18%
Maitenance	396,598,334	317,278,668	79,319,667	81,472,040	0.97	8%
Explosives	97,908,285	3,179,336	94,728,949	81,472,040	1.16	9%
1,815,882,229		788,895,986		81,472,040	12.61	100%

The main categories as delineated by the Pareto analyses (Reviews 2012) – refer to **Figure 3** Results of Pareto Analyses - are the key drivers that can now be manipulated within the stochastic process – i.e. a Monte Carlo (Reviews 2012) simulation.
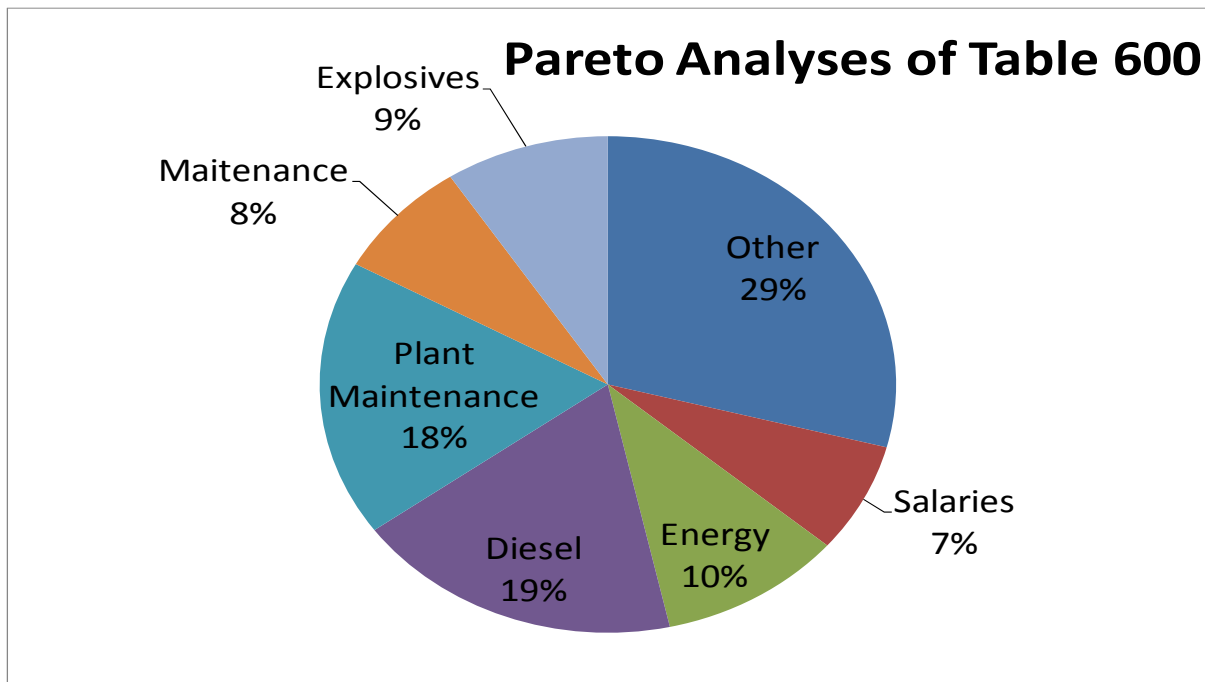
Figure 3 Results of Pareto Analyses

Further analysis highlighted the complexity of the problem. Diesel for example, is influenced by price fluctuations, over which the mine has no control. It is however also influenced by production, i.e. higher production will require more diesel. But if there are better standards i.e. l/ton produced, the mine will require less diesel than budgeted.

The main concept, is that if two or more key drivers (that have a large impact), have large variances as opposed to their budget assumptions, and are independent of each other, the probabilities of each may be multiplied to get a new probability. This new probability will have a larger "spread" than either of that of the individual drivers. This leads to the instability of budget achievement.

The problem with the above statement is that if too many drivers with too large a spread are chosen, the resultant probability will be worthless, i.e. multiplication with a lot of fractions, quickly approaches zero.

It is therefore clear that the key drivers should be chosen carefully. These drivers must also have the attribute that they are compiled of different secondary probabilities that may be influenced (or manipulated) so as to optimise the distribution of the primary probability.

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This logically leads to the investigation of how these 1st order (prime) probabilities may be influenced or manipulated to increase confidence, so the budget can be achieved. The natural deduction is that it will be mostly through the application of money, i.e. fix something, buy more, pay someone to do it, etc.

The above translates to the final objective: To provide a realistic budget in terms of a probability distribution that will indicate for certain confidence intervals the risk of not achieving the budget and show where capital should be applied to get the optimum return.

Applying standard stochastic methodology, the cost buckets were then combined to describe the cost function, broken down into fixed and variable cost. Income (through selling the product) was added to allow the results to be expressed as a Nett profit (prior to tax and cost of capital). The probability distributions were assumed to be triangular with a lowest, highest and most probable value (Risk & Handbook 2007).

This methodology did not work, as the multiplication of uncertainty just leads to a wider and wider spread of probabilities – to the extent that it is clearly an irrational approach. This is most probably the reason why Monte Carlo Simulation is not used in the standard budgeting process. From the literature it is clear that Monte Carlo simulation is mainly used for capital budgeting of large projects (Clark 2010). Such simulations are concerned with the cost of the project, while this model concentrates on the uncertainty inherent in the production process and regards cost fluctuations as risk i.e. uncontrollable (but explainable), for example price increases in diesel, electricity, etc.

A different approach was indicated and the Drum–Buffer–Rope (DBR), production planning methodology from the theory of constraints (TOC) as originally proposed by Eliyahu M Goldratt in the 1980s, was considered. Schragenheim, Eli (2000) summarises it as follows:

The Drum Buffer Rope strives to achieve the following:

- very reliable due-date performance
- effective exploitation of the constraint
- as short response time as possible, within the limitations imposed by the constraints

The problem with the DBR methodology is that although the beneficiation plants (specifically the tipping bins of these plants), are normally defined (through TOC) as the bottleneck, the analogy is not a true one as the mining process differs from the manufacturing production process. It should rather be described as a trail run with a specific obstacle that all the runners have to cross. It is clear that if trucks are seen as a buffer, the logical response would be to over truck the constraint. However, in the analogy of trail running, this is the worst possible decision. More athletes trying to cross the same obstacle result in more interference with each other and a slower throughput.

Envision athletes running a trail run. Some run faster and some slower. Some stumble and block others etc. There is no rope – i.e. communication once the athletes are running and this is exactly the problem with production haul trucks. Breakdowns, bad road conditions or secondary work on the road, intersections etc. causes unpredictable delays that can only be handled by probabilistic logic.

The correct solution is to express the budget as a probability distribution through examining the effect of the inputs in a logical way. These inputs will themselves be probability distributions. By managing these distributions, the final shape and position of the budget distribution may be influenced. At this stage it was clear that the problem of deteriorating probability distributions resulting in worthless answers, had to be solved if any realistic budget distribution were to be obtained.

The understanding of the difference between the risk and uncertainty clearly indicates that the focus must be on "controllable factors", as the assumption that these factors may be influenced by money (i.e. either men, material or equipment). This will also allow the tool to indicate to management where to optimally spend funds, so as to maximally impact the achievement of the budget.

The re-examination of the methodology with the above in mind, lead to re-defining the heartbeat of the operation. ROM must move and as ROM finally drives everything in the budget, the budget can be re-written in terms of ROM. To find the key impact on ROM movement, it is clear that for a large open pit operation it should be on wheels – i.e. trucks. So, by measuring and understanding truck cycle, the inherent uncertainty can be quantified as a probability distribution. These

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distributions may be tweaked through the application of money and will directly influence the production and therefore the achievement of the budget.

Further literature research led to the field of probabilistic logic. The application of logic to enable budget simulation without losing definition was the next approach.

Chapter 3

APPLYING PROBABILISTIC LOGIC
TO THE BUDGET

3   APPLYING PROBABILISTIC LOGIC TO THE BUDGET

3.1   Probabilistic Logic and Probability Theory

The basic aim of probabilistic logic is to make use of probability theory in combination with logic. Probability theory is used to handle uncertainty, while deductive logic is used to exploit structure.

One of the problems with probabilistic logic is, that they tend to multiply the computational complexities of their probabilistic and logical components (as noted earlier), resulting in an answer that is too vague, or broad to have practical meaning.

The term "probabilistic logic" was coined by Nils Nilson, published in a paper in 1986 (Nilson J. Nils n.d.), as the development of artificial intelligence applications, that require the ability to reason with uncertain knowledge.

The very idea of combining logic and probability might look strange at first sight Hájek (2001). This is obvious because probability theory deals with uncertainties, while logic deals with absolutes, i.e. a thing is, or it is not.

With the combining of Logic and Probability theory, two very different, but equally powerful premises are combined. Logic offers a rigid structural perspective, i.e. the qualitative side, while probability supplies the numerical or quantitative side.

By integrating these complimentary perspectives of both qualitative logic and qualitative numerical probability theory, probability logic offers a highly expressive account of interference, The general accepted strategy is to start with a propositional/model system of logic and then to "probabilify" it.

For this thesis, the selected model will be a standard budget for a large open pit coal mine. The answer of the budget is then "probilified" by adding uncertainty to the main drivers that will influence the outcome of the budget, resulting in a probability distribution of Nett profit for example.

In this system, it would probably be more accurate to describe it as "Model Probability Logic". By definition Model Probability logic makes use of many probability spaces, each associated with a possible world or state, Jøsang (2009).

So in essence Model Probability Logic associates to every world a probability distribution, while allowing for embedding of probabilities within probabilities. Accordingly, in this environment, the only way to handle a model setting, involving multiple probabilities, is with the help of stochastic modelling, e.g. using Monte Carlo (Reviews 2012) simulations. (In this instance ARENA® is used, as explained later).

Probability spaces are restricted to the primary space, e.g. the failure of a machine (and the influence thereof on its production capability), is seen as one primary probability distribution, and not as numerous discrete distributions coupled to all the separate parts that may fail.

This decision results in that, although the problem is still within the framework of model probability logic, the key drivers are limited to first order probability logic. (Although, during implementation second order probabilities that comprises the prime probability, may be used to influence the desired outcome.)

3.2   Definition of Risk & Uncertainty

Risk (and the chance of loss), i.e. in the event that the situation contains both favourable and unfavourable outcomes; is the probability that the event outcome will be unfavourable i.e. an unwanted event, Elkjaer (2000), while uncertainty is the indefiniteness associated with the event, i.e. the distribution of all the possible outcomes. Uncertainty is an intangible value, Elkjaer (2000).

As discussed, the biggest problem with the budget is that it uses point estimates only. Discrete estimates alone, are insufficient for good decisions (Risk & Handbook 2007), or a good budget.

3.3   1st Hypothesis

To "probilify" the budget, it should be expressed, as a range within a probability distribution, as depicted in **Figure 4   Probability Distribution – Influence of the variance and mean on the shape and size** and not as a singular number

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- The position of the budget point relative to the median is important, i.e. above equals a larger chance of failure, and below equals a bigger chance on success, i.e. of at least making and/or exceeding the budget.

- The shape of the distribution is important, i.e. a narrow "band" implies a greater chance of success, while a broad distribution equates to a higher risk environment with a larger chance of failure.
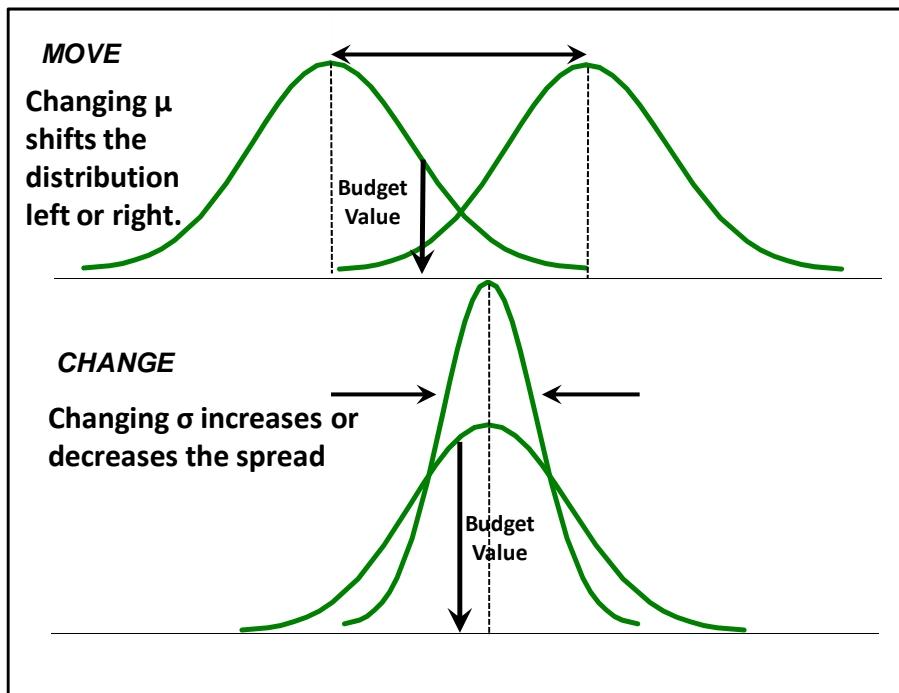
Figure 4   Probability Distribution – Influence of the variance and mean on the shape and size of the distribution

3.4   2nd Hypothesis

This hypothesis states that the variability (distribution) of some of the key drivers may be changed through the application of funds – i.e. training of personnel, appointing more personnel, buying and commissioning more production units, better maintenance to improve reliability etc.

- Not all key drivers can be influenced through application of money.

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- The inter-dependability obscures the relationships between some drivers to the extent that is impossible to define the value of changing a secondary driver without detail modelling.

3.5   Production – variability

The total production cycle comprises activities that are:

- Linked in sequence
- Variable in nature

Each separate part (link) of the production chain can be defined through their own probability distribution. Thus we may conclude that the total production process is highly variable and complex as each activity (in real time) has a variability component. The aim is to ascribe stochastic durations that mimicking actual real time occurrences.

The sub-components (2nd order drivers) of the process cycle times and cost can accurately be predicted, which means that where we may ascribe a degree of variability to these components, they can be reflected through a probability of occurrence.

3.6   The Probabilistic approach

The logic component is clearly defined in the budget process and combining this with a probabilistic approach aims to determine:

- What does the confidence levels look like for a given budget?
- Could the application of probabilistic logic influence the inherent risk associated with non compliance to the budget?
- Will a probabilistic approach allow the budget owner to establish a target probability with a higher confidence level?

To answer the above questions' impact on the budget or the possible achievement thereof, the budget must be simulated in a stochastic environment. However the methodology needs to be adapted so that the resultant probability distribution does not deteriorate to the extent that it is nonsensical.

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In re-examining the approach, it is clear that applying a normal Monte Carlo simulation, will not give the correct answer. A different concept is needed that will enable a simplification of the methodology without losing the accuracy needed. The budget utilises assets i.e. production units to mine and to supply ROM to the plant. The plant beneficiates and delivers product to be sold.

To use any asset for continuous production, three things are required:

- Capital (money)
- Utilisation (produce when it is not broken)
- Maintenance (fix it if it is broken – including planned maintenance)

In considering the use of the assets, the main drivers that will influence the budget can now be derived, albeit in a simplified form.

CAPITAL:

Only three things can happen to Capital expenditure. Capital may be replaced, sustained or increased, i.e. buy more production units.

USE of ASSETS:

Broadly speaking assets are either being used or maintained. If they are in use, they can be used productively, or not .The level of utilisation will depend on the skill level of the people and the amount of people, called FTE's. Both may be changed by applying more money i.e. Employ more people or train them better. The same basic argument can be applied to maintenance. Do better maintenance by spending more money (replace before failure etc), employ more FTE's (Full Time Employees) and/or train them better.
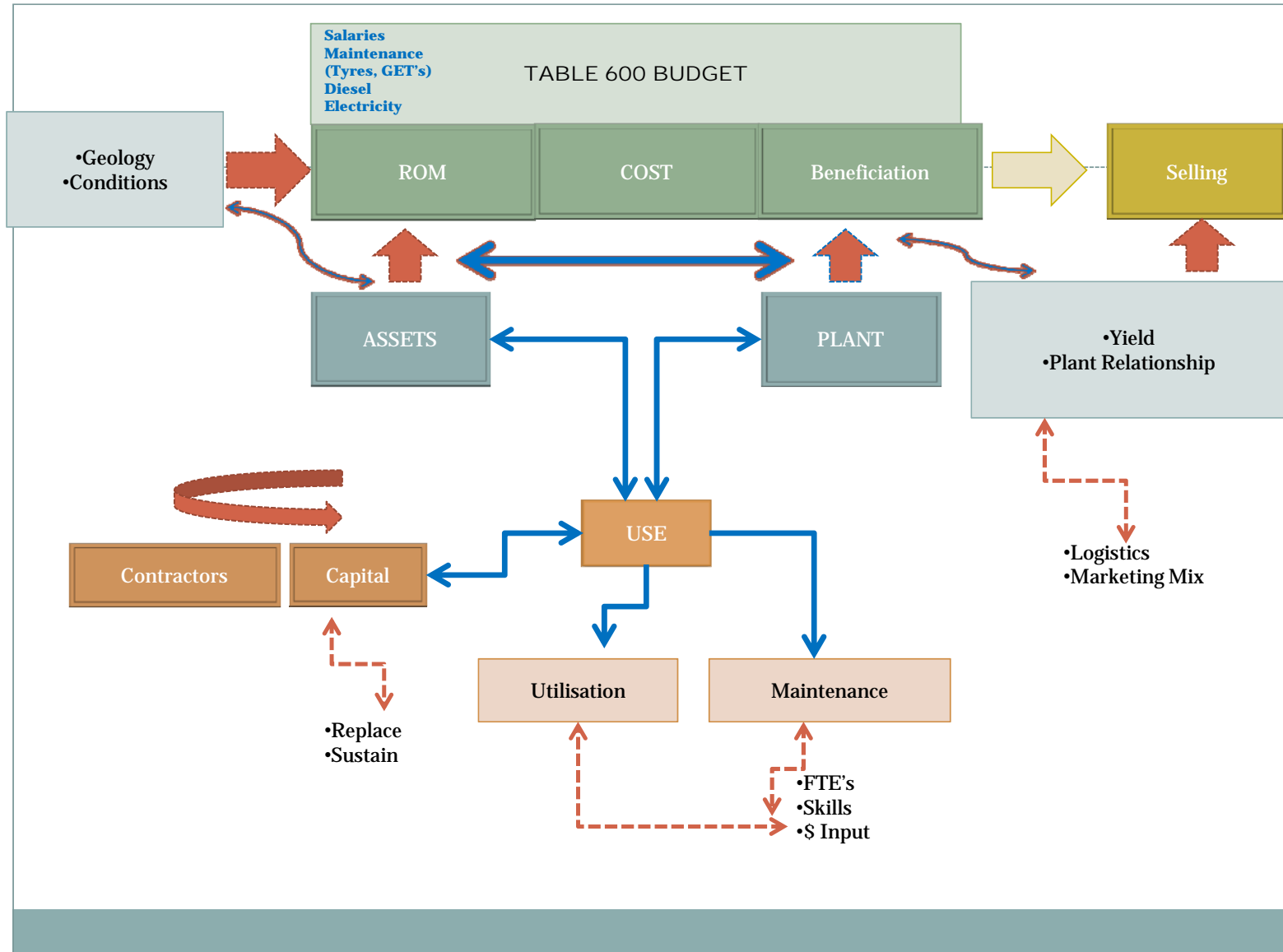
Figure 5 Interaction of Table 600 with the Production Process

The above picture, **Figure 5** Interaction of Table 600 with the Production Process, now clarifies the process.

The geology and other mining conditions are given inputs into to the budget. These are accessed through the mining schedule, which in reality tries to link time based production occurrences to the budget. This is done in XPAC®, where the yield and plant relationships that will exist sometime in the future, are now derived through a time based production schedule. The resultant product mix will impact on Logistics and the Marketing to determine the revenue.

The above description is a shortened version of the actual process, but based on Logic, accurate enough to cut through all the myriad confusing inter relationships that exist in such a complex environment. The methodology proposed here, to take cognisance of the "probability", is sound. This solution may then be used to calculate the Revenue culminating in the final budget figure, expressed as Nett profit.

All that is further required to complete the process, is to be able to couple the impact of each stochastic choice directly to the mining schedule. This is done by utilising the Logic component to link the effect of the probabilistic choice to the budget through the mine plan that underpins the schedule. The rigidity of the mine plan allows this logic to be deduced and imbedded in the methodology.

3.7   Rigidity of the mine plan

The development or mining of an open pit follows very strict rules, which may be logically exploited for simulation "shortcuts" - i.e. the creation of the void may be described as the development of a consecutive series of pit shells, governed by the need to keep the pit slopes at various stable angles and have roads and ramps in place for access to specific blast blocks. Although some deviations are possible, it can logically be proven that for a given budget period the interrelationship between the different material types may be approximated by a fixed distribution – for example – the slope has to be maintained (to honour spatial compliance), so the % distribution between benches will stay the same, but with increased production the slope will move faster (in the direction of mining), and with decreased production, it will move slower. Utilising the bench ratios, which is a fixed set for each pit layout, the ROM can now be determined and logically applied for each stochastic choice.

3.8 Basic Assumptions for Stochastic Parameters

The basic assumption is that all key parameters that can influence the budget will conform to some sort of a probability distribution. The following distributions are considered:

- Triangular
- Normal – Gaussian
- Weibull – skewed left
- Weibull – skewed right

These will be sufficient to describe any deviation, assuming a 90% confidence interval with the minimum, maximum and median derived by some "method" as described later. Due to the ability of a 3 parameter Weibull distribution to closely approximate a normal distribution, the normal distribution was ignored to a large extent.

3.9 Initial Concept

The initial concept was that .once the detail tool is in place and calibrated, the key drivers of the budget can be determined. These are the drivers that have the largest influence on the budget, and also have the largest variance. The main concept, is that if two or more key drivers (that have a large impact), have large variances as opposed to their budget assumptions, and are independent of each other, the probabilities of each may be multiplied to get a new probability. This new probability will have a larger "spread" than either of that of the individual drivers. This leads to the instability observed in the achievement of the budget.

It was then proved with a simulation that if too many drivers (primary) with too large a spread are chosen, the resultant probability will be worthless, i.e. multiplication with a lot of fractions, quickly approaches zero, resulting in a very "flat" (and worthless) probability distribution. The inherent interrelated complexity of what to change during the simulation brings to mind the age old observer's problem that plagues biologists during their experiments i.e. - *"That to observe is to change that what is being observed"*.

Budget risks e.g. higher inflation, higher diesel prices, underperforming assets, declining revenues can't be ignored, as for a large mine the influence may be such

that these risks may threaten the company's ability to fund new projects, pay dividends and such financial volatility can wreak havoc with the company's cash flow. A huge amount of nearly endless possibilities exist, that will influence the achievement of the budget. To stochastically examine them all creates so much "noise" that the outcome is valueless.

It is therefore clear that the key drivers must be carefully chosen. These drivers should also have the attribute that they are compiled of different secondary probabilities that may be influenced (or manipulated) so as to optimise the distribution of the primary probability.

This logically leads to the investigation of how these 1st order (prime) probabilities may be influenced or manipulated to increase confidence, so the budget can be achieved. The natural deduction (of management) is that it will be mostly through the application of funds, i.e. fix something, buy more, pay someone to do it, etc.

The above translates to the final objective, to provide a methodology that will realistically forecast budget achievement (or non-achievement) as a probability distribution and show where scarce capital should be applied to get the optimum return.

3.10 Original Intent

The original intent was to use only Xeras® to calculate the distributions as the input parameters vary. This is entirely possible, except that 10 000 runs for a large model will take about four years to run.

This was a major short coming of the methodology – and a way had to be developed to overcome the time constraints required by the calculations. For this to be possible, the budget is expressed in terms of a series of mathematical equations and Logic is coupled to the stochastic process to facilitate the simulation. This is achieved through re-defining the key drivers of the production process in terms of ROM, concentrating on the haul truck.

3.11 The Haul Truck – defining the heartbeat

A truck carries a payload, which is not a fixed tonnage, but may vary considerably. There are two specific components to the bowl design, i.e. volume and weight, Loader Operator expertise, material loose bulk density (i.e. after blasting) and the

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type of material (i.e. iron ore or coal), all vary considerably in a given pit. Truck bowls limit the volume, i.e. that, which is too much, will fall off and the truck has a maximum carrying capability, where after damage to the truck body will be occur.

A truck moves material from a given point to a fixed destination – normally from a series of benches to a plant, or crushing facility, or in the case of overburden to a waste dump.

A truck haul cycle consists of the following components:

- hauling / travelling to bin or crusher – full
- queue at bin
- tip
- hauling / travelling back to loader - empty
- queue at loader
- spotting (manoeuvre into loading position)
- load
- cycle starts again

It is clear that there is a rigidly defined or fixed amount of production hours per year/per day/per month etc. during which the truck may be utilised. During this time the truck must operate not only productively, but also be maintained. Waiting times (i.e. times not hauling) should be as short as possible.

This leads to the concept of over trucking and under trucking which may briefly be summarised as follows:

- Over trucking will optimise loader capacity and under utilise truck capacity.
- Under trucking will optimise truck capacity while under utilising loader capacity.

Because wasting capacity is considered poor management, i.e. large capital resources stand idle – a considerable effort goes into matching loader and truck capacity. Expensive systems (like Dispatch for example) are implemented to optimise hauling and loading capacity.

It should also be noted that there is a ridged logic to an optimum mine plan, i.e. the benches cannot undermine each other and although overburden stripping may be accelerated, this will come at the cost of moving less ore for instance. This may be

considered as un-economic (or irrational) during a specific budget period, unless "savings" for later is intended (and as such is ignored in the methodology proposed).

After the analysis shown, in **Figure 5** Interaction of Table 600 with the Production Process, it was clear that the main areas influencing the budget, will be:

- Primary production units
    - trucks
    - shovels
- Plant
- Market

It is known that the Plant capacity exceeds that of the Market (a design parameter), so the question is: Trucks or Shovels? From the budget analysis, it was clear that trucks have the biggest influence as the mine has spare shovel capacity.

This is confirmed by a TOC® (Theory of Constraint) (Goldratt n.d.) analysis, refer to **Figure 6** TOC Analyses on the Production Process.

Figure 6 TOC Analyses on the Production Process

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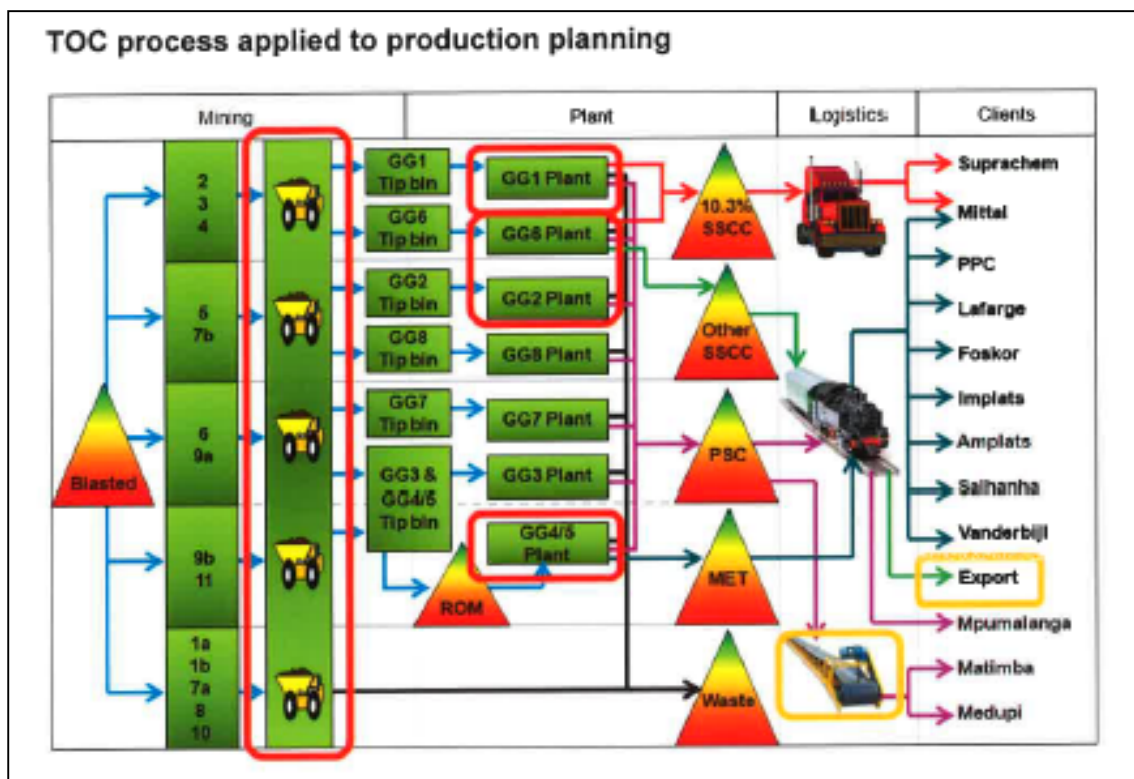
3.12 Re-defining the Problem Statement

A stochastic approach to financial modelling of the budget is needed. This approach must allow simulation of financial results under a variety of possible scenarios, showing how outcomes might be affected by changing business and economic conditions.

Simulated Nett cash flow under extreme movements in controllable budget inputs such as fluctuations in the norms and standards that underpins the budget is needed.

In its most general form, the process tries to measure the potential loss or profit (in monetary value) of the budget over a defined period, reflecting a probability distribution in which a given confidence interval may be assumed for the achievement –or non-achievement of the budget.

Furthermore, the influence of funds applied to specific areas of the budget must be reflected in the probability distribution of the budget achievement.

3.13 Probabilistic Methodology

Rom tons can be described by the Operational Performance drivers. These drivers can be described by probability distributions which can be **measured and managed and influenced.** The relationship between the Operational Performance drivers and tons can be determined with a function – refer to paragraph 4.1. The main Operational Performance drivers are:

- Maintenance (Availability and Utilisation)
- Operators (FTE's, Skills, Production Rate)
- Fleet Units

The Xpac® model, that drives the tonnage schedule on which the budget is based, is used to get Bench information for: Tons, Hours, Cycles, Payload and Destination – i.e. from where (blast block) to which plant or overburden dump (destination).

A Monte Carlo simulation is done to simulate the Cash Flow model. The model varies chosen Business Drivers in order to get a Nett Cash Flow distribution for the budget, based on the premise that tons mined are the main reason for a mine to exist. By selling the product, a profit is generated.

The model uses Excel® driver inputs (per destination per Bench) obtained from an Xpac® Life of Mine Plan, such as Cycle times, Bench Ratios, Payloads, Fleet Hours and Physical standards. The model then uses probability distributions to vary the

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drivers independently. The initial (pre-determined) probability distributions are obtained from the mine's history through a sequel server database. Values are generated using Weibull distributions as explained.

The Model adjusts the driver values and then ensures that the Fleet size and Bench Ratio is kept constant in order to simulate new Bench tons and Product tons. The model has product prices per bench, per destination, per product and calculates a Nett Cost and Nett Income.

The final Monte Carlo model was also expanded to be able to 'randomise" more than one parameter simultaneously so that any combination of parameters may be tested as to their influence on the budget. The interaction between the different environments and accompanying models are depicted in **Figure 7** Model Interaction.
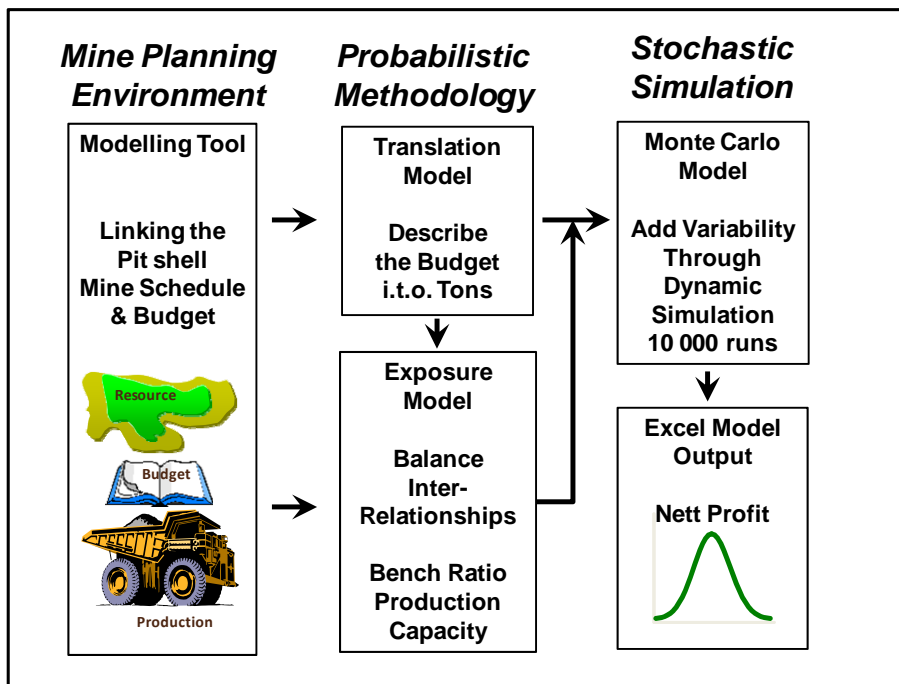
Figure 7 Model Interaction

Chapter 4

MATHEMATICAL DESCRIPTION OF

THE CASHFLOW MODEL

4 MATHEMATICAL DESCRIPTION OF THE CASHFLOW MODEL

4.1 Deriving the budget description in a mathematical expression

To facilitate the computational time requirement, the budget is described with a mathematical expression. This is called the translation model. For clarity refer to Figure 7 Model Interaction, to see the interaction.

The Budget function f can be described (from Xeras®) in terms of: Fixed (Fc) and Variable costs (Vc). The variable costs are a function of ROM Tons (t) and Tons (t) are a function of Operational Performance (OP).This leads to the Budget (Pareto based) Cost Function f, where:

f = Fc_Other + Fc_Salaries + (Vc_Salaries x tons)

- + Fc_Energy + (Vc_Energy x tons)
- + Fc_Diesel + (Vc_Diesel x tons)
- + Fc_Plant Maintenance + (Vc_Plant Maintenance x tons)
- + Fc_Maintnance + (Vc_Maintenance x tons)
- + Fc_Explosives + (Vc_Explosives x tons)

and the Budget Income f = (AvePrice x tons)

Rom Tons can be described by the Operational Performance drivers. These drivers can be described by probability distributions which can be *Measured, Managed and Influenced.* The relationship between the Operational Performance drivers and tons can be determined with a function. The main Operational Performance drivers (as previously shown) are:

- Maintenance (Availability and Utilisation)
- Operators (FTE's, Skills, Production Rate)
- Fleet Units

The Xpac® model, that drives the tonnage schedule on which the budget is based, is used to supply Bench information for:

- Tons
- Hours
- Cycles
- Payload

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- Destination – i.e. what plant or overburden dump

This is used to reflect the Tons/driver relationship. Expert "Guestimates" are used to get Normal or Triangular distributions of these inputs if no operational detail is available. In most cases detail data for (at least) the 6 month period prior to the budget, was used to develop the distributions, using a three parameter Wei Bull fit.

Repeated random sampling of the Computational algorithms is then run in order to compute the **Budget Function Probability Distribution**.

4.2 Steps for setting up the Probabilistic Cash Flow Model

– refer to Figure 8 Cash flow distribution process.

- Identify the macro economic variables or drivers that have a significant influence on the budget performance by using the Pareto principle.

- Set up the Business case to reflect the Budget.

- Analyse and acquire probability profiles for the identified drivers, using Dispatch SQL Database evaluation (**Figure 9** Example of Sequel server database) to supply the calibrated Weibull distributions.

    (Note that risk is derived from random, unexpected deviations from the forecasts).

- Use the Xeras® ABC model to estimate the exposure model, for a specific variable. The fundamentals and statistics interact to derive a model with economic logic (this is the basic cash flow model, underpinned by logic).

- Use a stochastic process to simulate values of the variables by randomly picking observations from their variance/covariance matrix. In each simulation run, draw a random value (for example, 10,000 Monte Carlo/Arena® simulations).

- Insert the simulated values in the exposure model via the translation model, to derive a distribution of cash flow that reflects the distribution conditional on macro-economic volatility as influencing the budget achievement

- Plot the Cash Cost Distribution

- Determine if more information is needed and re-iterate if needed. Measure where information value is high and reduce uncertainty.

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- Select the confidence level, and calculate probability distribution that is relevant to the specific budget.
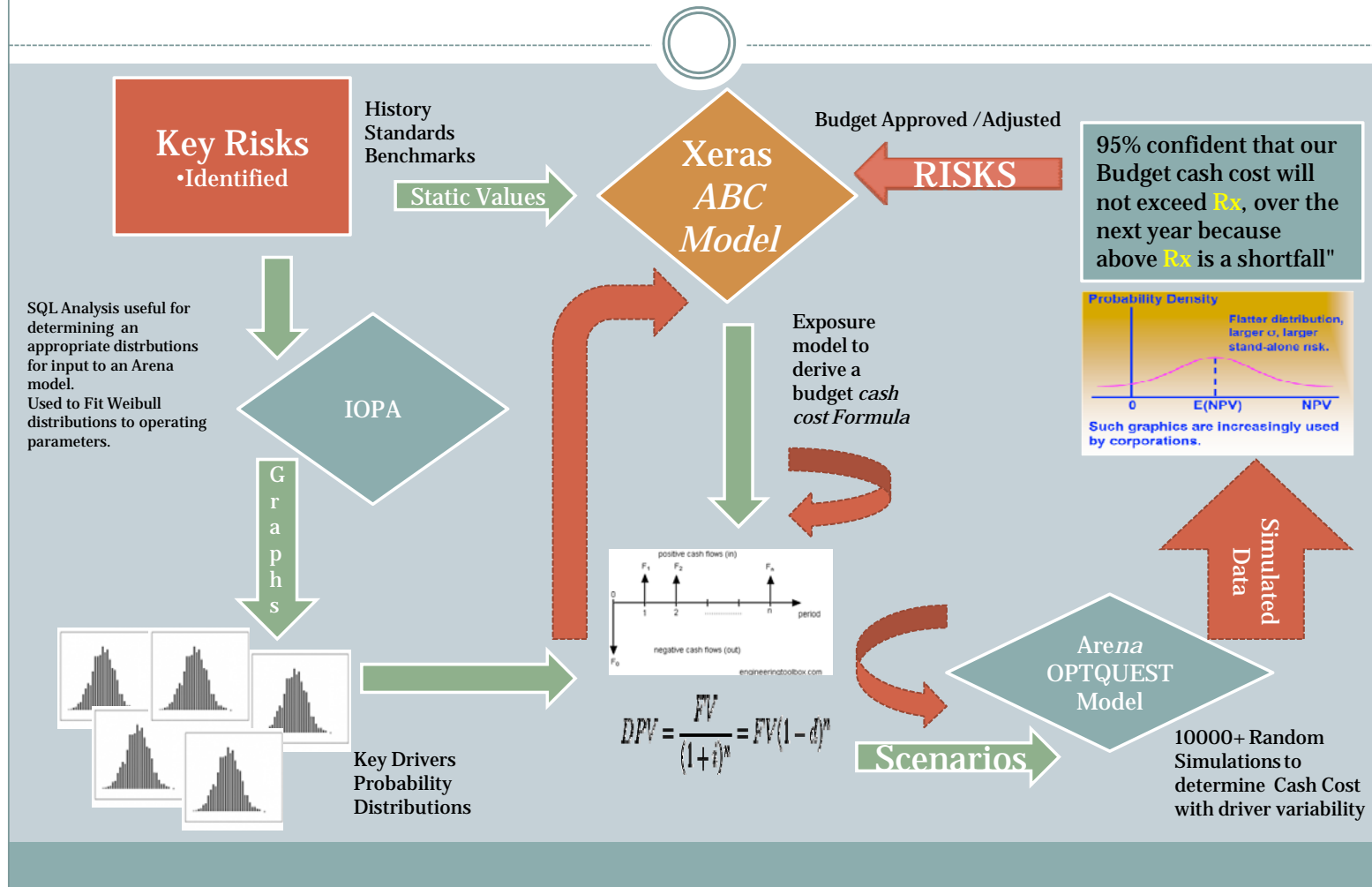
Figure 8 Cash flow distribution process

SQL Analysis Example Output

		measureton	emptyhaul	Spottime	queuetime	loadingtim	fullhaul	dumptime	Reassigntime	cycletime
Cond 1	Beta	7.00	1.80	2.00	1.07	2.20	2.00	1.60	1.56	2.00
	Eta	120.00	250.00	100.00	229.98	110.00	300.00	100.00	1 585.64	800.00
	Theta	80.00	450.00		-	120.00	450.00	25.00	-	1 200.00
Cond 2	Beta	5.00	1.70	2.00	1.33	3.50	2.00	1.72	1.72	2.50
	Eta	90.00	250.00	130.00	482.37	260.00	280.00	85.88	1 573.45	1 000.00
	Theta	100.00	380.00		-	120.00	450.00	25.00	-	1 200.00
Cond 3	Beta	5.80	1.80	2.00	1.15	2.50	2.60	1.20	1.35	2.00
	Eta	100.00	230.00	110.00	248.52	130.00	300.00	60.00	1 465.89	800.00
	Theta	90.00	430.00		-	130.00	450.00	45.00	-	1 200.00
Cond 4	Beta	6.58	2.00	2.00	1.09	2.50	2.50	1.20	1.17	2.20
	Eta	110.00	250.00	110.00	227.01	130.00	270.00	40.00	1 370.83	800.00
	Theta	80.00	430.00		-	130.00	450.00	30.00	-	1 200.00
Cond 5	Beta	6.58	2.00	1.80	1.07	2.20	2.50	1.60	1.34	2.20
	Eta	110.00	300.00	100.00	264.23	130.00	300.00	45.00	1 430.24	800.00
	Theta	85.00	350.00		-	140.00	400.00	45.00	-	1 200.00
Cond 6	Beta	6.58	2.00	1.80	1.40	2.20	1.70	1.30	1.31	2.50
	Eta	110.00	300.00	94.75	271.00	130.00	300.00	30.00	1 477.10	1 000.00
	Theta	85.00	350.00		-	140.00	500.00	30.00	-	1 000.00
Cond 7	Beta	7.00	2.00	1.80	1.04	2.20	2.00	1.30	1.18	2.50
	Eta	120.00	280.00	105.14	251.57	130.00	280.00	40.00	1 342.20	1 000.00
	Theta	75.00	350.00		-	140.00	450.00	30.00	-	1 000.00
Cond 8	Beta	7.00	2.00	1.80	1.16	2.20	2.00	1.80	1.25	2.50
	Eta	120.00	280.00	97.34	242.12	130.00	250.00	45.00	1 410.67	900.00
	Theta	75.00	350.00		-	140.00	450.00	45.00	-	1 000.00

Figure 9 Example of Sequel server database

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Chapter 5

DYNAMIC SIMULATION MODEL

5 DYNAMIC SIMULATION MODEL

An Arena® Dynamic simulation model (which is a Mote Carlo simulation) was built to simulate the Cash Flow model that is used for analysis. The objective of the model is to vary chosen Business Drivers in order to get a Nett Cash Flow distribution for the budget based on the premise that tons mined are the main reason for a mine to exist and by selling the product it will generate a profit.

The model uses Excel® driver inputs (per destination per Bench) obtained from an Xpac® Life of Mine Plan. Typical driver inputs like Cycle times, Bench Ratios, Payloads, Fleet Hours and Physical standards are READ IN by the model.

The model then uses probability distributions to vary the drivers independently like Cycle times, Payloads and Fleet Hours (Making provision for *force majeure* events, and Operator absence). The probability distributions are obtained from the mine's history through the sequel server database refer **Figure 9** Example of Sequel server database. Values are generated using Weibull distributions with an Excel® program – as shown in **Figure 13** An example of Weibull distribution analyses in Excel®.

The Model adjusts the driver values and then ensures that the Fleet size and Bench Ratio is kept constant in order to simulate new Bench tons and Product tons through the exposure model – refer to Figure 7 Model Interaction.

The model has product prices per bench, per destination, per product and also has the variable and fixed costs as derived from Table 600 Budget, in order to calculate a Nett cost and Nett income.

Initially 2500 variable runs of each Independent Driver was simulated and the values were recorded in order to apply a statistical analysis of the Profit distribution using an Excel® input sheet with built in formulas for evaluation.

An example of the model outputs is shown in **Figure 10** An example of Arena® simulation runs.

The Arena model's structure is briefly displayed in **Figure 11** Arena Model – Part A and **Figure 12** Arena Model – Part B

Through inspection of the results, it was determined that 2500 runs did not give consistent answers. Through testing the optimum was determined to be at 10 000 runs, and since this has a negligible impact on the time needed for a run, all subsequent runs have been set to 10000.

Because Arena® does not use "time" in the sense that the scheduling model does, an extra iteration to limit the total production hours available, had to be implemented. **Table 2:** Exposure Model below, shows the impact on the complexity of the model

Table 2: Exposure Model
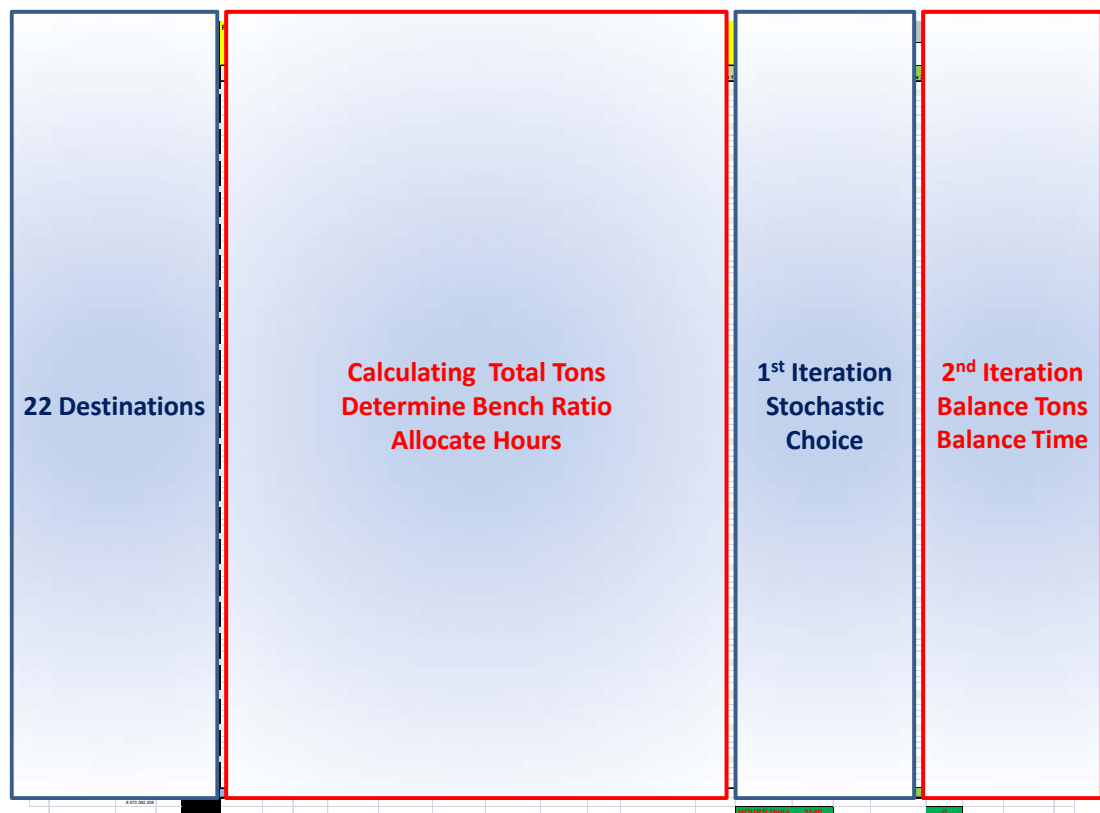
The final model was also expanded to be able to 'randomise" more than one parameter simultaneously. It is now possible to choose any combination of parameters to test their combined influence on the budget.

The model had to be developed from starting only with a single stochastic variable. This was done to prove the concept and ensure that the desired outcomes are achieved in a highly complex environment. All answers were

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first done with a singular choice. This was replicated in an Excel®
spreadsheet to ensure accuracy and correctness. Each parameter was
accepted as valid, only after it passed all testing.

Arena Simulation Run Outputs

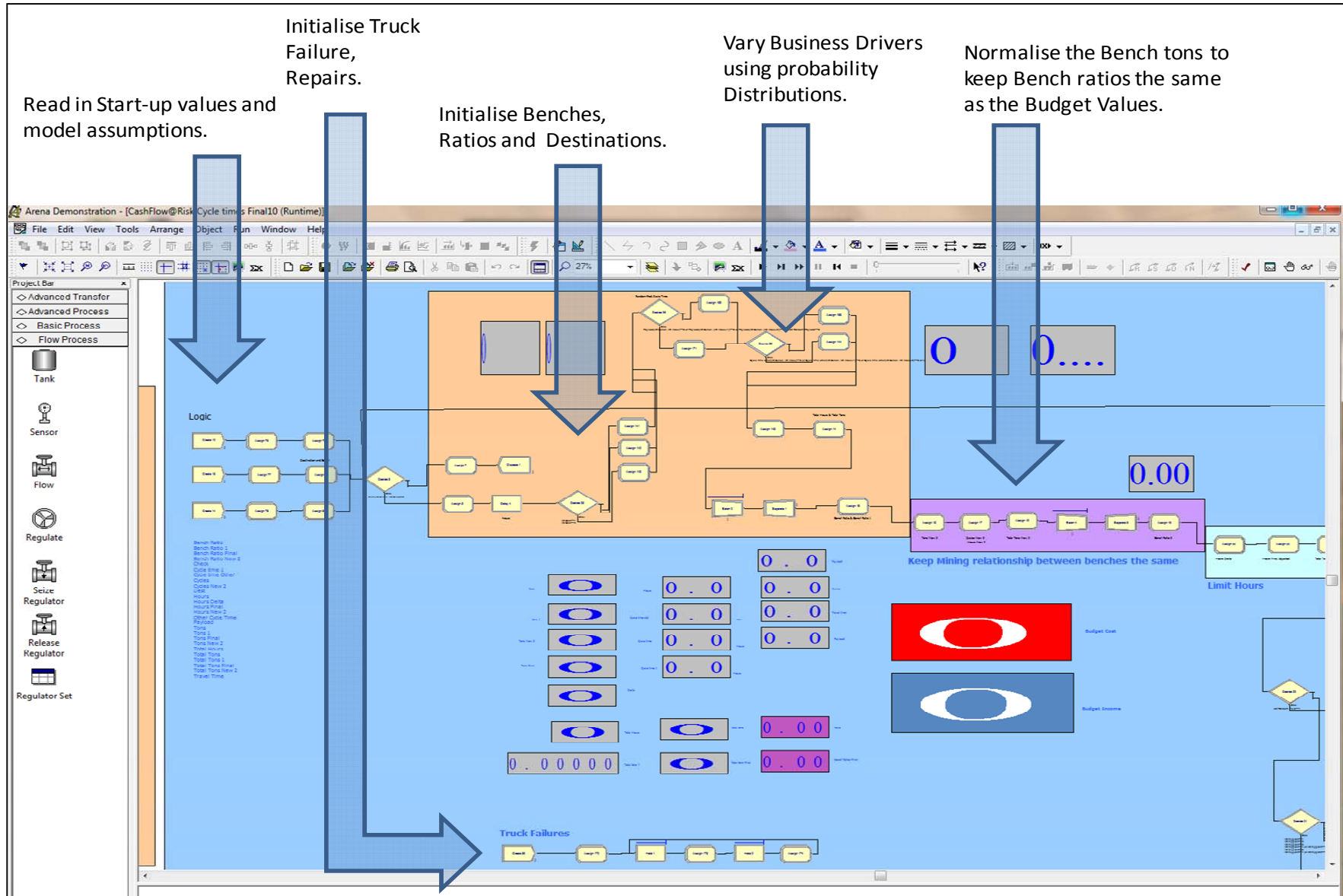| Arena Model Inputs	Tons	R m	R m	Tons All Dest	Tons All Dest	Tons All Dest	Tons All Dest	Tons All Dest	Tons All Dest	Tons All Dest	Tons All Dest	Tons All Dest	Tons All Dest	Tons All Dest
Run Num	Total Tons Final	Budget Cost	Budget Income	Bench1	Bench2	Bench3	Bench4	Bench5	Bench6	Bench7A	Bench7B	Bench8	Bench9A	Bench9B
1	78 932 467	1 784	2 212	14 150 104	7 936 029	9 710 519	11 528 958	11 133 456	2 963 167	7 302 621	1 437 648	5 237 540	752 652	2 408 600
2	77 107 288	1 761	2 154	13 876 035	7 758 986	9 511 770	11 218 317	10 840 681	2 894 050	7 104 612	1 396 856	5 154 397	733 124	2 348 940
3	77 015 924	1 760	2 151	13 870 797	7 736 537	9 498 770	11 211 394	10 839 248	2 885 397	7 087 109	1 391 548	5 162 753	731 632	2 342 654
4	80 849 883	1 808	2 260	14 556 531	8 134 445	9 954 074	11 767 945	11 384 006	3 033 939	7 450 662	1 464 645	5 395 248	767 811	2 462 876
5	75 699 809	1 743	2 119	13 586 634	7 612 930	9 325 479	11 055 053	10 640 583	2 844 862	6 998 121	1 373 469	5 033 988	721 441	2 315 722
6	85 479 202	1 866	2 397	15 224 755	8 629 560	10 546 753	12 467 152	12 078 763	3 234 582	7 867 499	1 558 875	5 686 412	817 872	2 619 699
7	76 953 991	1 759	2 155	13 780 220	7 747 157	9 493 414	11 225 731	10 841 413	2 896 285	7 101 557	1 395 555	5 128 961	732 658	2 346 614
8	81 273 807	1 813	2 272	14 595 911	8 183 580	10 026 898	11 831 046	11 445 367	3 053 305	7 487 755	1 471 816	5 432 510	773 832	2 476 313
9	81 981 860	1 822	2 292	14 704 480	8 254 170	10 102 692	11 912 355	11 551 664	3 081 715	7 585 793	1 487 169	5 455 401	782 960	2 509 207
10	80 882 233	1 808	2 260	14 557 288	8 128 670	9 972 707	11 775 086	11 386 111	3 033 061	7 445 483	1 462 929	5 418 943	768 696	2 461 691
11	78 786 955	1 782	2 204	14 140 719	7 904 791	9 718 325	11 497 737	11 088 737	2 959 949	7 270 261	1 428 539	5 265 383	749 567	2 402 991
12	83 675 430	1 844	2 340	15 006 111	8 434 778	10 320 049	12 202 083	11 766 119	3 146 559	7 743 042	1 521 056	5 553 020	798 820	2 558 577
13	81 271 298	1 813	2 278	14 446 131	8 211 431	10 002 496	11 852 052	11 499 893	3 064 987	7 532 483	1 488 581	5 414 896	778 292	2 479 749
14	79 644 168	1 793	2 226	14 334 215	7 995 235	9 821 810	11 604 085	11 204 862	2 988 482	7 337 989	1 441 893	5 326 657	757 741	2 423 182
15	77 730 267	1 769	2 172	13 987 725	7 813 534	9 587 285	11 317 038	10 941 704	2 915 375	7 160 037	1 405 697	5 195 279	739 327	2 367 190
16	78 117 822	1 774	2 182	14 061 998	7 849 201	9 635 625	11 365 824	10 992 712	2 929 222	7 197 243	1 413 287	5 230 133	742 796	2 378 171
17	78 396 589	1 777	2 192	14 087 865	7 879 496	9 661 220	11 421 582	11 044 112	2 941 373	7 220 297	1 420 507	5 248 086	745 963	2 389 790
18	81 315 728	1 814	2 272	14 618 675	8 176 429	10 029 015	11 819 022	11 450 322	3 054 920	7 506 313	1 473 923	5 433 557	774 201	2 477 918
19	80 053 251	1 798	2 238	14 396 434	8 043 008	9 869 468	11 664 539	11 267 808	3 003 815	7 371 941	1 449 874	5 359 524	761 031	2 437 803
20	77 666 000	1 768	2 172	13 965 976	7 808 841	9 572 168	11 317 605	10 931 815	2 913 809	7 155 838	1 407 643	5 190 392	738 320	2 365 913
21	83 641 076	1 843	2 341	14 972 124	8 424 280	10 279 259	12 154 419	11 814 819	3 152 679	7 753 004	1 521 861	5 569 515	799 740	2 563 266
22	80 080 449	1 798	2 240	14 379 950	8 061 534	9 879 236	11 685 660	11 254 264	3 003 963	7 393 828	1 454 785	5 332 406	762 407	2 443 249
23	80 630 403	1 805	2 254	14 478 087	8 122 307	9 945 851	11 756 709	11 335 753	3 029 268	7 431 978	1 462 024	5 386 846	767 909	2 456 944
24	80 844 976	1 808	2 260	14 551 841	8 118 576	9 961 812	11 783 877	11 371 129	3 030 356	7 448 371	1 463 969	5 408 100	769 124	2 463 746
25	83 899 621	1 846	2 345	15 088 441	8 437 726	10 345 402	12 220 807	11 799 614	3 145 813	7 726 829	1 520 236	5 616 304	798 460	2 557 395
26	80 897 163	1 809	2 260	14 566 982	8 126 526	9 976 868	11 775 667	11 385 524	3 031 827	7 446 203	1 461 799	5 422 584	768 508	2 461 217
27	79 271 203	1 788	2 216	14 259 055	7 961 456	9 769 686	11 549 572	11 166 163	2 974 866	7 309 830	1 436 061	5 292 016	754 058	2 415 093
28	78 526 889	1 779	2 195	14 126 101	7 893 738	9 682 134	11 440 793	11 055 284	2 944 582	7 230 044	1 419 932	5 251 329	746 267	2 391 039
29	77 498 462	1 766	2 170	13 896 476	7 800 030	9 538 386	11 308 257	10 916 701	2 912 553	7 168 721	1 407 164	5 148 408	739 654	2 366 157
30	80 731 222	1 807	2 259	14 460 498	8 116 841	9 950 020	11 773 416	11 337 711	3 036 851	7 487 155	1 468 289	5 391 917	769 094	2 466 724
31	78 898 397	1 783	2 205	14 200 988	7 927 007	9 726 373	11 489 511	11 105 782	2 958 596	7 267 411	1 426 943	5 280 713	750 082	2 401 494
32	81 775 101	1 820	2 287	14 678 622	8 236 442	10 103 329	11 914 594	11 504 998	3 076 811	7 518 646	1 485 918	5 460 087	779 370	2 494 395
33	78 443 001	1 778	2 191	14 129 325	7 879 695	9 674 620	11 418 355	11 040 278	2 938 632	7 217 791	1 417 010	5 260 027	745 033	2 385 793
34	79 982 254	1 797	2 235	14 330 575	8 056 204	9 895 147	11 643 788	11 210 562	3 007 100	7 399 467	1 454 085	5 335 688	761 500	2 449 297
35	77 631 618	1 767	2 169	13 979 548	7 798 209	9 574 011	11 301 523	10 925 945	2 909 015	7 145 878	1 402 766	5 202 874	737 561	2 361 873

Figure 10 An example of Arena® simulation runs
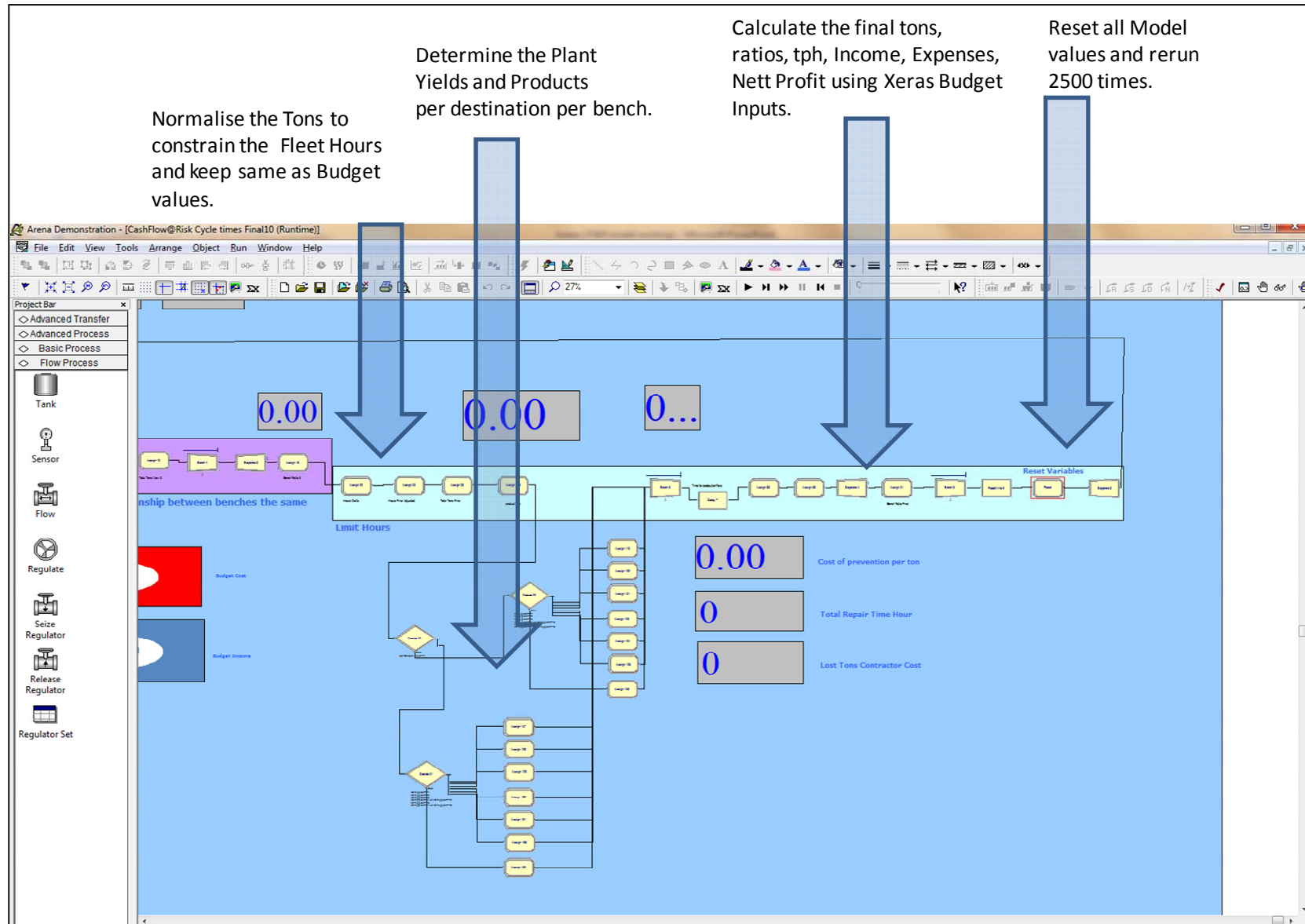
Figure 11 Arena Model – Part A

Figure 12 Arena Model – Part B

Chapter 6

DATA AND CURVE FITTING

TO THE HAUL CYCLE

6   DATA AND CURVE FITTING TO THE HAUL CYCLE

The curves fitted are 3-parameter Weibull curves. The Maximum Likelihood Estimation (MLE) method is generally considered to be the best method at estimating the curve parameters for a 2-parameter Weibull curve (balancing resources and accuracy), but poor with 3-parameter methods (Cousineau 2009).Therefore the method for estimating the shape of the distribution is a modified MLE, which intelligently identifies the offset parameter before applying the MLE. The resulting curve accuracy has proven to be consistently adequate during testing on real data.

An Excel® program was developed to facilitate curve fitting (using Weibull distributions) to generate the values that were used in the model– as shown in **Figure 13** An example of Weibull distribution analyses in Excel®. Results are shown below in graphical format as probability distribution- and cumulative probability distribution curves.

6.1   Examples of Data Fitted

The following are examples of curve fitting to real data as obtained from the Dispatch sequel server database:

- The payload distribution (depended on the material density of the Road)
- The empty hauling time (route length and road conditions)
- Spot time (truck operator influenced)
- Queuing time (over- or under trucking)
- Loading time (should be operator influenced)
- Full Haul time (route length and road conditions)
- Dump time (fragmentation of blast block)
- Reassign time (time defined as other production influences)
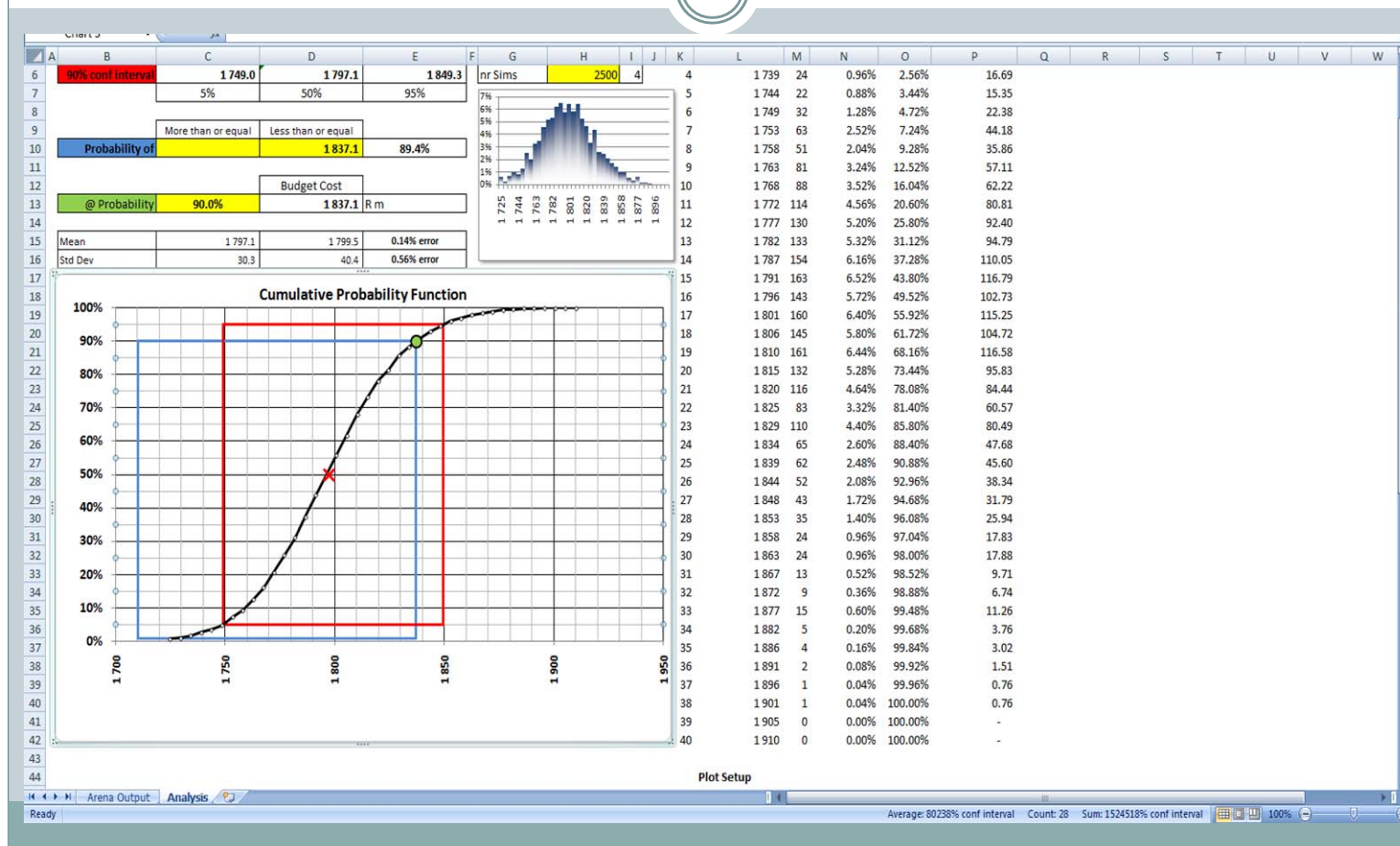- Total cycle time (the total sum of the above)

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Figure 13 An example of Weibull distribution analyses in Excel®

From a visual inspection it is clear that the methodology applied, i.e. using a three parameter Weibull curve fitting technique gives the desired results.

The data was accumulated and visually plotted using Excel. The three parameter Weibull distribution, namely shape scale and offset was applied to the data. The different curve fits were visually inspected to empirically determine if this methodology was suitable to replicate the curves that would eventually be needed for the probability simulation utilising Monte Carlo techniques.

- Shape – the parameter that affects the shape of the function
- Scale – affects the scale or dispersio0n of the function, i.e. if it is spread out or concentrated.
- Offset – also known as the location or threshold parameter.
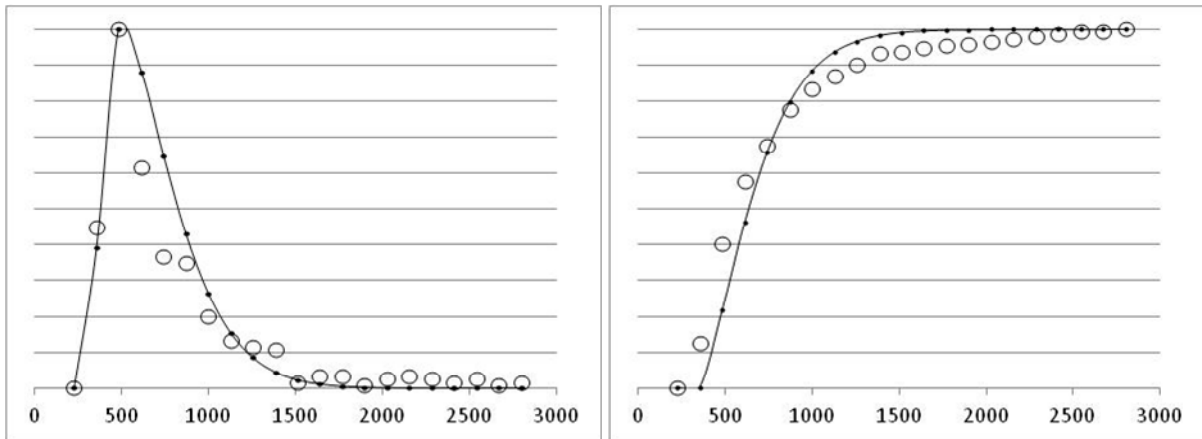
R^2 values for the cumulative probability function are above 90%, indicating a good approximation.
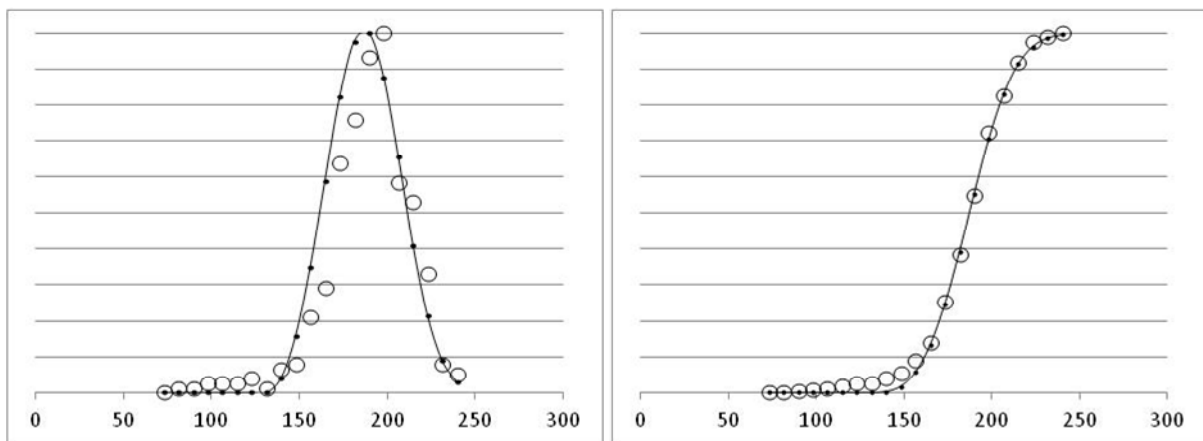
**Figure 14** The payload distribution

Table 3 The payload distribution

Payload			
Weibull Parameter	Results	Stats & Fit	Result
Shape	3.197	Mean	205.4
Scale	64.113	Median	187.2
Offset	130	Mode	187
		R^2 Prob	74.80%
		R^2 Cum Prob	99.30%
		nr Samples	430

Figure 15 The empty haul cycle

Table 4 The empty haul cycle

Empty Haul Time			
Weibull Parameter	Results	Stats & Fit	Result
Shape	1.373	Mean	935.3
Scale	370.407	Median	633.6
Offset	346	Mode	493.5
		R^2 Prob	82.50%
		R^2 Cum Prob	91.20%
		nr Samples	430
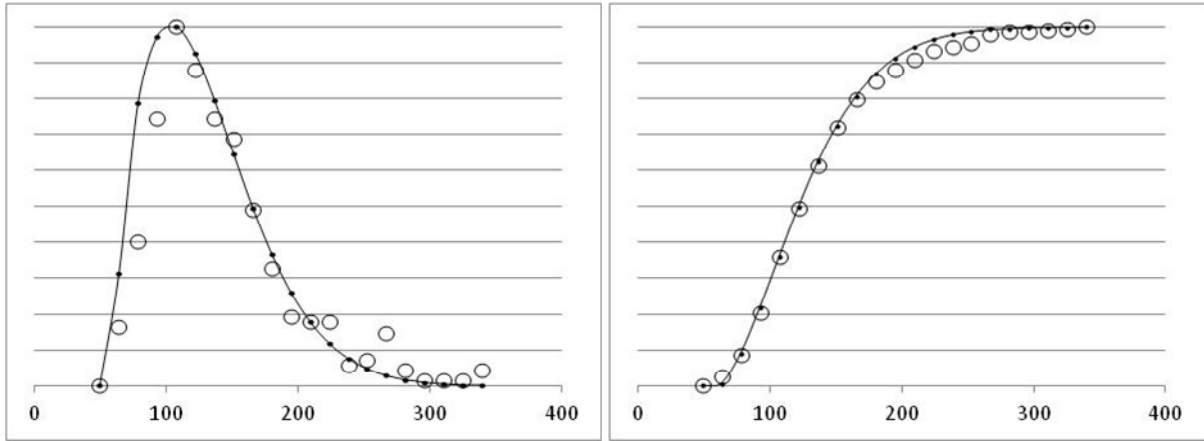
Figure 16 The spot time

Table 5 The spot time

Spot Time			
Weibull Parameter	Results	Stats & Fit	Result
Shape	1.619	Mean	172.4
Scale	77.539	Median	121.8
Offset	60	Mode	102.8
		R^2 Prob	74.50%
		R^2 Cum Prob	99.30%
		nr Samples	430
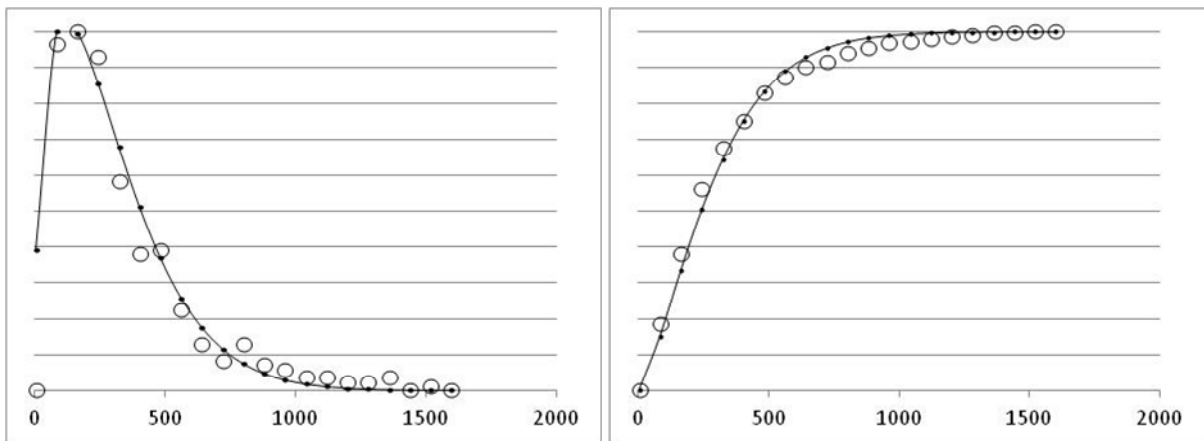
Figure 17 The Queue time

Table 6 The Queue time

Queue Time			
Weibull Parameter	Results	Stats & Fit	Result
Shape	1.36	Mean	500.9
Scale	314.538	Median	241.2
Offset	1	Mode	119.4
		R^2 Prob	80.00%
		R^2 Cum Prob	98.60%
		nr Samples	430
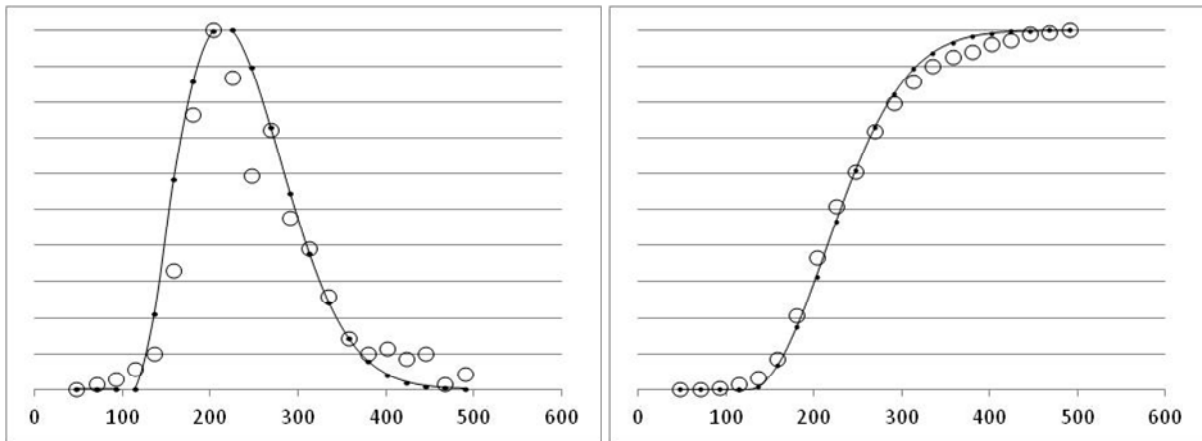
Figure 18 The loading time

Table 7 The loading time

Loading Time			
Weibull Parameter	Results	Stats & Fit	Result
Shape	2.003	Mean	292.3
Scale	125.923	Median	229.9
Offset	125	Mode	214.2
		R^2 Prob	77.80%
		R^2 Cum Prob	98.50%
		nr Samples	430
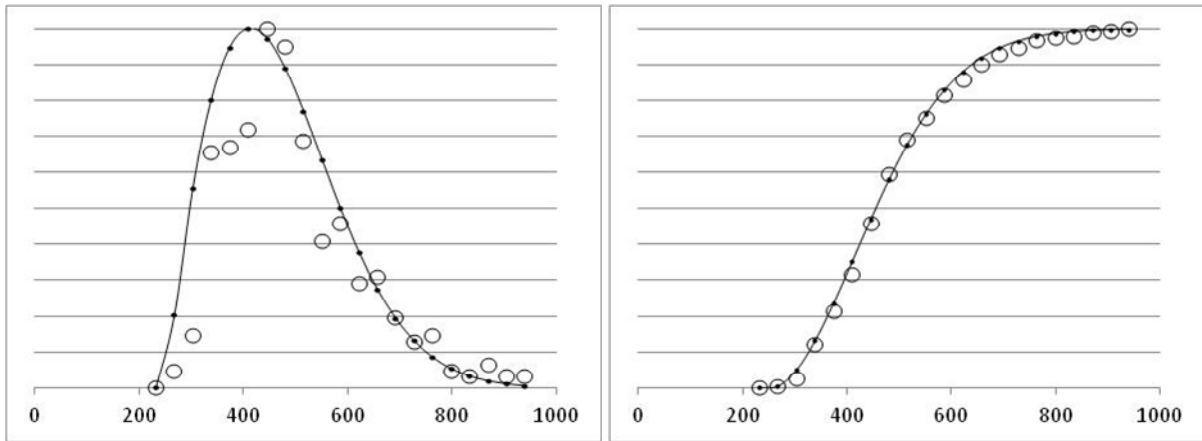
Figure 19 The full haul time

Table 8 The full haul time

Full Haul Time				
Weibull Parameter	Results	Stats & Fit	Result
Shape	1.849	Mean	587.9
Scale	244.686	Median	453.7
Offset	253	Mode	413.7
		R^2 Prob	55.50%
		R^2 Cum Prob	99.50%
		nr Samples	430
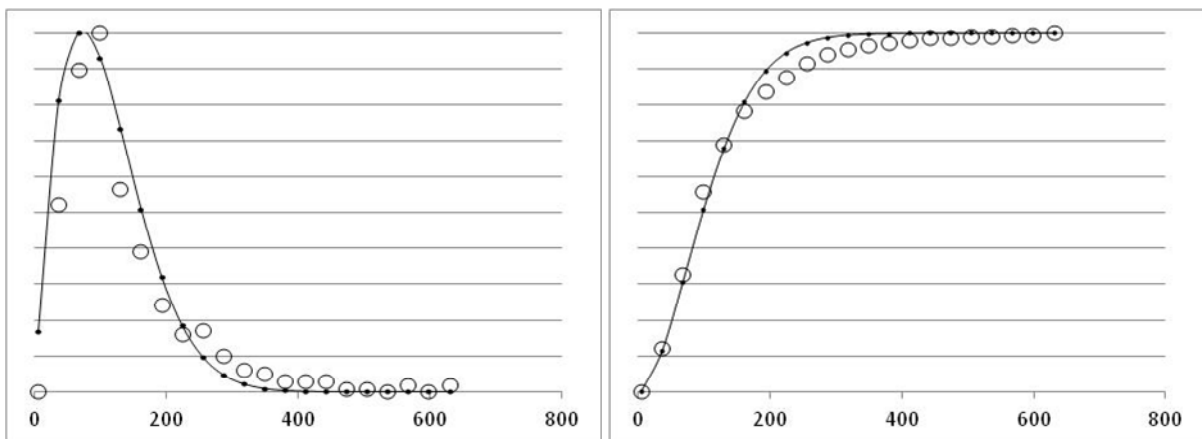
Figure 20 The dump time

Table 9 The dump time

Dump Time			
Weibull Parameter	Results	Stats & Fit	Result
Shape	1.696	Mean	169.9
Scale	118.324	Median	97.3
Offset	2	Mode	72
		R^2 Prob	80.90%
		R^2 Cum Prob	97.80%
		nr Samples	428
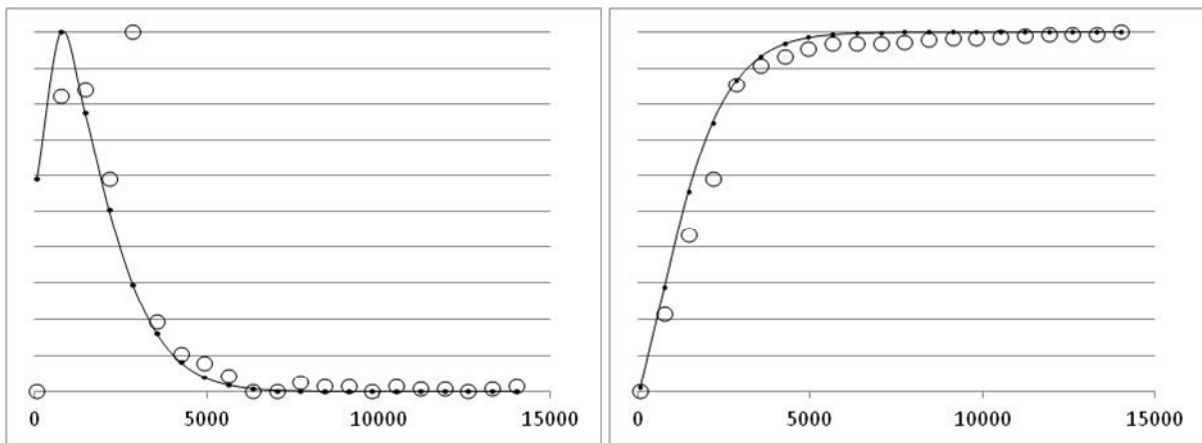
Figure 21 The Reassign time

Table 10 Reassign Time

Reassign Time			
Weibull Parameter	Results	Stats & Fit	Result
Shape	1.344	Mean	2684.8
Scale	1 674.300	Median	1279.7
Offset	5	Mode	612.4
		R^2 Prob	8.60%
		R^2 Cum Prob	94.40%
		nr Samples	430

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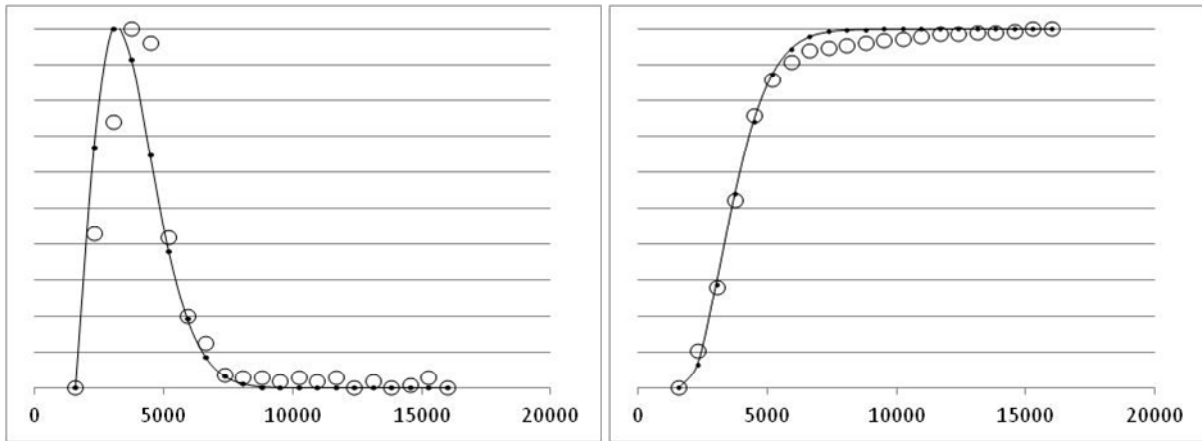
Figure 22 The total cycle time

Table 11 Total Cycle Time

| Total Cycle Time			
Weibull Parameter	Results	Stats & Fit	Result
Shape	1.732	Mean	4940.1
Scale	2 213.334	Median	3620.2
Offset	1 829.000	Mode	3175.3
		R^2 Prob	76.40%
		R^2 Cum Prob	98.70%
		nr Samples	430

6.2 Results of the first runs

Three runs were done to test the methodology. Only three distributions were used:

- Cycle times
- Payload
- Combination of Cycle times and payload

The cumulative probability curve displayed to the right of the probability distribution refers. The lower and upper limits are automatically calculated for a 90% confidence interval. This is displayed by the red box. The blue box allows the user to calculate the probability of being more than and less than certain parameters. In Table 12, for

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example, the user would want to know what is the probability of the budget being more than 400 units, but less than 600 units. The answer is 56, 6%.
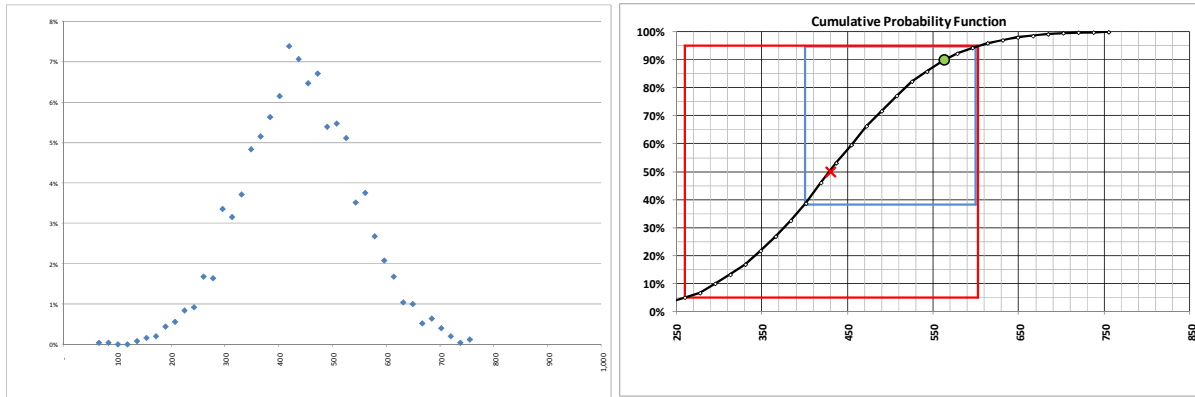
Figure 23 Budget distribution with cycle times

Table 12 Budget distribution with cycle times

	Low	Mean	High
90% Confidence interval	**260.2**	**430.1**	**602.6**
Probability	of	More	Less
	56.6%	**400.0**	**600.0**
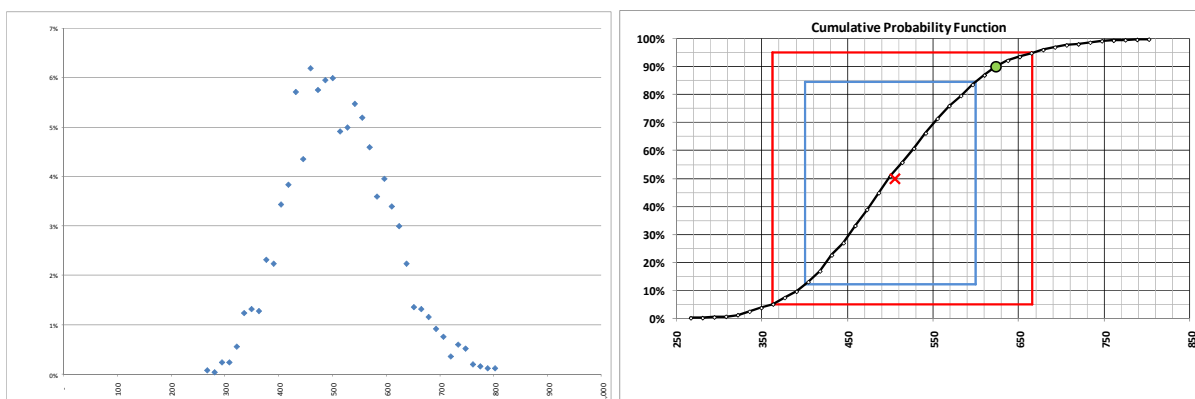
Figure 24 Budget distribution with payload

Table 13 Budget distribution with payload

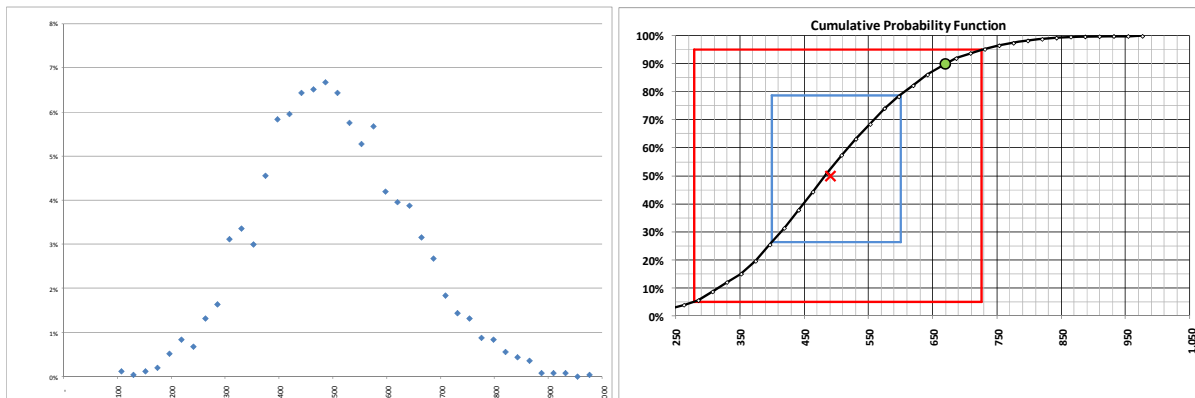| 90% Confidence interval	Low	Mean	High
	362.8	**505.0**	**665.7**
Probability	of	More	Less
	72.6%	**400.0**	**600.0**

Figure 25 Budget distribution with cycle times and payload combined.

Table 14 Budget distribution with cycle times and payload combined.

90% Confidence interval	Low	Mean	High
	278.6	**490.3**	**726.5**
Probability	of	More	Less
	52.5%	**400.0**	**600.0**

The original intent was to analyse data from the Dispatch sequel server database so as to get probability distributions for the separate components that make up the haul cycle. Although this proved to be very accurate and allowed the detail analysis of the impacts of the different portions of haul cycle on the total cycle, these could not be used. The main reason is that if the probability distributions are multiplied through a Monte Carlo simulation their resulting answer of the haul cycle, that is then made up from its different components, is useless due to the distribution being very wide and flat. It is suspected that some form of co-linearity exists between the different data sets. From the subsequent analysis it was clear that the complete haul cycle

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distribution as a whole had to be used. Payload could make up a separate distribution.

The following Chapter (Chapter 7) explains the impact of the above on the budget distribution. The following distributions were deemed to be the most important:

- cycle time
- payload
- production hours
- yield

Chapter 7

EXAMPLES OF THE IMPACT ON BUDGET DISTRIBUTIONS

7   EXAMPLES OF THE IMPACT ON BUDGET DISTRIBUTIONS

(Note: all examples refer to a large open pit mine)

The following results are based on a real "case" study. The budget has been normalised, so as not to release sensitive information. The answers are given in profit units, called Nett Profit and expressed as R million.

In the analysis that follows, it must be born in mind that the budget was completed at least 3 months prior to the start of the budget year. The cycle time and payload information that were used, was the actual of 3 months into the budget, and the preceding 3 months, i.e. 6 months of real time data.

## 7.1   Cycle & Payload – (Example with real Data)

In this particular example, the mine had a problem prior to budgeting, with the standards used for their cycle times. They either, were under pressure not to drop the physical standards too much, or did not fully understand the implication of the trend that they were seeing, or a combination of both. It would appear that they thought, that the longer cycle times could be countered by, by increasing the payloads that the trucks were carrying. In other words, compared to reality they "under budgeted" on their payloads.

Table 15. Cycle Time and Payload

Description	Base Case	Cycle	Payload	Cycle & Payload	0
	R m	R m	R m	R m	R m
	Nett Profit	Nett Profit	Nett Profit	Nett Profit	Nett Profit
Low (5%)	1 862	1 064	1 730	1 155	-
Mean (50%)	1 862	1 401	1 933	1 554	-
High (95%)	1 862	1 756	2 142	1 986	-
Median	1 862	1 395	1 931	1 544	-
Mode	1 862	1 430	1 981	1 540	-
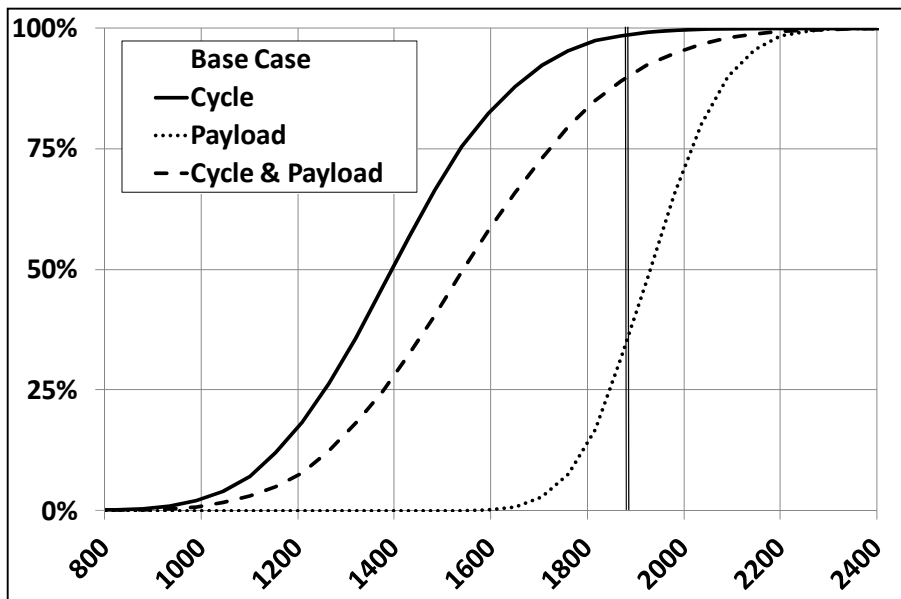
Figure 26. Cumulative probability Distribution – Cycle Time and Payload
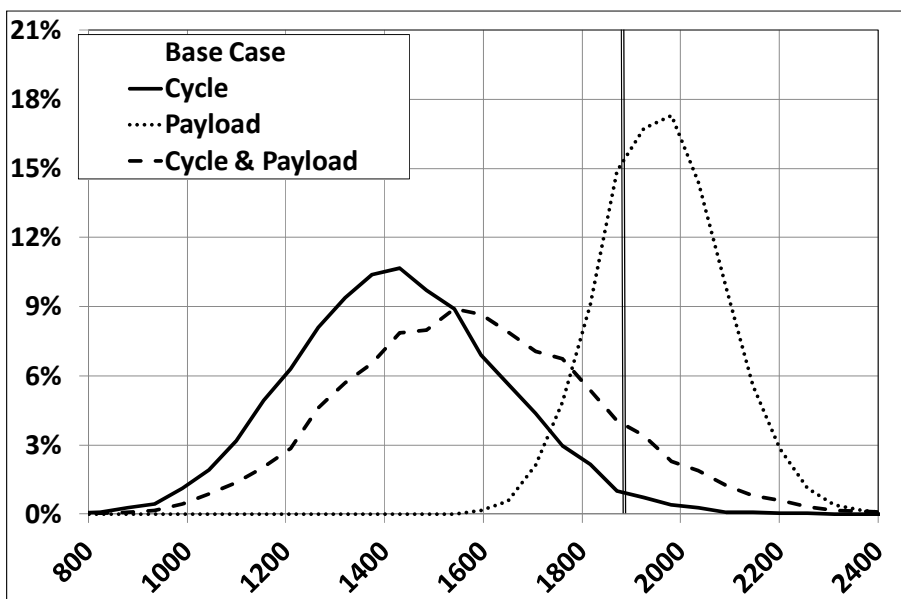
Figure 27. Probability Distribution – Cycle Time and Payload

The graphs above gives a visual picture of what has happened. The budget was set at 1862 units- refer to **Table 15.** Cycle Time and Payload. The effect of the poor cycle times @ 50%, gives a target of 1401 – 461 units below the budget. It is clear that the effect of the cycle time deterioration was not apparent when the budget was compiled. The strategy of countering the poor cycle time performance with loading

(1933 units @ 50%) is obviously not working as the increase in payload only moves the target to 1554 units against a budget of 1862.

7.2 Production Hours (FM's)

In the following example, the influence of lost production hours is examined – refer to **Table 16.** Yield and FM's added to Cycle Time and Payload. Firstly, a triangular distribution is deemed to be the best fit to describe this problem – depicted in **Figure 29.** Probability Distribution – Yield and FM's added to Cycle Time and Payload. The mine has on average 2 trucks down, either through an accident or an unforeseen rebuild. Section 54 (Mine Health and Safety Act) stoppages cause a loss of on average 4 production days. The rest is made up of Truck Standing No Operator (Dispatch code). The fit for the data is a triangular distribution with a mean of 21340 production hours, less 10% plus 5%. (The trucks see these events as a *force majeure*, hence the terminology FM.) The mean drops to 1519 against the budget of 1862, with a very narrow distribution as indicated – refer to **Figure 29.** Probability Distribution – Yield and FM's added to Cycle Time and Payload

7.3 Yield (Influence)

Because yield causes a distribution around the budget line – refer to **Figure 29.** Probability Distribution – Yield and FM's added to Cycle Time and Payload, it only gives a target of 1802 against the budget of 1862, as expected.

Table 16. Yield and FM's added to Cycle Time and Payload

	Base Case	Cycle & Payload	HRS/FM	Yield	Murphy
Description	R m	R m	R m	R m	R m
	Nett Profit	Nett Profit	Nett Profit	Nett Profit	Nett Profit
Low (5%)	1 862	1 154	1 472	1 731	977
Mean (50%)	1 862	1 554	1 519	1 802	1 354
High (95%)	1 862	1 987	1 570	1 861	1 774
Median	1 862	1 544	1 519	1 802	1 341
Mode	1 862	1 580	1 524	1 803	1 357
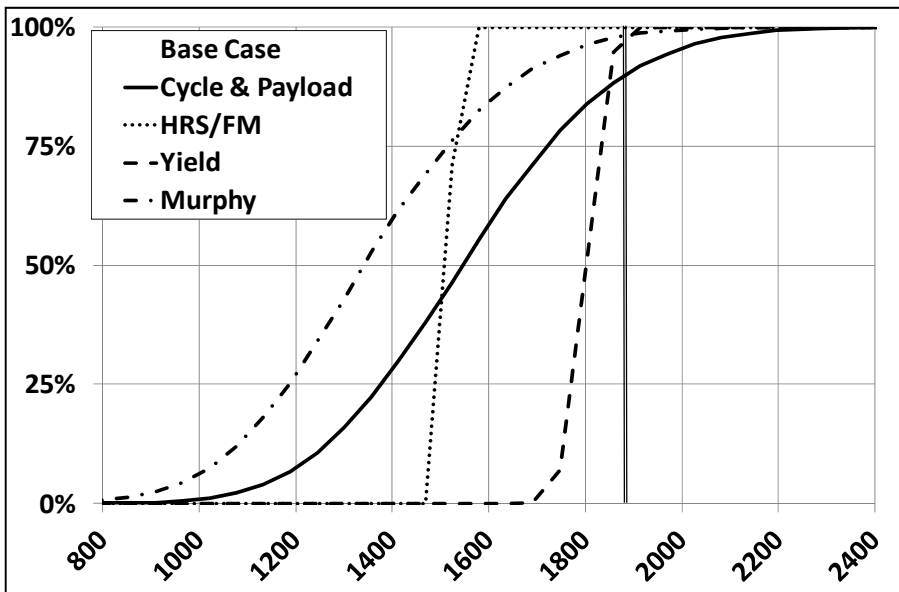
Figure 28. Cumulative Probability Distribution – Yield and FM's added to Cycle Time and Payload
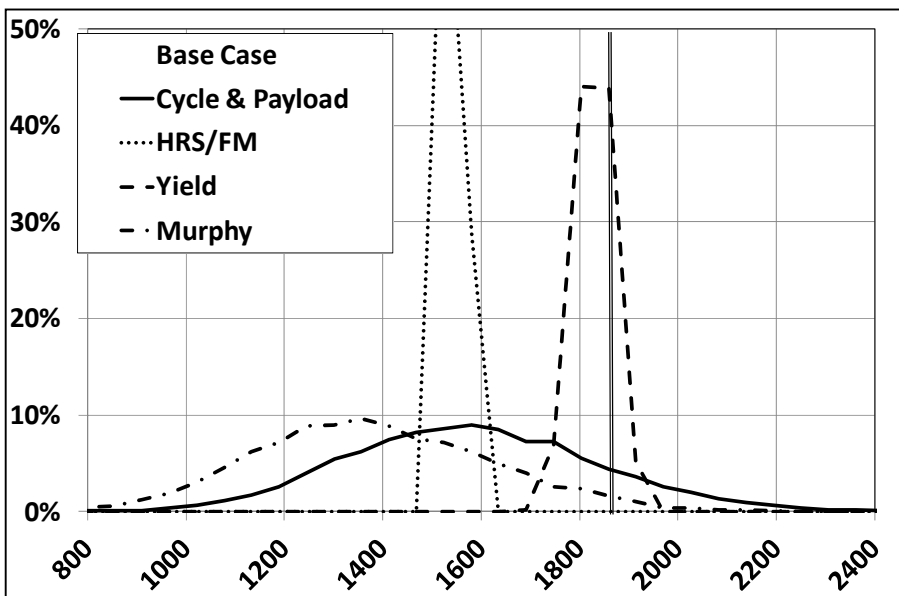
Figure 29. Probability Distribution – Yield and FM's added to Cycle Time and Payload

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7.4 Murphy

It is clear that if all of the above events or combine the results - named Murphy (this refers to the common statement that if anything can go wrong it will go wrong) are somewhat catastrophic and gives a mean of 1345 units.

7.5 Example of Capex Optimisation

The following example demonstrates the power of the model to determine the correct application of where money should be spent. In striving to achieve the budget, the mine now has the option of:

- Spending R10 000 000 on upgrading the roads and improving the rolling resistance. This gives a minimum advantage of 2 min per cycle and a maximum of 4 min per cycle.
- Alternatively buy 2 additional trucks for R75 000 000, which will add 2 x 5500 hrs = 11 000 hrs for the year.

The results are compared below.

Table 17. Capex Optimisation

Description	Base Case	Cycle	Cycle 2min Saving	Cycle 4min Saving	2 New Trucks + Cycle
	R m	R m	R m	R m	R m
	Nett Profit	Nett Profit	Nett Profit	Nett Profit	Nett Profit
Low (5%)	1 862	1 065	1 190	1 241	1 179
Mean (50%)	1 862	1 401	1 570	1 649	1 542
High (95%)	1 862	1 757	1 975	2 084	1 928
Median	1 862	1 395	1 562	1 641	1 536
Mode	1 862	1 397	1 545	1 643	1 545
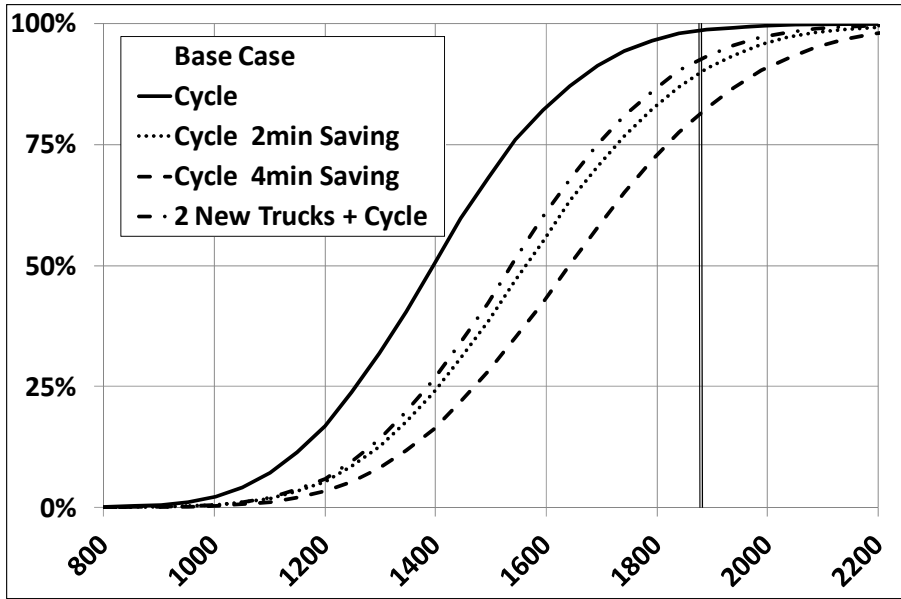
Figure 30. Cumulative Probability Distribution – Capex Optimisation
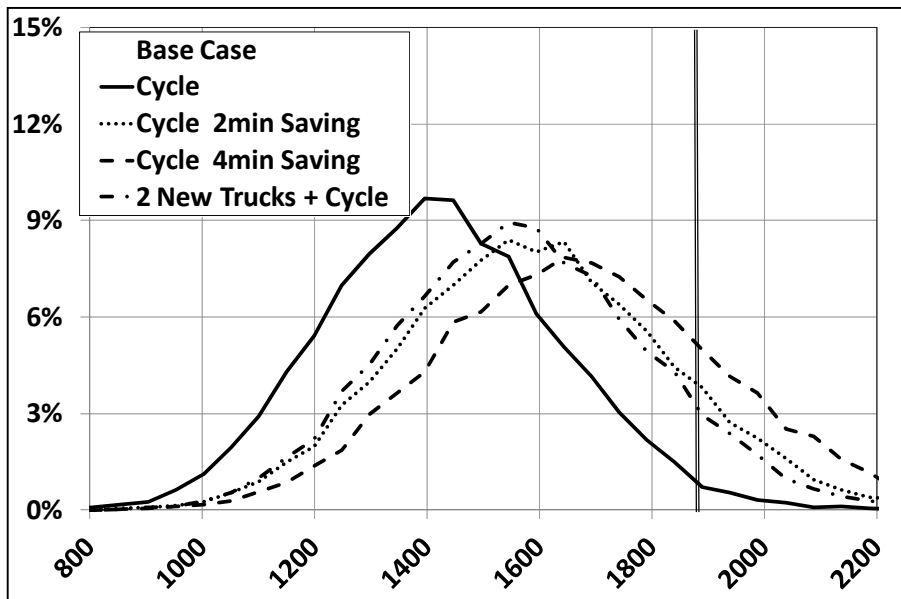
Figure 31. Probability Distribution – Capex Optimisation

The Mean moves from 1401 to 1542 with 2 extra Trucks = 142 units. If the cycle is adjusted by 2 minutes, (through better roads) it moves to 1570, generating 159 units. A saving of 4 minutes will give 248 units. It is clear that the better option will be to spend money on the roads instead of buying more trucks.

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Chapter 8

CONCLUSION

8 CONCLUSION

This thesis investigates a large, complex problem that faces the mining industry. The budgeting process which is supposed to produce the basis for the operation of the business is fraught with uncertainty. Top management desires that this budget is strictly adhered to so that the financial results can accurately meet established goals and predictions. In reality, the budget is not a plan that can be imposed on the enterprise, but emerges as the sum of the operational plans of the enterprise. These plans are dependent on unforeseeable events, in addition to the details of the operational decision-making process and in addition they are highly interdependent. This can be summarised in the following statement:

"The biggest question confronting senior management of a mine is: *"Why does the budget of a mine degenerate to the extent that it is totally worthless, sometimes in so short a time as a quarter?" This question seems to plague both small and large mines indiscriminately."* (Page 12).

The thesis takes an approach to this problem that is novel and presents a significant contribution to the state of the art. The thesis assumes that the budget is ultimately measured in terms of the net profit, which is a random variable compounded from other random variables, which are assumed to be independently distributed. While the thesis recognizes that there are large numbers of such random variables, and not all of them are independently distributed, it finds it necessary to ignore most of those.

"A huge amount of nearly endless possibilities exists, that will influence the achievement of the budget. To stochastically examine them all creates so much "noise" that the outcome is valueless" (page 41).

For this reason Monte Carlo simulation, as a budgeting tool, is not used in the industry. There are a few examples where it is used mainly for capital budgeting and the prediction of the variations within the budget in the project environment. (The main reason for it not being used in the normal budget process is that the multiplication of the distribution of the key drivers of a budget, leads to a spread in the budget distribution that gives an unreliable conclusion or no conclusion at all).

To avoid this problem the thesis focuses on a selected set of "key drivers." On these, it builds a probability model based on sampling from a simulation of the mine operation process. The strength of the model lies in the determination of the main drivers (first order) that are independent of each other and may be influenced through the application of funds. Probability logic offers a highly expressive account of deduction of where funds should be applied to optimally influence the achievement of the budget.

The probabilistic logic model circumvents the original problem in using the related activity-based costing, so that when standards change the influence thereof is clearly reflected in the new probability distribution of the budget.

Robustness of the model is guaranteed through the exploitation part of the model that directly links the deviation in standards to production. Correcting standards through the application of men, material or money is something that management has been trained to do and are good at. The impact and value of changing the standards is directly reflected in the probability of achieving the budget.

The stochastic model uses real data wherever possible. Hubbard (2010) makes the point that the model should only be accurate enough and states that uncertainty can be overcome by adding more complexity to the model. This is precisely wrong in the stochastic modelling environment. The robustness of the model proposed lies therein that it differentiates between the primary drivers and secondary drivers, while appearing to be important, generates so much noise that the answers become invaluable or worthless.

Implementing the model and running the process on a real budget proved the ability of the model and the value that may be unlocked through this approach. A foreseeable, but secondary effect of the process is that the primary standards influencing the key drivers suddenly became highly visible. (The consequence of any sub-standard performance can now directly be translated to the bottom-line influence on the budget). This resulted in that the model is currently also being implemented to drive operational excellence.

Chapter 9

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9 REFERENCES

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Chapter 10

APPENDECEES A - D

10 APENDECEES

10.1 Appendix A

IOPA (INTELLIGENT OPERATOR ASSIST)

Although the primary intent of the work is to develop a tool that will assist management with achieving the budget by understanding the "risk profile" and give direction to where to spend money optimally, it was quickly clear that there is a huge opportunity to be captured in the operational environment.

Based on the old saying: "Feedback is the Breakfast for Champions", an automated reporting program was developed, with the aim of influencing the cycle and payload distributions positively.

IOPA stands for "Intelligent Operator Assist". The optimal distributions for the components of the cycle times and payload under current operating conditions are known and the system will influence operator behaviour to achieve better results.

Extraction of the data from the Sequel Server data base has been automated. A maximum of 5 primary key performance areas are measured by plotting the shift's results against the optimal distribution. Deviations are calculated and expressed in tons gained, or lost. The shift foreman gets a shift report at the beginning of each shift about this shift's performance for the previous day, clearly indicating the areas that he needs to concentrate on.

Operators can be measured against their peers. Weak or poor performers are encouraged to adopt better "habits" or be re-trained, if needed.

The system is fully automated. It will extract the reports, do the comparisons and then send the e-mail. The system is currently in its final stages of testing for full implementation.

Current results exceed all expectations. The system has the further advantage that is directly linked to the probabilistic measuring tool, so the impact is directly translated into a measurable effect on the budget profile.

Figure 32 IOPA Process

	Shiftindex	Start Date & Time	Shift	Shift Duration	Team
From					
To	**47675**	05/07/2013/14:00	Afternoon Shift	8.00 h	Crew C

	Actual	Target	Delta
Truck Hours Operational:	221.65 h	227.29 h	-5.64 h
Effective Fleet Size:	27.7	28.4	-0.7
Number of Dumps:	377	413	-36
Average Cycle Time:	35.28 min	< 33 min	2.28 min
Average Travel Time:	24.15 min	< 25 min	-0.85 min
Full:Empty Travel Time:	132.6%	> 100%	32.6%
Tons Dumped:	67 904 t	74 433 t	-6 529 t
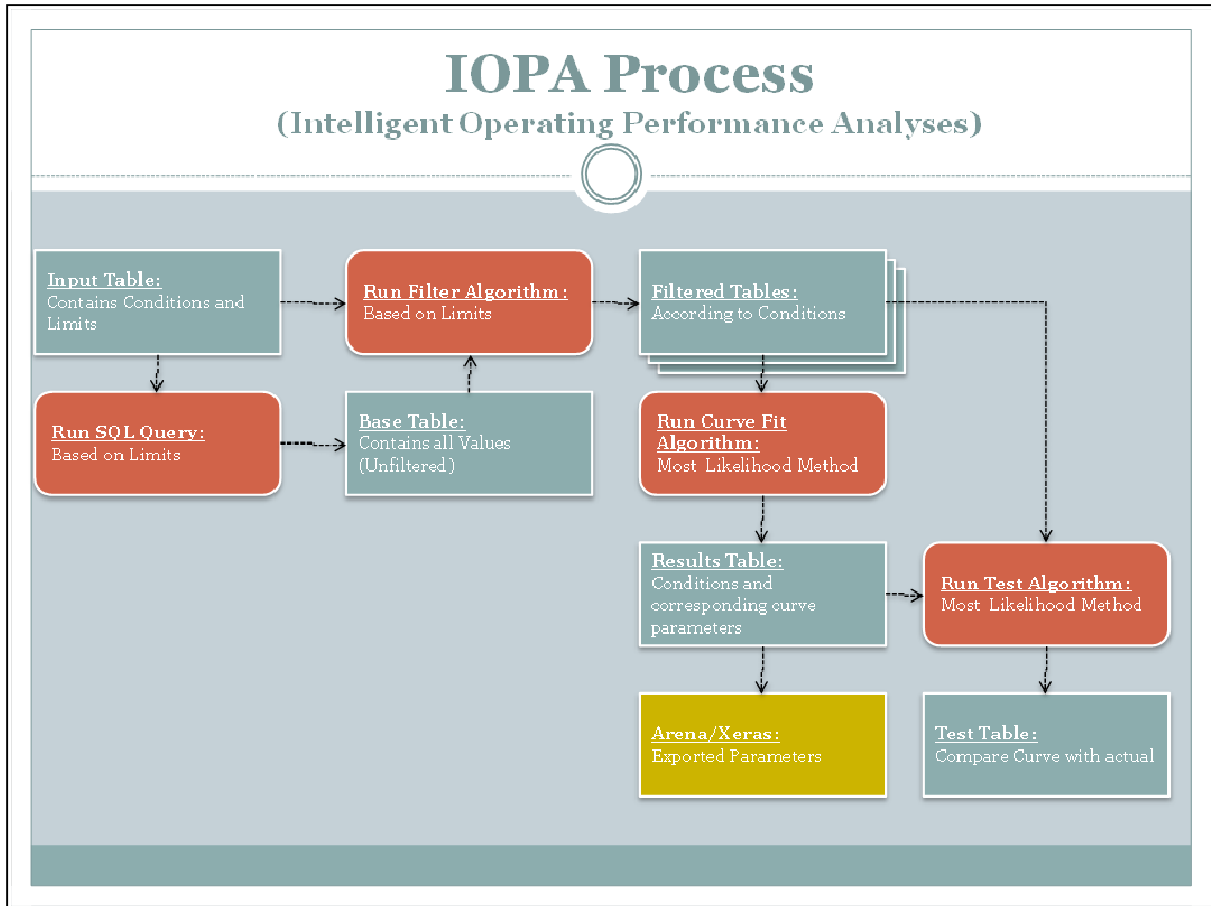
Figure 33 IOPA Process – Shift Foreman Report

Above is an example of the type of feedback that the shift foreman gets. Everything is translated to tons and time, measurable quantities that production personnel can easily relate to.

10.2 Appendix B

TALPAC® - Background on Talpac® Analyses

Runge Talpac® Version 2000 was utilised to simulate all haul routes within the open pit. TALPAC® has been designed for the mining industry. With over 300 licenses world-wide, Runge's TALPAC® Software has long been accepted as the industry standard for determining the productivity and economics of truck and loader haulage systems. Within TALPAC®, the haul route for the truck can be specified, the truck type selected from the database and operating limitations, including speed limit, set. This system is flexible in allowing each user to determine loading strategy, material characteristics and work roster applicable to the fleet.

Applications (Generic)

- Truck travel time calculation.

- Fleet productivity estimation for long & short term planning.

- Determination of optimum loading technique or bucket size.

- Sensitivity analysis to road design criteria.

- Calculation of TKPH or TMPH ratings for use in tyre selection.

- Estimation of fuel usage.

- Determination of haulage costs using discounted cash flow and incremental truck costing.

- Truck fleet size optimisation to quantify the economic effect of over and under trucking.

- Equipment loading analysis to optimise loader bucket size, truck capacity and number of passes.

- Collation of results from calculations to examine the relationship between variables in the calculation, eg. haul distance vs productivity, haul distance vs truck fleet size.

- Bench marking.

- Equipment selection and justification.

- Incremental analysis.

General : Information on Mine LOM simulation

Haulage profiles and other reference points for each bench were used. The ramps that were used are the Eastern Ramp and the New Northern Ramp. Both Ramps were simulated with the operation of trolley lines/pantograph system and diesel only. The average rolling resistance used was assumed to be 3%.

Talpac® was only used to determine cycle times for travelling to and from the pit to different Plant destinations, as well as determining fuel consumption. All other facets of the cycle times like Loading/Spotting/Dumping etc. were used as global settings. This information was taken from mine time studies. The various loading equipment information was utilised as taken from their respective time studies and performance charts. Refer to the table below.

Table 18 Global Settings

	Description	Time
1	Queuing Time (Coal)	2.5 minutes
2	Queuing Time (Waste)	1.5 minutes
3	Spotting Time (load)	0.5 minute
4	Spotting Time (dump)	0.5 minute
5	First Bucket pass Delay	0.5 minute
6	Dumping Time	1 minute

Equipment Detail

Haul trucks used:

Komatsu 730E haul truck   Capacity: 190.3 tons
These trucks were utilised for all types of material from everywhere within the pit.
Euclid-Hitachi EH4500   Capacity: 254.19 tons
This equipment was utilised for overburden only on bench 1. These trucks were not simulated in the pit or utilising the trolley lines.

Note: Due to the similarity of the capacity and performance Euclid-Hitachi EH3500 and Komatsu 730E, the same results were used for the EH 3500.

Haul Truck Payload

The simulation was performed using the maximum payload to simulate the truck's performance. However, in practice the average payload is lower than the maximum payload, and should therefore be used to determine the equipment requirements accordingly.

Table 19 Actual payload

Haul Truck	Maximum Payload	Actual Payload
Komatsu 730E	190	174
Euclid-Hitachi EH3500	183	174
Euclid-Hitachi EH4500	255	242

Speed Limitations Due to Safety and Road Conditions.
- All haul trucks running down ramps were limited to 30km/h
- All haul trucks running on developing benches were limited to 30km/h

Fuel Usage

The recommended fuel consumption rates from the OEM were used to emulate the duty cycle of the diesel engines. The following fuel burn rates, were used and was also used to calibrate against the current average fuel consumption and duty cycle values

Table 20 Fuel Burn Rates

Haul Truck Type	Idle Rates	Full Load Rates	Average Fuel Consumption	Engine Duty Cycle
Komatsu 730E	15 l/hr	360 l/hr	73 l/hr	20.2%
Euclid-Hitachi EH3500	15 l/hr	360 l/hr	73 l/hr	20.2%
Euclid-Hitachi EH4500	18 l/hr	440 l/hr	100 l/hr	22.7%

The current fuel cost including the savings from the tax rebate, was used in the financial model. No long term fuel cost forecasts were used in the model, except R/US$ escalation's impact on a yearly basis.

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Trolley Assist on Haul Trucks

The Talpac® simulation model does not cater for the use of trolley assist on partial haul road sections. Therefore, the Talpac® simulation is manipulated by using the time taken to complete the section under the pantographs. This has been proven to be accurate, as both the fuel rate and electrical consumption can now be taken into consideration.

Each haul cycle is calculated both for diesel only operation as well as with trolley assist. Using the current utilisation on the pantograph gives an accurate answer to the overall machine hours used and the average fuel burn rate. The time spend on the pantograph is used to determine the variable component of the electrical power used. The fixed portion for the maximum demand is also included under the total mining cost.

Projections for future haul roads

In order to cater for the future expansion of the pit, 45m intervals were simulated from 45 m up to where it stays constant. This methodology is used to extend the pit away from the crusher as well as on the developing benches. In order to verify actual performance against the theoretical Talpac® simulations, 3 months data was obtained from the mine and compared to the Talpac® simulations. With this information the Talpac® haulage information was re-calibrated to simulate the actual performance at the mine. Extra "stops" were inserted and speeds were reduced at busy intersections.

Shovels used

The following loading tools were used in the simulation:

Table 21 Shovels Used

Shovel	Type	Bucket Size	Average Pass Cycle
P&H	2300 Mk2	16 m3	0.67
P&H	2300 Mk2	18 m3	0.67
P&H	2300 Mk2	18 m3	0.67
P&H	2300 Mk2	22 m3	0.67
P&H	2300 Mk2	19 m3	0.67

Shovel	Type	Bucket Size	Average Pass Cycle
DEMAG	H285	18 m3	0.6
DEMAG	H285	16 m3	0.6
DEMAG	H285	18 m3	0.6
DEMAG	H455	26 m3	0.6
Caterpillar	994	18 m3	0.67

If new, additional or replacement equipment is required during the evaluation the following loading equipment will be used.

Table 22 Additional Shovels

Current Shovels	Replacement / New / Additional
P&H 2300 Mk2	Komatsu PC 5500
DEMAG H285	Komatsu PC 3000
DEMAG H455	Komatsu PC 5500
Caterpillar 994A	Caterpillar 994D

Shovel Allocation

For the simulation of the mining operation, the variability of the mining operation was forced by allocating the various shovels to preferred levels in the pit. Prioritising of these shovels was done to simulate the loading activities as closely as possible to the current way of operating.

Table 23 Shovels Bench Allocation

Bench	Material Type	Primary Shovel 1st Priority	2nd Priority	3rd Priority
1a	Overburden	Demag 7	Demag 8	CAT 944
1b	Overburden	P&H 1	CAT 944	P&H 2
2	Coking Coal	P&H 2	CAT 944	P&H 1/3
3	Coking Coal	P&H 3	CAT 944	P&H 2/4
4	Coking Coal	P&H 4	CAT 944	P&H 3/5

Bench	Material Type	Primary Shovel 1st Priority	2nd Priority	3rd Priority
5	35% ash	P&H 5	CAT 944	P&H 4
6	Coal	CAT 994	Demag 6	CAT 944
7a	Interburden	Demag 7	Demag 8	CAT 944
7b	35% ash	Demag 6	Demag 9	CAT 944
8	Interburden	Demag 8	Demag 7	CAT 944
9a	Coal	CAT 994	Demag 9	CAT 944
9b	Coal	Demag 6	Demag 9	CAT 944
10	Interburden	Demag 7	Demag 8	CAT 944
11	Coal	Demag 6	Demag 9	CAT 944

10.3 Appendix C

XPAC® = Mine Scheduling

The geological information is presented on a 45 m x 45 m centroid grid. The database contains separate layers, with each bench represented as a layer. Each centroid contains the in situ properties including a fully-analyzed wash table. The 45m x 45m grid is used as a standard and the geological data is dumped for each bench separately. The basic layout is then imported into a CAD program and linked to the geological database.
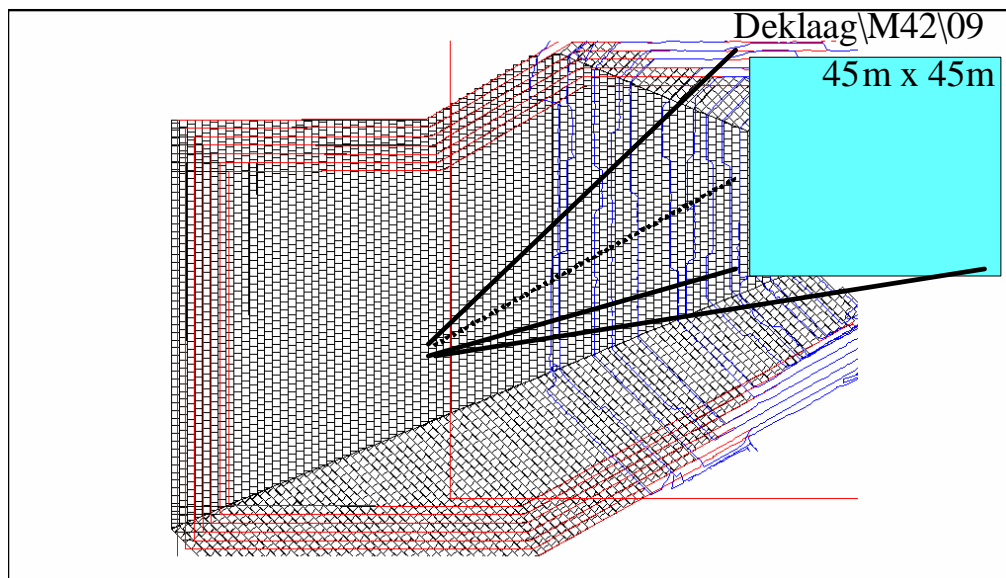

Figure 34 The above picture shows geological blocks overlaid onto the mine layout. This shows the high-resolution of the geological data used.

A mine layout (drawing) is then placed over the data depicting the various mining benches. From the mining blocks a weighted average is calculated for each mining block. This includes the in-situ values so as to give a fully representative value for each mining or blasting block. This data is then compiled for each mining bench and exported to XPAC®. The new polygon coordinates as depicted by the mine layout (per bench) is automatically transcribed. Issues such as slope stability and main haul routes are already incorporated in the layouts per bench.

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Once the information per bench is imported into XPAC®, products are calculated per block. Various plant products may be calculated for the same block. A block on bench 4, for example, can either go to a single or double stage process as and when it becomes available, depending on which plant is available first and demanding feed. Once the schedule has run, a node is registered back in the main database indicating to which plant the block went. From this information a final product value is derived, with the corresponding products generated from that plant. From the same node XPAC® can determine which haul route should be taken for minimum distance or minimum fuel consumption. The cycle time and fuel consumption are then written back to the main database for reporting purposes.

The scheduling principle applied is that Run of Mine (ROM) goes to each plant, with specific plants set as a priority, taking cognisance of both product and energy requirements. Although XPAC® schedules ROM for each plant, the energy in Giga Mega Joules (GMJ) needed, is kept as a total sum until the limit is reached. This limit is dictated by the marketing demand. So, in the case of power station coal, a continuous calculation is used to ensure that the variation of geological yields and calorific values are captured to the extent that the total energy demand will be met by the mining production.

Mining blocks for each bench is designed separately. Benches 6, 7 and 8 share a common mining boundary limit. Benches 9, 10 and 11 are also combined as one final bench. This was done to optimise the overburden stripping. The priority order of available mining blocks per bench to plants is from bottom to top. This is done in order to keep the pit geometry and mining slope (working slope) as steep as possible so as to allow maximum pit bottom exposure. Because benches are prioritised from the bottom to the top, blocks from the lowest bench (Bench 11) will be taken before a higher bench (Bench 2) is taken. If no available blocks are at the lowest bench, the next higher bench suitable for the specific plant will be taken.

Benches are divided into strips following at 45 meter increments. Strips are then subdivided into 90 meter mining blocks along the strips. Strips are mined consecutively from left to right following along the strip, with every second strip from right to left resulting in a figure 8 pattern. Mining logic is controlled by a dependency restriction with provision for the figure 8 principle as well as the distance that must be

kept open between benches. This is to allow the installation of mining services – Bench 5 for example carries in pit power lines, and to accommodate travelling on the benches. This is displayed graphically in Figure 36 Section through the pit].
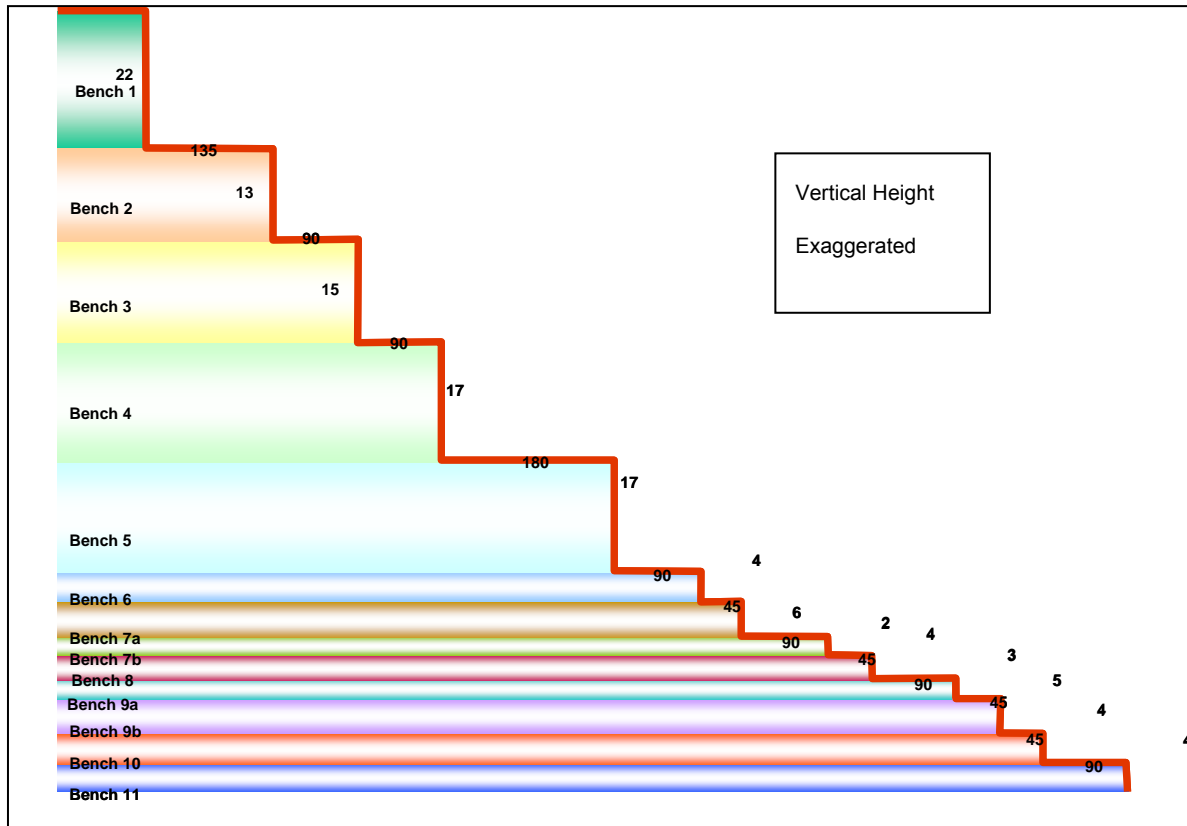

Figure 36 Section through the pit

Because XPAC® works with areas, volumes and thickness, drill and blast consumables are calculated from first principles, with the number of drill holes as per space and burden standard for each bench. The results are graphically displayed in Table 24.

Table 24 Drill & blasting consumables and Haul time + fuel

	Code	Data Field Name	Deklaag *	Bank2 *	Bank3 *
Drill & Blast	+ att	**Pit Atractiveness**			
	– db	**Drill&Blast**			
	. h	Holes per Block	120,687.73	170,979.35	100,187.36
	. m	Total Meters	1,984,839.05	1,964,280.35	1,511,126.17
	. e	Total Explosives (Ton)	40,556.38	39,186.24	31,332.70
Trucks	+ tc	**Truck Calculations**			
Time & Fuel	– t1	**Truck 195 Tons**			
	. nc	Number of Cycles 195	350.70	201.55	282.07
	. tdb	Total Distance Block	2,463.16	490.89	618.05
	. ctd	Cycle Time Diesel	21.07	30.82	31.57
	. ctp	Cycle Time Panto	0.00	29.70	30.13
	. tth	Total Truck Hours	388,959.36	349,224.32	511,367.27
	. tthp	Total Truck Hours Panto	0.00	336,661.06	488,417.47
	. ttup	Total Time Under Panto	0.00	2,756.67	3,703.49
	. lpc	Liters Per Cycle	45.07	71.44	74.56
	. lpcp	Liters Per Cycle Panto	0.00	65.27	66.68
	. lph	Liters Per Hour	126.16	137.63	140.94
	. lphp	Liters Per Hour Panto	0.00	130.22	131.73
	. tl	Total Liters	50,273,713.69	48,523,204.31	72,612,417.39 7
	. tlp	Total Liters Panto	0.00	44,380,217.50	65,055,440.91 6
	. rth	Rate (t/hour)	522.35	362.14	352.15
	. tpl	Tons Per Liter	4.14	2.62	2.50
	. bfh	BackFill Hours	440,621.27	0.00	0.00
	. bfl	BackFill Liters	59,380,028.65	0.00	0.00

Rosters:
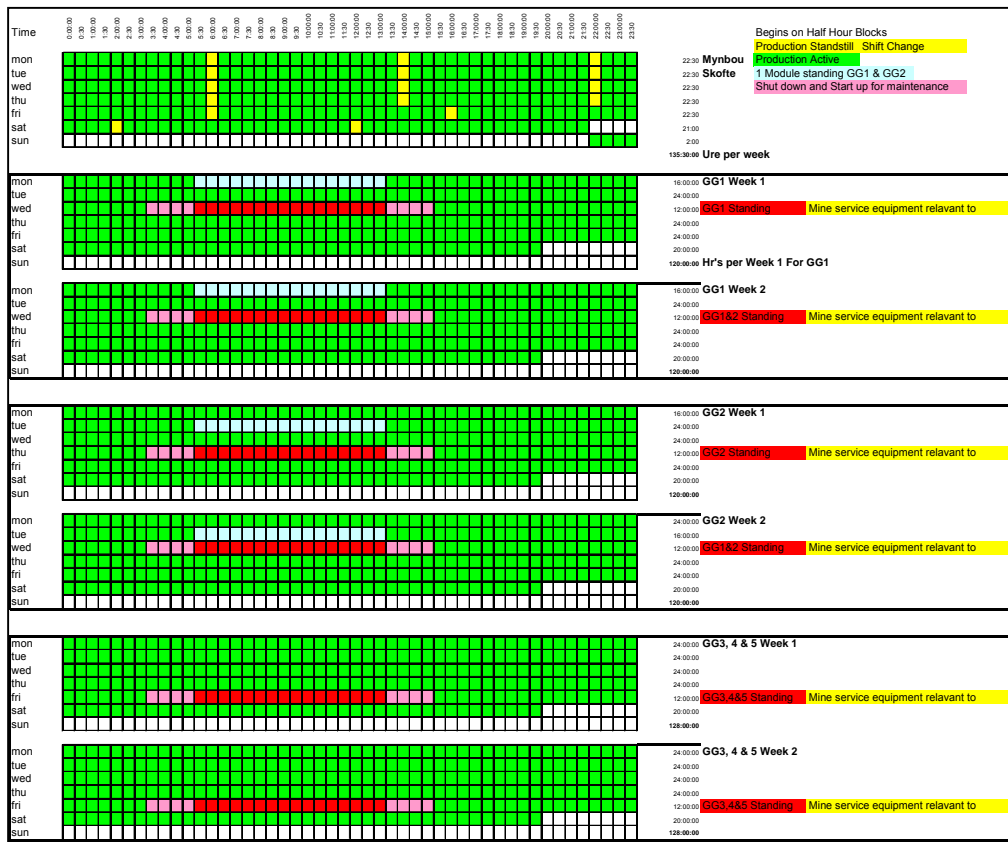
Figure 37 Example of a Bi- weekly Roster

A bi-weekly roster is set up for each plant. Maintenance is done on different days of the week as prescribed by the mine. The roster time also takes into account 2 hours lost when shutting down. Before the maintenance shift begins, a 2 hour start-up is allowed for before and after the maintenance shift ends. During these times, it is assumed that there is no production of coal through that specific plant. Alternatively, one stream is shut down per shift, as indicated in the above roster, when only one module stands. The mining production uses its own roster.

Table 25 Roster exceptions

	Start	Finish	Activity	Recurrence
1	16/Dec/2003 00:00	17/Dec/2003 00:00	101 Public Holiday	1 Year x31
2	25/Dec/2003 00:00	28/Dec/2003 00:00	101 Public Holiday	1 Year x31
3	01/Jan/2004 00:00	01/Jan/2004 00:00	101 Public Holiday	1 Year x30
4	21/Mar/2004 00:00	22/Mar/2004 00:00	101 Public Holiday	1 Year x30
5	09/Apr/2004 00:00	10/Apr/2004 00:00	101 Public Holiday	1 Year x30
6	27/Apr/2004 00:00	28/Apr/2004 00:00	101 Public Holiday	1 Year x30
7	16/Jun/2004 00:00	17/Jun/2004 00:00	101 Public Holiday	1 Year x30
8	09/Aug/2004 00:00	10/Aug/2004 00:00	101 Public Holiday	1 Year x30
9	24/Sep/2004 00:00	25/Sep/2004 00:00	101 Public Holiday	1 Year x30
*				

Over and above the rosters, a roster exception is drawn up with the various Public Holidays that occur throughout the scheduling period. The roster exceptions are independent of the roster. Within the hourly calculation in XPAC®, the total hours for each plant and mining process is calculated with Sundays and maintenance shutdowns incorporated in a chronological process. The Public Holiday hours are progressively deducted when such holidays are within or occur over the time roster of actual production. It is assumed that the total mine is on a no-production basis for 24 hours in the case of a holiday.

	Code	Data Field Name	1	2	3	4	5
2 −	Cal	CALENDAR INFORMATION					
3 .	srtdate	Start Date	1/1/2001	1/1/2002	1/1/2003	1/1/2004	1/1/2005
4 .	nxtmnth	Next Period Start Date	1/1/2002	1/1/2003	1/1/2004	1/1/2005	1/1/2006
5 .	wkdays	Working Days	365	365	365	366	365
6 +	Shd	SCHEDULING INFORMATION					
12 +	phr	**Plant Hours**					
18 +	cfd	**Crusher Feed Design**					
24 +	pf	**Planned Feed**					
30 +	pu	**Pland Utilization**					
41 +	pt	**Plant Tempo Per Hour**					
47 −	prom	**Plant Totals ROM**					
48 .	gg1	GG1 Total	16,692,686	16,692,686	16,446,722	16,341,426	16,199,934
49 .	gg2	GG2 Total	17,910,782	17,903,375	17,666,579	17,501,309	17,341,362
50 .	gg3	GG3 Total	2,323,671	2,319,529	2,295,712	2,270,860	2,258,434
51 .	gg4	GG4/5 Total	3,797,777	3,791,007	3,752,082	3,711,464	3,691,155
52 .	gg6	GG6 Total					
53 −	pro	**Products**					
54 .	pow	Powerstation	14,225,543	14,258,461	13,821,076	14,367,521	14,528,363
55 .	cc	Coking Coal	1,893,907	2,144,421	2,705,996	2,799,373	2,776,673
56 .	mc	Duff	396,111	491,695	518,739	532,088	550,552
57 .	pci	PCI	180,047	180,381	177,393	170,019	158,171
58 .	sal	Saldanha					
59 .	psl	Peas, Small Nuts, Large Nuts	792,290	898,684	922,728	922,993	920,118
60 .	o	Overburden Target	9,878,102	9,241,342	9,241,342	9,241,342	9,878,102

Figure 38 Calculation of the Plant ROM:

After the roster and holiday exceptions, hours are calculated for each scheduling period. Each plant's hours are written into the calendar database. The crusher feed design is added to each plant as an average rate per hour. This rate is multiplied by the average plant availability and utilisation (use of availability) per plant. These may differ from period to period. The feed rate is calculated for each plant respectively. The final tip bin feed that is needed for the mining equipment is displayed as a constant rate per hour

Table 26 Calculation of Plant tempo's

12	– phr	**Plant Hours**				
13	. gg1	GG1 Hours	6,764	6,764	6,664	6,622
14	. gg2	GG2 Hours	6,448	6,446	6,360	6,301
15	. gg3	GG3 Hours	6,732	6,720	6,651	6,579
16	. gg4	GG4/5 Hours	6,732	6,720	6,651	6,579
17	. gg6	GG6 Hours	7,094	7,094	7,005	6,934
18	– cfd	**Crusher Feed Design**				
19	. gg1	GG1 t/hr	3,300	3,300	3,300	3,300
20	. gg2	GG2 t/hr	3,300	3,300	3,300	3,300
21	. gg3	GG3 t/hr	1,100	1,100	1,100	1,100
22	. gg4	GG4/5 t/hr	1,100	1,100	1,100	1,100
23	. gg6	GG6 t/hr	1,500	1,500	1,500	1,500
24	– pf	**Planned Feed**				
25	. gg1	GG1 t/hr	3,247	3,247	3,247	3,247
26	. gg2	GG2 t/hr	3,247	3,247	3,247	3,247
27	. gg3	GG3 t/hr	408	408	408	408
28	. gg4	GG4/5 t/hr	674	674	674	674
29	. gg6	GG6 t/hr	1,476	1,476	1,476	1,476
30	+ pu	**Pland Utilization**				
41	– pt	**Plant Tempo Per Hour**				
42	. gg1	GG1 t/hr	2,468	2,468	2,468	2,468
43	. gg2	GG2 t/hr	2,778	2,778	2,778	2,778
44	. gg3	GG3 t/hr	345	345	345	345
45	. gg4	GG4/5 t/hr	564	564	564	564
46	. gg6	GG6 t/hr				

The feed rate to the plant is multiplied with the total amount of hours available as calculated for each plant. This derives the potential Run of Mine (ROM) through each plant, i.e. the amount that can be handled for the specific scheduling period. This ROM then becomes the scheduling target which must be met by the mining operation. It may be capped by the marketing plan, which will result in spare capacity.

Haul Roads:

A simulated database from Talpac® was imported into XPAC® with the relevant truck information. This incorporates the fuel consumption and time taken to do one trip from the first available block on each bench on the Northern and Southern side respectively. Talpac® gives results for the ramps using diesel only or trolley assist. Way points are installed as measured survey points with gradients and distances. XPAC® thus has a fixed value for these increments to each bench. This results in the exact distance from the centroid of the mining block being available for calculation purposes.
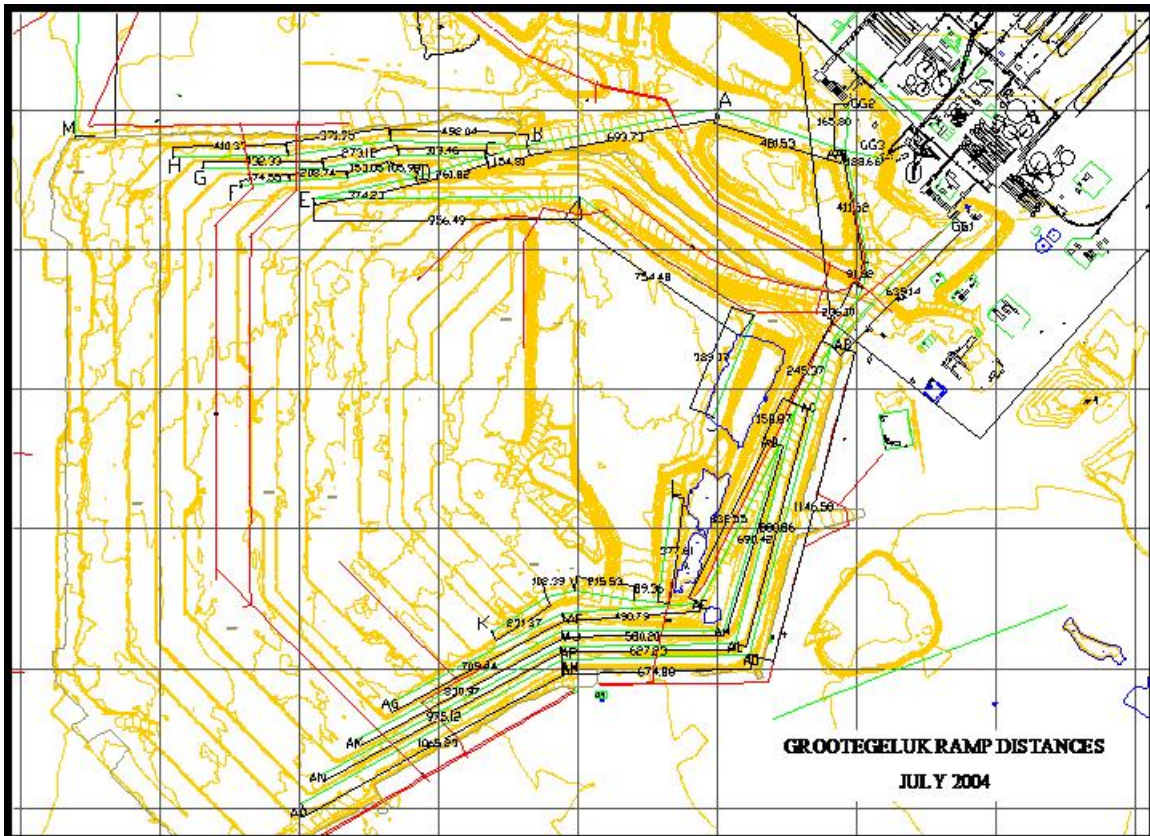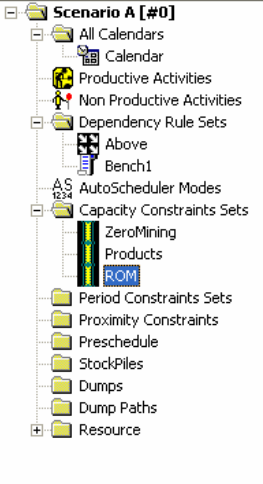
Figure 39 Surveyed way points

For each strip from the connection point on the Southern side to the connection point on the Northern side, mining blocks were drawn in 90 m increments. Accordingly, a second table with 90 m increments for time and fuel with travelling "in bench" properties was used. The strips follow each other at 45 m increments. Any block on any strip will then have a total distance and fuel value for travelling either North or South towards a destination tip bin. After scheduling, the block is allocated to one plant only, and the shortest distance between the Northern and Southern ramps are selected. A graphical display, summarizing the haulage distance over the southern part of bench 6 is shown in Figure 40 **Haulage distance over the southern part of bench 6**.
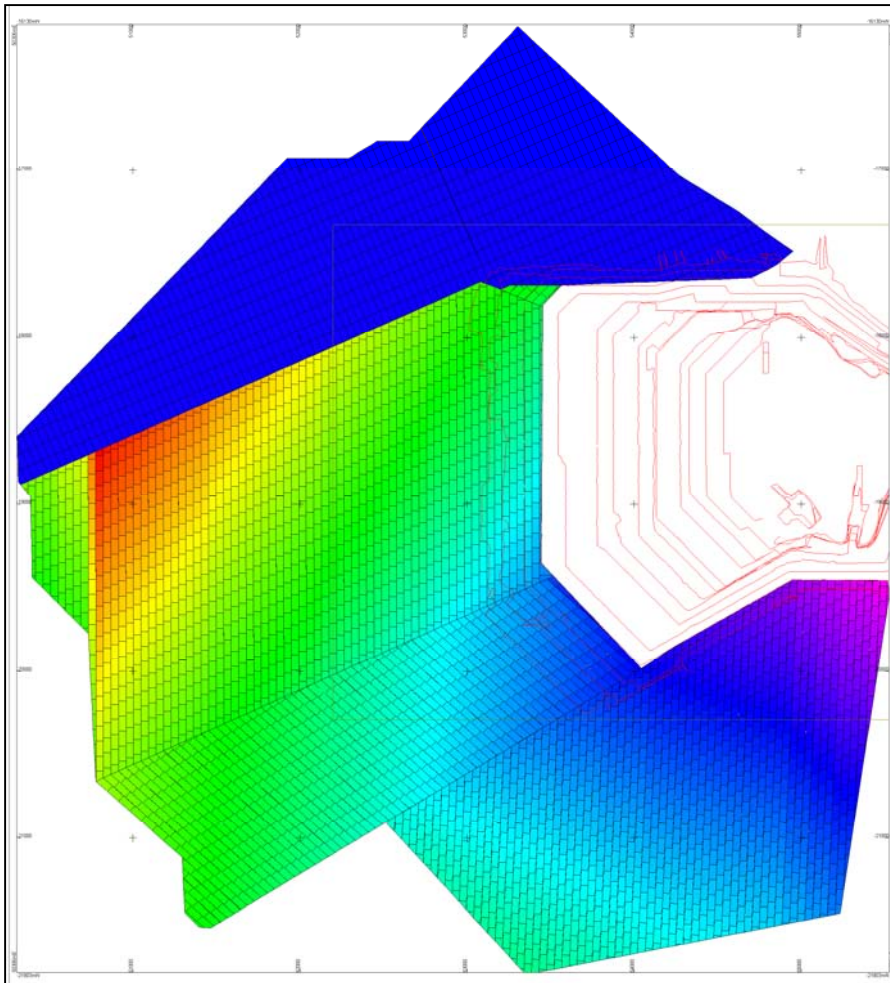
Figure 40 Haulage distance over the southern part of bench 6

Capacity Constraints

XPAC® is configured so that all the plants will be supplied with ROM, to reach the target set by the rosters. The crushing tempo is used to calculate the ROM demand for each Scheduling period. The main priority is to fill the plants to full capacity for each of the scheduling periods. Because of various market considerations and the possibility of a mining block that is capable to be allocated to more than one plant, capacity constraints have been used to maintain the market demand, i.e. contractual demand for power station coal.

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Figure 41 Example of capacity constraints

The mining logic determines that the Plant 1 and Plant 6 must be supplied to their full capacity, unless limited by market considerations. Secondly, Plant 3 will be supplied until all available coal from benches 6 and 9A have been utilised, or its full capacity is reached. Plants 4 and 5 are supplied as reserves become available

Scheduling Results

Results are produced in .csv files, called flat sheets. These files can seamlessly be imported into Xeras®.

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10.4 Appendix D

XERAS® - Costing Model

To perform a financial cost evaluation Xeras® is used. The principle of activity based costing (ABC) is applied, either on the Life of Mine Schedule or a budget schedule, The Xeras® model was developed to perform the financial calculations that culminated in total cost and revenue. The following sections explain the methodology used to calculate the cost of operating the mobile equipment.

The outputs from the XPAC® scheduling were mainly the active machine hours and fuel burned. These machine requirements were then fed into the automated equipment-planning model, as part of Xeras®. The model uses the equipment life, availability and utilisation to calculate new machine hours after each period. If the machine reaches replacement norms, the model automatically selects and purchases a new machine based on the rules defined in the model. If too little capacity is available, additional equipment may also automatically be purchased. The following equipment life, availabilities and utilisation figures are examples of what is used in the model:

Table 27 Machine Norms, Availability and Utilization

Machine	Model	Replacement Hrs	Maintenance Availability	Utilisation of Availability
KOMATSU	730E	80,000	92%	85%
HITACHI	EH3500	80,000	92%	85%
P & H	2300 Mk2	150,000	88%	85%
DEMAG	PC5500	90,000	88%	80%
SANVIK D25	D25KS	30,000	85%	75%
CAT Dump Truck	777D	50,000	85%	70%
CAT Water Tanker	777C	50,000	85%	70%
CAT FEL	994	50,000	85%	70%

Machine	Model	Replacement Hrs	Maintenance Availability	Utilisation of Availability
CAT Grader	16H	42,000	85%	70%
CAT Track Dozer	D10N	36,000	85%	70%
CAT Rubber wheel	D834	36,000	85%	70%

Dividing the required machine hours by the planned utilised annual hours, the number of machines required is obtained. If additional equipment is required, new machines may be purchase depending on the rule set applied. The following prices, which include freight, delivery, erection and commissioning cost are used as an example (price base not current);

Table 28 Machine Expected Life and Replacement Cost

EQUIPMENT	GROUP	EXPECTED LIFE	REPLACEMENT COST
P&H 2300 Mk2	Rope Shovel	150,000	R 109,578,680
DEMAG 455	Hydraulic Shovel	90,000	R 56,891,200
HITACHI EH3500	Haul Truck	80,000	R 18,300,000
KOMATSU 730E	Haul Truck	80,000	R 18,300,000
DRILL DM25	Drill	30,000	R 6,133,000
CAT 994	FEL	50,000	R 23,335,000
CAT D10	Dozer	36,000	R 7,780,000
CAT 992	FEL	36,000	R 9,133,000
CAT 777	Haul/Water	50,000	R 7,456,000
CAT 824	Rubber Tyre Dozer	36,000	R 4,112,000
CAT 16H	Grader	42,000	R 3,188,000

After establishing the number of machines required, the operating cost can be calculated using the Life Cycle Cost of each machine type.

The maintenance and repair life cycle cost for each machine type was determined from first principles. The major components of the machine are scheduled according to the component norms over the life of the machine in 1000-hour intervals, benchmarked with the different OEM's. The cost of each respective component is then assigned at the time of the maintenance intervention. Xeras® is then configured so that the model can interpolate between these intervals to determine the real-time expected maintenance cost. These costs were also calibrated against the mine's current expenditure and performance measures.

The tyre costs of the machines were determined using by dividing the cost of a set of tyres by the latest budgeted life of tyres, per specific machine type.

For mines that make use of trolley assist, the effect of the Pantograph utilisation is incorporated into the Xeras® model. This will impact cycle times and fuel consumption. The Xpac® model predicts the fuel consumption of the haul trucks. The remainder of the other equipment's fuel consumption rates were taken from the current budgeted values, as it does not have a significant impact on the budget.

The current cost for ground engaging tools and lubrication was used in the financial model. Refer to Table 29 Capital and Average Operating Cost per machine type for the average operating cost for the various machines used in the model, over the life of the equipment (Costs for demonstration purposes only).

Table 29 Capital and Average Operating Cost per machine type

EQUIPMENT	GROUP	TYRE COST	REPAIR COST	GET	LUB
P&H 2300 Mk2	Rope Shovel	R 0	R 713	R 193	R 38
DEMAG 455	Hydraulic Shovel	R 0	R 920	R 199	R 96
DEMAG 285	Hydraulic Shovel	R 0	R 677	R 149	R 74
HITACHI EH4500	Haul Truck	R 165	R 339	R 17	R 26
HITACHI EH3500	Haul Truck	R 86	R 244	R 12	R 20

EQUIPMENT	GROUP	TYRE COST	REPAIR COST	GET	LUB
KOMATSU 730E	Haul Truck	R 106	R 244	R 13	R 20
DRILL DM25	Drill	R 0	R 201	R 0	R 18
CAT 994	FEL	R 182	R 266	R 210	R 51
CAT D10	Dozer	R 0	R 194	R 48	R 28
CAT 992	FEL	R 83	R 160	R 97	R 32
CAT TIGER	Rubber Tyre Dozer	R 83	R 160	R 97	R 32
CAT 777	Haul/Water	R 43	R 152	R 10	R 9
CAT 824	Rubber Tyre Dozer	R 25	R 89	R 29	R 19
CAT 16H	Grader	R 17	R 66	R 32	R 18

The above prices were calculated using the following exchange rates:

US$ 1.00= ZAR 7.50 : GBP 1.00 = ZAR 11.36 : EURO 1.00 = ZAR 8.16 (Used as an example only).

The remainder of the utility and supporting fleet was added as a fixed portion, based on the number of primary equipment. This fleet would therefore increase in the same percentage as the primary mining fleet.

Mining Operator and Maintenance Labour

A table was developed utilising industry standards to calculate the proposed number of operators, helpers, artisans and maintenance operators required for each machine type. These numbers are in line with the current labour structure at the mine. After determining the number of mining equipment pieces, the associated labour requirements are calculated automatically. Standard cost to company values for each labour category was used to calculate the total labour cost. Additional overtime and shift allowance cost were also added. These costs are considered variable and

will increase or decrease according to the fleet size. However, it was assumed that the management and support personnel would be unaltered. These overhead costs were reflected as a fixed labour cost in the model.

Production Equipment

Xeras® also determines the required fleet size for each specific scenario. This allows the model to determine the impact of increased production on the fleet requirements and to accurately model capital expenditure on the purchase of additional equipment as well as the capital expenditure required to replace equipment over the LOM.

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