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KLIPSRUIT COLLIERY SIMULATION MODEL

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Executive Summary

Klipspruit Colliery is an opencast coal mine located close to Ogies and was established by BHP Billiton Energy Coal South Africa in October 2003. The many possible unforeseen complications on a mine demand frequent altering of the production plans. When this happens, decisions are taken without any means of testing the repercussions on the overall mining process. The aim of this project is thus to prove that simulation modelling can be used to model the interdependencies that exist between the high level mining processes and evaluate the impact of these plan alterations on the overall system. This is accomplished by creating a systems dynamics simulation model in AnyLogic. The model is based on an adaptation of the BHP Billiton Mitsubishi Alliance's cell concept. The construction of the model, along with all the necessary constraints and auxiliary functions, is discussed and followed by a demonstration of the model's reliability and consistency. The report concludes with an example of how the model is used to evaluate decision alternatives and a brief discussion on recommended improvements for the full scale, implementable model.

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Chapter 1

Introduction

BHP Billiton is a global mining, oil and gas company headquartered in Melbourne, Australia. It is the world's largest mining company when measured by revenues (ABC News, 2007) and was created in 2001 by the merger of Australia's Broken Hill Proprietary Company and the Anglo-Dutch Billiton plc. The result is a dual listed company that operates a variety of mining activities in twenty five countries and employs approximately forty one thousand people worldwide (O'brien, 2001).

By producing a variety of coal qualities, BHP Billiton Energy Coal is able to provide product solutions for almost any application in the electric power generation industry. In addition to their seaborne supply into the Atlantic and Pacific markets, they service domestic markets in South Africa, Australia and the United States.

BHP Billiton Energy Coal South Africa (BECSA) has one underground and four opencast coal mines in the Witbank/Middelburg area. Klipspruit Colliery (Figure 1.1) is an opencast coal mine located near Ogies and was established in October 2003. This is the first new coal mine to be established by BECSA in more than fourteen years (BHP Billiton, 2011a).

Figure 1.1: Klipspruit Colliery

1.1 The Problem

Coal mining is an unpredictable industry with numerous *interdependent* processes, each experiencing varying degrees of uncertainty that have to be carefully coordinated to ensure production targets are met. Planning and scheduling these operations is a challenging undertaking.

At Klipspruit Colliery, three primary functional groups work together to maximize the mines consistency in meeting the production targets set by management: Long Term Planning, Short Term Planning and the Mining Production team. Klipspruit Colliery's Mining Production team follows their plans as closely as possible. The many possible unforeseen complications on a mine, however, demand frequent altering of the plans. When this happens, decisions are taken without any means of testing the repercussions on the overall mining process.

Currently, the planning departments use numerous *independent* models for analysing and planning the various mining processes. The problem, according to André Roux (Personal interview, 2011), Klipspruit's Mine manager, is that when the plan is altered, the decision often addresses current concerns, but creates an immeasurable setback for future operations. The existing planning models fail to address *interdependence*: a change in the plan for one process is not automatically reflected in the other process models.

1.2 Research Design & Methodology

Klipspruit Colliery's planning departments would greatly benefit from a "tool" that can model the interdependence of the mining processes and estimate the consequence of a decision on the entire mining process. It should be noted that this tool is intended to be a decision making aid, specifically when the plans need to be adjusted. It is not intended to replace the planning and scheduling models currently in place.

With this in mind, the aim of this project is to prove that simulation modelling can be used to model the interdependencies that exist between the high level mining processes at Klipspruit Colliery. The model should allow the user to adjust key process performance parameters and estimate the effects of these changes on the entire mining process. The changing of performance parameters is representative of the decision being considered. It is crucial that the model incorporates mine specific constraints and procedures to ensure that a realistic and relevant outcome is calculated. This project is intended to be a "proof of concept" of what is achievable using simulation modelling. Only if the proof of concept is successful, should the development of a full scale, implementable model be initiated.

1.3 The Scope

To address the identified problem, the proposed model should incorporate the highest level mining activities: from the moment that the ground is disturbed by the excavators that remove the topsoil, to the final extraction of the coal in Klipspruit Colliery's "main pit" (Figure 1.2). These high level processes include:

- Topsoil stripping.
- Burden drilling.
- Burden charging and blasting.
- Blasted burden dozing.
- Dragline Burden removal.
- Coal drilling, charging and blasting.
- Coal extraction.
- Parting drilling, charging and blasting.
- Parting extraction.

The role of each process will be discussed in Chapter 3. The auxiliary pit, known as Smaldeel, will be excluded from the model along with the Phola coal processing plant (Figure 1.2). These two sections of the mine are independently managed and insignificant to Klipspruit Colliery's planning departments.

Figure 1.2: Klipspruit Colliery Sections

Chapter 2

Literature Review

The director of Mechanised Mining Systems at the University of the Witwatersrand, and owner of Jim Porter Mining Consulting (Pty) Ltd, explains that the rising costs and the need to remain competitive in a demanding global economy has placed the mining industry under increasing pressure to improve and optimise operations (Porter, 2011). As the specialists in operational improvement, it is crucial for industrial engineers to become involved and apply their skills in the mining industry.

According to Hattingh and Keys (2010), however, industrial engineering as a discipline has seldom been applied in mining. Mining is arguably very different from the traditional manufacturing sectors where industrial engineering has its roots. In spite of this, Hattingh and Keys reassure us that due to its nature, industrial engineering can be successfully applied to numerous aspects of the mining value chain: from the design of new mines, to the physical extraction of the mineral bearing ore and final processing of the commodity sold to the customer.

Following research into existing mine modelling methods, it has become apparent that the modelling techniques openly discussed and published, are models for specific processes. These processes overlook the interdependencies that exist with other processes. Examples include an optimisation model for drilling operations (Knowles, 1999), a model for scheduling front end loaders (Sepulveda, 2006), the costing of coal receiving operations (Boleneus, 2009), a simulation of coal mining's environmental impact (Singh and Singh, 1985) and prediction of methane gas leaks in coal seams (Cook, 2005). Models that include an entire mine's operations, or even just a few interdependent mining processes, appear to be rare, or more likely, confidential.

Research into the desired modelling techniques would need to find sources within BHP Billiton. According to Roux (Personal interview, 2011), a model for analysing the repercussions on the overall mine, associated with changing key process performance parameters, is non-existent within BECSA. The BHP Billiton Mitsubishi Alliance (BMA) is nevertheless developing a model similar to the one required by Klipspruit Colliery. The BMA owns and operates seven coal mines in Central Queensland, Australia (BHP Billiton, 2011b). Five of BMA's mines are similar to Klipspruit Colliery in that they are open cast coal mines, using a dragline for burden removal. A dragline and its function in coal mining will be discussed in chapter 3.

The BMA is creating a model to analyse the cumulative effects resulting from the different types of variation encountered in coal mining. During the design of this model, the BMA has developed what is known as the "BMA Cell Concept". To enable their model to geographically track mining processes, BMA's cell concept divides a mine into "cells" that are further broken down into "sections". In their model, the mining processes are programmed to follow a predetermined route through the cells and sections, recording their progression as they advance. The primary objective of BMA's proposed model, using the cell concept, is to improve forecasts of dragline idle and waiting time given a set of operating conditions. These operating conditions may be adjusted as desired, the model re-executed and the new dragline idle and waiting times forecasted (BHP Billiton Mitsubishi Alliance, 2010).

The BMA cell concept's cells and sections are notably similar to what Klipspruit Colliery uses to label areas in their main pit: strips and blocks (Figure 2.1). The main pit is divided into fifty meter wide strips that run the length of the mine. These strips are further divided into one hundred meter long subdivisions known as blocks. Compatibility with the BMA cell concept permits Klipspruit Colliery's model to use a methodology similar to that of the BMA model. In other words, Klipspruit Colliery's model can manage the process progression through a predetermined path and simultaneously monitor the performance, given a set of operating conditions.

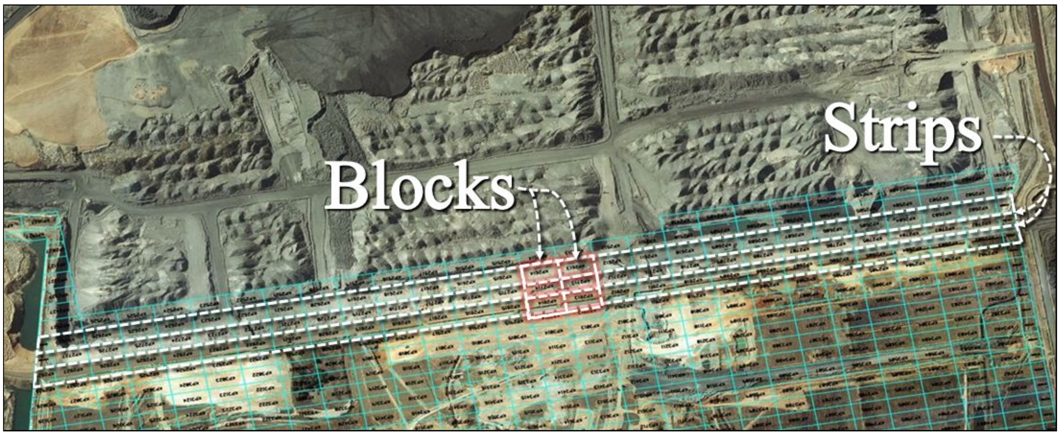


Figure 2.1: Strips and Blocks

When considering the inherent complexity associated with mining processes, coupled with the requirement to re-execute the model repeatedly, it becomes clear that a computer would be best suited for this task. A computer based methodology of particular interest in the given set of circumstances is simulation modelling. Computer simulations are computer programs that attempt to create an abstract model of a particular system and imitate certain key characteristics and behavioural patterns inherent to that system.

As the objective of this project's model is not to optimize operations, but rather estimate the effects of changing key process performance parameters on the overall mine, traditional optimization approaches are inappropriate. Another possible alternative to a time-based simulation model is to design a Microsoft Excel or other spreadsheet based model. The difficulty with these types of models is that they are essentially static and thus drastically limit the modelling accuracy and complexity achievable.

Strogatz (2007) deliberates the use of computer simulations in industry by insisting that they have become a useful part of mathematical modelling in many natural systems, including engineering systems. He argues that "simulations can be used to explore and gain new insights into new technology, and to estimate the performance of systems too complex for analytical solutions". This modelling technique will further enable the incorporation of the time dependencies associated with the process progression and allow a variety of users to repeatedly run the model with ease.

For construction of the Klipspruit Colliery Simulation Model, a variety of simulation packages were considered: Oracle Crystal Ball, Preactor, Arena, Simio, XPAC and AnyLogic. Consideration of the cost, advantages and disadvantages associated with each alternative, has identified AnyLogic as the most appealing option. AnyLogic is compatible with commonly used programs like Microsoft Excel and is accessible to students through the Department of Industrial and Systems Engineering. More importantly, as the name suggests, AnyLogic accommodates almost any modelling approach when creating a simulation model. When using AnyLogic, one can follow an agent based, pedestrian dynamics, system dynamics or discrete event simulation methodology. The characteristics of each alternative needs to be explored before a selection of the appropriate modelling technique is made.

The developer of AnyLogic, the XJ Technologies Company (2011), defines agent based modelling as an essentially decentralized, individual-centric approach to model design. When designing an agent based model the modeller identifies agents that represent people, companies, projects, assets, vehicles, cities, animals or products.

The modeller defines behaviour conventions for the agents, places them in a virtual environment and establishes connections between them. The goal of agent based modelling is to predict the global or system-level behaviour that results from the interactions between the agents, based on their individually simulated behaviour patterns.

AnyLogic's pedestrian dynamics library allows the modeller to create a special kind of agent based model intended to analyse physical queuing systems like subway stations, security checks or toll gates. The purpose of creating such a model is to collect statistics on pedestrian densities in different areas of the simulated environment, to ensure acceptable performance of service points with hypothetic loads, estimate the lengths of queues in specific areas and detect potential problems with interior geometry.

The XJ Technologies Company (2011) describes the system dynamics approach as a methodology that allows the modeller to create simulations of complex systems in order to better understand the structure and behaviour of the system. Where agent based modelling approaches are aimed at analysing the behaviour of the individuals within a system, system dynamics modelling is focused on studying the behaviour of the system itself. The system dynamics approach accomplishes this through the use of two primary modelling elements: stocks, representing the process inventory quantities, and rates, which continually extract and replenish the quantities represented by stocks.

The discrete event modelling paradigm suggests that certain moments in time, or events, can be systematically arranged to represent the important aspects of a continuous process. Discrete event modelling is "process-centric" and models the progression of entities through a flowchart representation of a system.

Selecting the appropriate modelling approach for designing the Klipspruit Colliery Simulation Model requires careful consideration of the information available. The available information is arguably the largest constraint on a model's accuracy (Henricksen and Indulska, 2005). In addition to the available information, the desired level of detail for the proposed model should correspond to that of the modelling approach. According to the XJ Technologies Company (2011), the system dynamics methodology should be used for "macro", strategic models that are focused on the high level aggregation of the objects being modelled. If a system's finer, lower level details are important, they recommend that one rather use an agent based or discrete event modelling approach.

In terms of available information, Klipspruit Colliery has equipped all of their vehicles and machinery with monitoring devices that record their activities on a continual basis. This data is transmitted to a centralised control room that processes the data and generates a daily report. This daily report summarises the entire mine's process related information for a particular day. Amongst other useful information, the volume of material handled by each operation, or each operation's daily processing rate, is obtainable from this report. Klipspruit Colliery also possesses a Microsoft Excel spreadsheet that details the geological characteristics of the mine. This spreadsheet contains information pertaining to the thickness of each of the geological layers, the estimated coal quality and the surface area for every block on the mine. The product of each geological layer's thickness and the given surface area provides a good estimation of the volume of each material contained in a block. These volumes can be interpreted as inventories to be processed by the rates in the daily report.

The Klipspruit Colliery Simulation Model is aimed at imitating the high level interdependencies between processes rather than the detailed operations of each process. Combining this observation with the available information (process rates and inventories) promotes the adoption of a system dynamics modelling approach when modelling Klipspruit Colliery.

With the modelling methodology established, chapter 3 details the procedure of creating the Klipspruit Colliery Simulation Model and each of the essential functions incorporated. Chapter 4 will then explain how the model is used to analyse decisions and their effects on the overall mine, thus serving the dual purpose of project value demonstration and solution validation.

Chapter 3

Modelling Klipspruit Colliery

A simulation model has been defined as a computer program that attempts to create an abstract model of a particular system to imitate certain key characteristics and behavioural patterns inherent to that system. The system to be imitated by the Klipspruit Colliery Simulation Model is the collection of processes involved in reaching and extracting the coal. The high level processes to be included in the model are summarised in section 1.2.

Delivery of a useful simulation model, which addresses the identified need satisfactorily, requires each mining operation to be thoroughly understood, carefully modelled and appropriately integrated. If these three steps are successfully executed, the model should be a reliable representation of the mine's true operations and the interdependencies that exist between the processes. This chapter, in accordance with these steps, starts in section 3.1 with a discussion about Klipspruit Colliery's mining processes. Section 3.2 explains how the mine's processes are represented in the model, with section 3.3 documenting how the interdependencies have been incorporated. The chapter concludes with a final discussion, in section 3.4, of the auxiliary functions included in the model.

3.1 Klipspruit Colliery Mining Procedures

In essence, the goal of opencast coal mining is to extract as much coal as possible. This can, however, only be accomplished once all of the material covering the coal is removed. This unwanted material is commonly referred to in the mining industry as "burden". Every high level process at Klipspruit Colliery is aimed at either burden removal or coal extraction.

When there are multiple coal seams on a mine, each layer of burden is individually labelled. Klipspruit Colliery has three different coal seams in their main pit. They use the terms topsoil, overburden, midburden and parting to refer to the various layers that exist above and between the coal seams. Figure 3.1 depicts the typical composition of the strata, or geological layers, encountered in each individual strip.

In geology, coal seams are categorised according to their relative depths. The deepest coal seam is labelled “1 seam coal”. Each distinct seam encountered between the 1 seam coal and the surface are labelled in ascending order. At Klipspruit Colliery, the 3 seam coal has such low quality that it is completely overlooked. From figure 3.1, note that the 2 seam coal layer appears throughout the strip with the other two seams emerging at opposite ends. The 4 seam coal vein is approximately one kilometre wide and encountered only between blocks one and eleven. The 1 seam coal vein appears from block twelve and continues to the end of the strip.

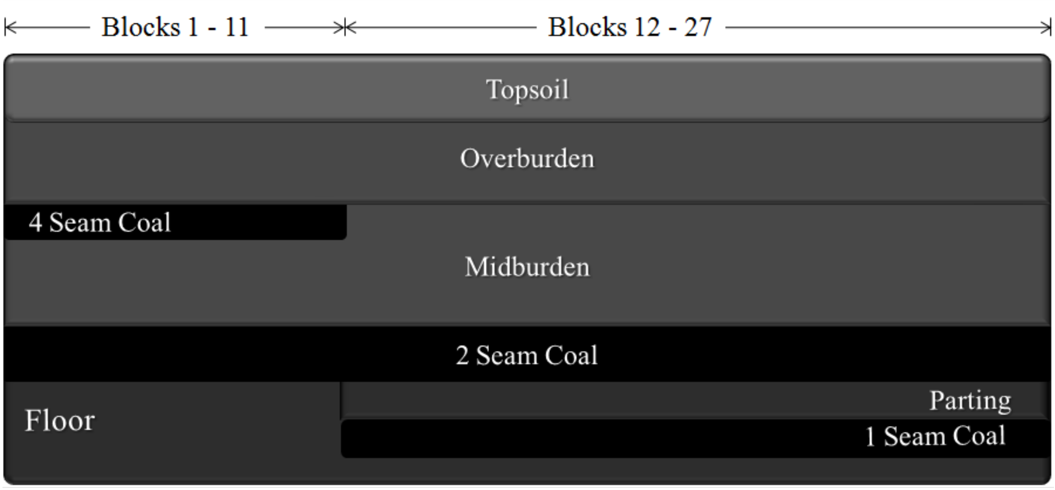


Figure 3.1: Klipspruit Colliery Strip Geological Layers

The thick midburden, separating the 4 seam coal from the 2 seam coal, necessitates the use of a “double bench”. A double bench simply means that the 4 seam and 2 seam coal is mined simultaneously in adjacent strips. Figure 3.2 is a side-view section of a double bench. Once the lowest seam of coal has been extracted, the “floor” of the mine is encountered. The resulting empty strip is called a void. In the double bench operation, the floor of the mine lies directly below the 2 seam coal. Following the extraction of both seams of coal in the double bench, the midburden and overburden of the subsequent strips are removed and placed in the void. The burden in the void adds to the previous bench’s waste material and the resulting mound is called the “spoils”. The removal of overburden exposes 4 seam coal with the adjacent midburden removal exposing 2 seam coal. These two parallel strips represent the new double bench. This cycle is repeated continually, advancing the mine, one strip at a time.

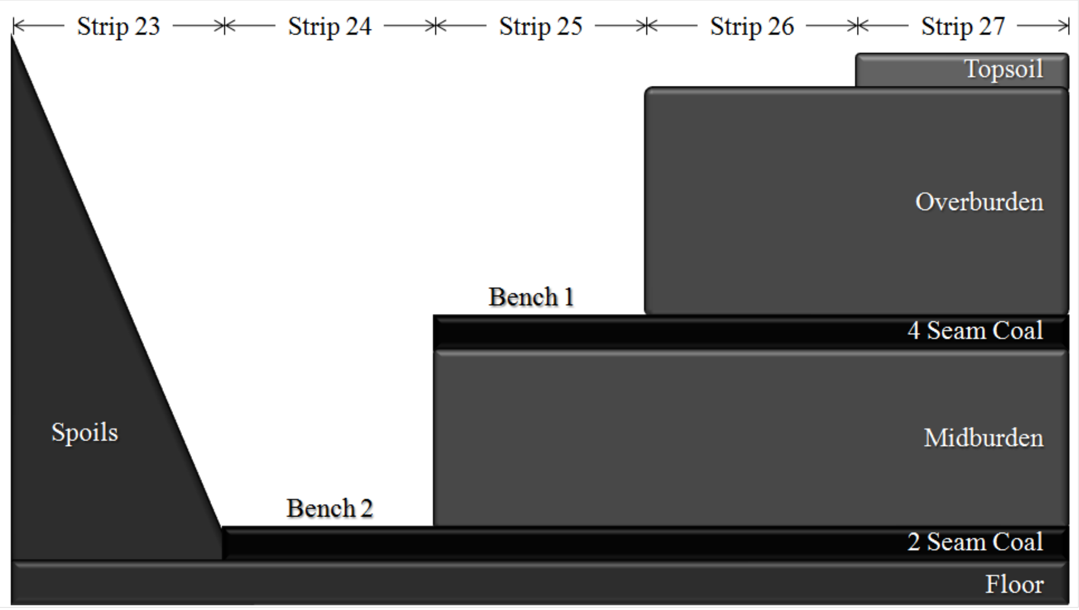


Figure 3.2: Double Bench

The parting between the 2 seam and 1 seam coal veins has an average thickness of eighty six centimetres. The parting can thus be easily removed once the 2 seam coal has been extracted, thereby eliminating the need for a double bench. Figure 3.3 depicts the typical structure of a single bench.

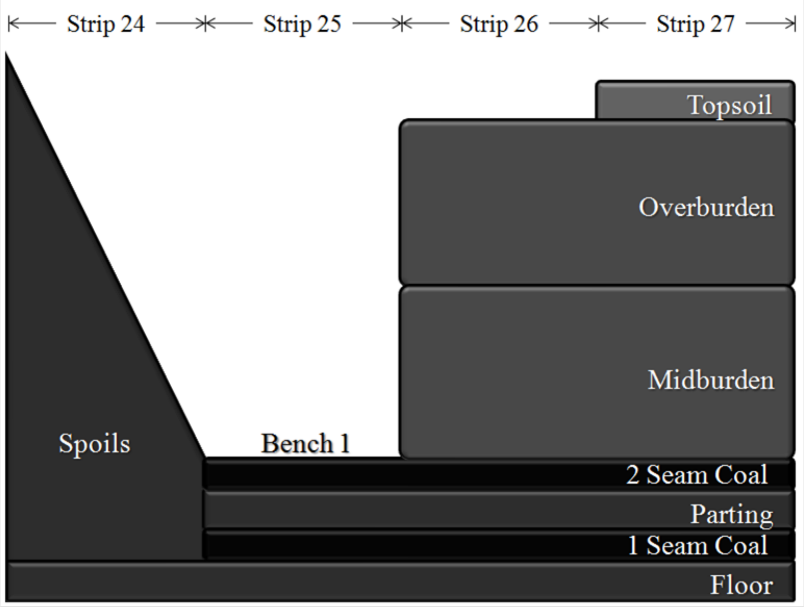


Figure 3.3: Single Bench

The configuration of each strip, and the associated benches, creates the environment in which the individual mining processes operate. All of the processes follow the same path throughout the mine. This processing route is depicted in Figure 3.4 and is referred to as a "figure 8 processing pattern". Processing equipment starts on the border of the two benches and processes the single bench first. They then relocate to the start of the single bench and process the double bench. Once the double bench has been processed, the process equipment advances to the next strip to process its single bench. This pattern is repeated until end of the mine is reached.

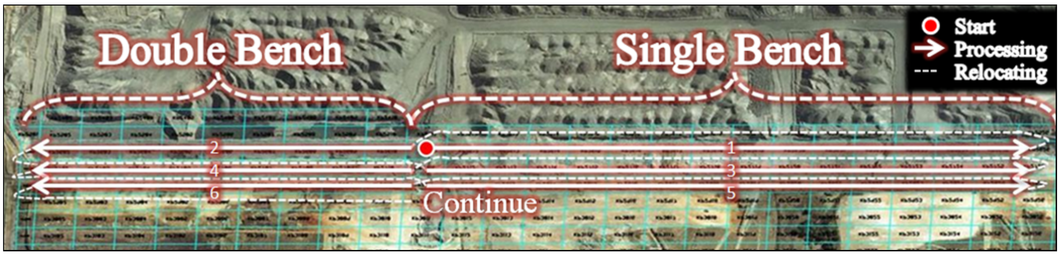


Figure 3.4: Processing Route

Each high level mining processes that follows this path, and needs to be incorporated into the Klipspruit Colliery Simulation Model, will now briefly be discussed.

Topsoil Stripping: Topsoil is the soft, outermost layer of earth that contains many of the minerals and nutrients necessary to sustain vegetation. Therefore, once excavated, topsoil is stored in large stockpiles that will later be used during the mine's environmental rehabilitation.

At Klipspruit Colliery, a 'truck and shovel' operation is used to remove topsoil. All this means is that an excavator is used to dig up soil before loading it on an automated dump truck (ADT). The ADT transports the topsoil to a stockpile, dumps it and returns to the excavator to reinitiate the continuous truck and shovel cycle. An example of the excavators and ADTs used at Klipspruit Colliery can be seen in Figure 3.5.

Figure 3.5: Topsoil Truck and Shovel Operation

Burden drilling: Both the overburden and midburden layers are solid rock. In contrast to the easily excavated topsoil, these layers of rock need to be demolished before they can be moved into the void. The rock can, however, only be blasted once specialised heavy-duty drills, known as Pit Vipers, have drilled through the rock. The cylindrical cavities created by these drills are used to house the explosive charges that, upon detonation, demolish the rock. Two of the Pit Viper drills used at Klipspruit Colliery are shown in Figure 3.6.

Figure 3.6: Pit Viper Drills

Burden charging and blasting: The holes drilled by the Pit Vipers are filled with porous prill ammonium nitrate (PPAN) explosive. This explosive is commonly used in the mining industry because of its stability. PPAN is water soluble, insensitive to normal handling and can even be exposed to an open flame without exploding (BME Mining, 2011). When detonated, the force of the explosion propels some of the blasted rock into the void and eliminates the need for any future handling. Klipspruit Colliery refers to this as "blast gain" and expresses it as a percentage of the total burden volume blasted.

Blasted burden dozing: Following a blast, the burden that has not been forced into the void has to be relocated manually. As is to be expected, however, the blasted burden is uneven and inaccessible. Large track-type dozers, each weighing over one hundred tons (Caterpillar, 2010), are used to smooth the surface of the blasted burden. In the process of levelling the blasted rock surface, the dozers push some burden into the void. Klipspruit Colliery refers to this as "dozer gain" and expresses it as a percentage of the total burden volume handled by the dozers. An example of a dozer used in this process can be seen in Figure 3.7.

Figure 3.7: Burden Dozer

Dragline Burden removal: The dragline is the key component in the burden removal process and costs between R350,000,000 and R700,000,000 (Winstanley et al., 1997). Klipspruit Colliery's dragline, shown in Figure 3.8, is over one hundred meters long and is, in essence, a massive excavator.

Figure 3.8: Klipspruit Colliery's Dragline

Once the blasted burden has been levelled and made accessible by the dozers, the dragline can safely operate on the burden surface. The dragline scoops up burden and drops it in the void, exposing coal as it advances. When working on the double bench, the dragline relocates both the blasted midburden and overburden into the void. Exposing coal by removing burden is the dragline's principle function.

Coal drilling, charging and blasting: Before the coal can be extracted, it needs to be drilled and blasted. ECM drills, shown in Figure 3.9, are used to bore cavities in the coal. As with the burden drilling operation, these cavities house the explosive charges. The exposed coal is hard and brittle and upon detonation of the explosives, a shockwave travels through the coal, shattering it. The coal may now be extracted with relative ease (S. Mabuza, Personal interview, 2011).

Figure 3.9: ECM Drill

Coal extraction: Klipspruit Colliery uses Caterpillar 993 front end loaders to shovel twenty two tons of the blasted coal, per bucket, into Caterpillar 777 mining trucks. Each mining truck is able to haul a maximum of ninety tons of coal per trip (Caterpillar, 2010). Figure 3.10 shows a front end loader tipping coal into a mining truck.

Figure 3.10: Coal Extraction Equipment

Once fully loaded, the mining trucks take the coal to the run-of-mine (ROM) stockpile. From the ROM stockpile, coal is continually fed into a series of crushers that prepare the coal to be processed by the Phola plant.

Parting drilling, charging and blasting: In the single bench, the 2 seam coal extraction exposes the parting that covers the 1 seam coal. Parting is an extremely durable material and needs to be blasted before it can be removed. ECMs, identical to those used to drill the coal, bore holes into the parting. These holes are filled with explosives which upon detonation pulverise the parting.

Parting extraction: In exactly the same way as the coal extraction process, a Caterpillar 993 front end loader shovels the blasted parting into mining trucks. As the dragline has already filled the void with overburden, parting needs to be hauled elsewhere. In response to this predicament, Klipspruit Colliery has found an innovative use for the extracted parting. Once extracted, the parting is sent through a crusher that creates pebbles, approximately one centimetre in diameter. The durability of the parting allows Klipspruit Colliery to scatter the pebbles over the mine's gravel roads to provide grip for the vehicles and increase the road's resilience (C. Coertze, Personal interview, 2011).

Examination of the entire mining system, reveals that every mining process is dependent on its predecessor; a delay in one process results in a delay for all subsequent processes. Coal extraction is an especially important process. Apart from providing the entire mine's source of income, coal extraction completes the mining process. When advancing to the next strip, burden blasting, and thus the entire chain of mining processes, has to wait for coal extraction to create a void. Without a void, the blasting of the burden in the subsequent strip will bury the coal. This situation, along with the other dependencies that exist throughout the mining process, highlights the need for a tool like the Klipspruit Colliery Simulation Model. A model that incorporates the inherent interdependence between the chain of processes is crucial for analysing the consequences of a decision on the overall system. Without such a model, Klipspruit Colliery's planning departments have to rely solely on practical experience and chance when choosing between solution alternatives.

3.2 Process Modelling

As previously discussed, a system dynamics modelling approach was used to create the Klipspruit Colliery Simulation Model. The two primary building blocks for a system dynamics model are stock variables, which represent process inventory quantities, and rate variables which represent the processing of the stocks. Consequently, when creating the simulation model the first step is to replicate the mining process using stocks and rates. Figure 3.11 shows the series of stocks and rates used to model Klipspruit Colliery's mining processes.

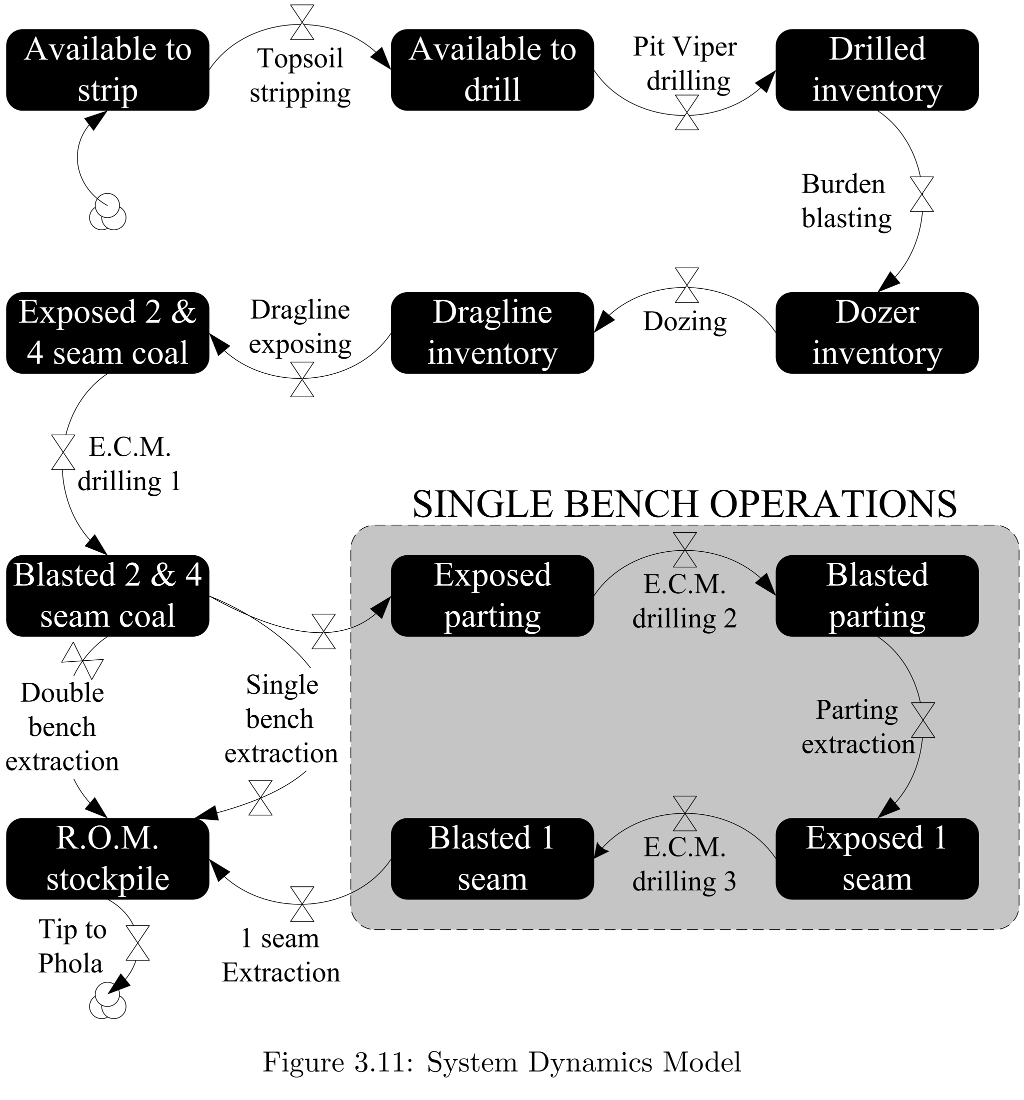


Figure 3.11: System Dynamics Model

Each stock in the model represents the distance between a pair of successive processes, expressed as inventory that still needs to be processed. For example, the Dragline inventory stock indicates how much blasted burden has been levelled by the dozers and is ready for the dragline to process. The actual amount of burden moved into the void, during a given time period, is determined by the Dragline exposing rate variable.

The stock and rate variables model creates the foundation upon which the rest of the model is built. This high level platform allows the modeller to incorporate functions and constraints into the model, creating a structure similar to a hierarchy. This "top-down" approach is used to increase the model's accuracy and functionality, one step at a time, until the desired level of detail is realised. Before any additional functions can be integrated, however, the stocks and rates need to be assigned initial values.

As previously mentioned, Klipspruit Colliery has a Microsoft Excel spreadsheet that details the geological characteristics of every block on the mine. If the starting positions of the processes are known, the initial process inventories can be calculated using values from this spreadsheet. The individual inventory calculations vary in complexity but share a common underlying rationale: the initial stock value is equal to the sum of every block's processing inventory, from the given starting position, up to (but not including) the next process' starting block. In order to do the necessary calculations, before the model is executed the user needs to input the relevant equipment starting positions. Using the given starting positions, the initial processing inventories are recalculated every time the model is initiated.

To test whether the model calculates the initial inventories correctly, the calculations were done manually in Microsoft Excel for three randomly generated starting positions. The Excel values are compared with those computed by the model to highlight areas for improvement. Any faulty calculations were corrected, the process repeated, and the results tabulated in Table 3.1 on the next page. As shown in the table, the verification process reduced the average difference from 70.76% to 0.21%. The primary cause of the initial inaccuracy was the complex double bench calculations.

The reliable calculation of initial inventories permits the incorporation of the processing rates. Given the available information, specifically the daily production reports generated by Klipspruit Colliery's central control room, the processing rate variables can be estimated using historical data. The required analysis is accomplished using a specially designed Microsoft Excel spreadsheet. As input to this spreadsheet, the user can insert the daily reports for the past year. Based on the data in the daily reports, the spreadsheet eliminates outliers before creating frequency distributions for each processing rate. The user may inspect these distributions and indicate if they appear to be approximately normally distributed.

INITIAL INVENTORY VERIFICATION						
			Before verification		After verification	
Process	Sample #	Excel Value	AL Value	% Difference	AL Value	% Difference
Available to strip	1	11 667 517.80	11 667 513.80	0.00%	11 667 513.80	0.00%
	2	995 577.54	995 573.54	0.00%	995 573.54	0.00%
	3	5 460 923.88	5 460 920.38	0.00%	5 460 920.38	0.00%
Available to drill	1	454 103.12	375 964.63	20.78%	453 318.63	0.17%
	2	2 719 424.66	1 064 131.68	155.55%	2 755 878.43	1.32%
	3	772 883.46	431 069.30	79.29%	787 304.81	1.83%
Drilled inventory	1	8 239.78	8 243.38	0.04%	8 243.38	0.04%
	2	41 871.48	41 874.63	0.01%	41 874.63	0.01%
	3	34 568.06	34 570.76	0.01%	34 570.76	0.01%
Dozer inventory	1	120 104.82	120 102.37	0.00%	120 102.37	0.00%
	2	14 643.20	14 640.05	0.02%	14 640.05	0.02%
	3	98 147.66	98 144.16	0.00%	98 144.16	0.00%
Dragline inventory	1	2 636 590.32	2 636 590.67	0.00%	2 636 590.67	0.00%
	2	13 307 846.43	6 621 617.31	100.98%	13 294 766.28	0.10%
	3	110 235 478.60	33 525 510.92	228.81%	110 670 055.63	0.39%
Exposed 2,4 seam	1	1 469 359.00	509 013.80	188.67%	1 469 042.80	0.02%
	2	3 284 013.00	1 074 148.10	205.73%	3 193 767.40	2.83%
	3	2 386 432.00	745 783.10	219.99%	2 382 998.70	0.14%
Blasted 2,4 seam	1	20 013 428.06	7 065 456.65	183.26%	19 997 346.18	0.08%
	2	2 739 434.31	1 756 097.39	56.00%	2 739 431.91	0.00%
	3	15 017 490.66	5 620 825.05	167.18%	15 005 989.94	0.08%
Exposed parting	1	774 856.00	2 160 771.40	64.14%	774 857.40	0.00%
	2	24 180.00	98 438.40	75.44%	24 181.60	0.01%
	3	1 345 020.00	3 288 502.20	59.10%	1 345 021.60	0.00%
Blasted parting	1	264 273.00	734 081.00	64.00%	264 272.13	0.00%
	2	112 426.00	298 642.13	62.35%	112 425.13	0.00%
	3	1 792 080.00	3 897 759.75	54.02%	1 792 079.13	0.00%
Exposed 1 seam	1	422 683.00	956 977.88	55.83%	422 683.88	0.00%
	2	422 683.00	921 978.00	54.15%	422 683.88	0.00%
	3	44 586.00	194 745.00	77.11%	44 586.88	0.00%
Blasted 1 seam	1	0.00	28 417.25	100.00%	0.00	0.00%
	2	11 721.83	14 481.80	19.06%	11 721.23	0.01%
	3	7 016 479.13	12 407 719.40	43.45%	7 016 478.53	0.00%
				70.76%		**0.21%**

Table 3.1: Initial Inventory Verification

When initiated, the Klipspruit Colliery Simulation Model reads in the process rate data from this spreadsheet. If the user has indicated that a process rate should be normally distributed, the simulation model will generate random processing rates based on the calculated mean and standard deviation. If the user has not indicated that the processing rate is normally distributed, however, only the mean will be used throughout the simulation.

Successfully assigning values to the stock and rate variables finalises the framework upon which the rest of the model is built. Before discussing the constraints included in the model, it is important to understand the assumptions made throughout the process modelling phase:

- When operating in the double bench, processes treat the adjacent blocks as one. The processing equipment can therefore, be modelled to travel along the 4 seam bench but process the inventory contained in both benches. For example, when the dragline enters the first block of double bench, it removes both the midburden and overburden before advancing to the next block.

- A "triple bench" cannot occur. In essence, this assumption states that the model will not allow the 4 seam, 2 seam, and 1 seam to overlap. If the model detects 4 seam coal in a block, a double bench will be formed and any 1 seam that may be present will be ignored.

- The burden blasting and ECM drilling processes have excess capacity. This assumption is primarily due to a lack of information about these processes. Klipspruit Colliery's mine manager (Roux, Personal interview, 2011) has confirmed that this assumption is valid. The model, therefore, uses default rates for these processes but allows the user to edit them, if necessary. The default rates have been set to advance each process half a block per day. This is faster than any other process on the mine, but is still realistic.

- There cannot be more than one 2 seam extraction point. This assumption limits the coal 2 seam coal extraction processes to only one block at a time. It therefore eliminates the possibility of extracting 2 seam coal in both the single and double bench simultaneously. In reality, two extraction points are possible. This is, however, an exception and not commonplace.

These assumptions may be addressed, if necessary, in the development of the full scale implementable model. They do not retract from the effectiveness of the proof of concept.

3.3 Constraints Modelling

The model has been equipped with the capability of calculating initial inventories, and the rates which process them. The next step is to control the progression of the processes throughout the mine.

When a process has finished processing the inventory in a particular block, it needs to advance to the next block. When this happens, the model needs to add the completed block to the subsequent process' inventory. The source of each block's processing inventory is the geological spreadsheet. It is therefore logical to link the progression of process equipment to the geological spreadsheet. This can be accomplished by re-ordering the contents of the geological spreadsheet, to reflect the desired processing route. The processes can then be modelled to advance through the new, rearranged spreadsheet.

There are over two thousand mining blocks at Klipspruit Colliery. To order the spreadsheet one requires an algorithm that can systematically dictate the desired processing path through the mine. The processes start, for each strip, on the border between the single and double bench. The processes complete the single bench before returning to process the double bench. Once the double bench has been completed, the processes advance to the next strip's single bench. The critical consideration in determining the processing route is establishing the border between the benches. After consulting Klipspruit Colliery's Integrated Planning Manager, C. Hulley (Personal interview, 2011), it was discovered that the double bench stops as soon as the 4 seam coal vein becomes less than one meter thick. A single bench is formed across the remainder of the strip. An ordering program, written in Java, restructured the geological spreadsheet accordingly.

The modelled processes are linked to this sorted geological spreadsheet. As soon as a process exhausts a block's inventory, it advances to the next block in the spreadsheet. The model detects this progression and increases the succeeding process' inventory with the inventory contained in the completed block.

To verify the process progression functionality of the model, the inventory to be added to the subsequent process was calculated manually in Microsoft Excel. This calculation was done for three successive block progressions, from a randomly generated starting position. The Excel values were compared with those computed by the model to highlight areas for improvement. Minor calculation adjustments were made, the process repeated and the results tabulated in Table 3.2 on the next page. As shown in the table, the verification process reduced the average difference from 10.44% to 0.00%.

PROCESS PROGRESSION VERIFICATION

					Before verification		After verification	
Process	**#**	**Strip**	**Block**	**Excel Value**	**AL Value**	**% Difference**	**AL Value**	**% Difference**
Topsoil stripping	1	50	20	2 495.13	2 495.13	0.00%	2 495.13	0.00%
	2			2 425.53	2 425.53	0.00%	2 425.53	0.00%
	3			2 124.64	2 124.64	0.00%	2 124.64	0.00%
Pit Viper drilling	1	32	5	100.00	100.00	0.00%	100.00	0.00%
	2			100.00	100.00	0.00%	100.00	0.00%
	3			100.00	100.00	0.00%	100.00	0.00%
Burden blasting	1	61	17	36 039.84	133 862.28	73.08%	36 039.84	0.00%
	2			23 608.18	121 116.10	80.51%	23 608.18	0.00%
	3			29 765.64	110 558.10	73.08%	29 765.64	0.00%
Dozing	1	54	19	130 117.00	130 117.00	0.00%	130 117.00	0.00%
	2			129 026.48	129 026.48	0.00%	129 026.48	0.00%
	3			127 993.34	127 993.35	0.00%	127 993.34	0.00%
Dragline exposing	1	15	1	3 397.00	3 397.00	0.00%	3 397.00	0.00%
	2			4 489.00	4 489.00	0.00%	4 489.00	0.00%
	3			4 489.00	4 489.00	0.00%	4 489.00	0.00%
ECM drilling (1)	1	55	3	50 864.50	50 235.26	1.25%	50 864.50	0.00%
	2			15 258.29	15 617.60	2.30%	15 258.29	0.00%
	3			35 632.76	35 632.76	0.00%	35 632.76	0.00%
2,4 seam extraction	1	42	9	0.00	0.00	0.00%	0.00	0.00%
	2			0.00	0.00	0.00%	0.00	0.00%
	3			0.00	0.00	0.00%	0.00	0.00%
ECM drilling (2)	1	27	27	4 000.44	3 922.00	2.00%	4 000.44	0.00%
	2			1 433.10	3 922.00	63.46%	1 433.10	0.00%
	3			5 835.42	3 922.00	48.79%	5 835.42	0.00%
Parting extraction	1	37	20	5 000.00	5 000.00	0.00%	5 000.00	0.00%
	2			5 000.00	5 000.00	0.00%	5 000.00	0.00%
	3			5 000.00	5 000.00	0.00%	5 000.00	0.00%
ECM drilling(3)	1	62	5	0.00	0.00	0.00%	0.00	0.00%
	2			0.00	0.00	0.00%	0.00	0.00%
	3			0.00	0.00	0.00%	0.00	0.00%
1 seam extraction	1	26	11	N/A	N/A	0.00%	N/A	0.00%
	2			N/A	N/A	0.00%	N/A	0.00%
	3			N/A	N/A	0.00%	N/A	0.00%
						10.44%		**0.00%**

Table 3.2: Process Progression Verification

In addition to guiding the processes through the mine, the model also needs to control the various progression restrictions. The easiest way to accomplish this is to monitor each process through continual testing of a variety of stopping conditions. If any of these conditions are met, the process should cease all operations. Only when none of the stopping conditions are met, is the process allowed to continue processing its inventory. The model continually tests five major stopping conditions:

Geographic limits: The most elementary stopping condition discontinues a process when it reaches the end of the mine. If a process attempts to progress to a block that does not exist, the model deactivates that process, permanently.

Insufficient inventory: This activity-prohibiting constraint monitors each process' available inventory. As a process draws nearer to the subsequent one, its available inventory approaches zero. A processing inventory equal to zero indicates that the process is ready to advance to the next block, but is impeded by the presence of the subsequent process' equipment. The process therefore needs to stop and wait until the block is unoccupied. To implement this constraint, the model discontinues a process' activities whenever it has less than two hours of inventory remaining. The moment the preceding process' equipment advances to the next block, processing may continue.

Blasting restrictions: For safety reasons, none of the processes are allowed within five hundred meters of a blast. It is assumed, however, that the dozers and Pit Vipers can be evacuated prior to a blast and are therefore allowed to operate within two hundred and fifty meters of the burden blasting process. The only processing equipment that needs to be monitored in terms of the blasting restrictions are the Pit Vipers, Dozers and the Dragline. If these processes adhere to the blast radius restrictions, none of the other processes will be in danger. The moment one of these processes enters the blasting radius, the model forces the process to wait until the burden blasting advances to the next block. An additional blasting restriction is concerned with preventing any burden from being blasted until the void has been created. Consequently, the model continually monitors the block adjacent to the burden charging process and prevents all blasting activities until the lowest coal seam has been extracted.

Single bench constrained processes: This stopping condition is only applicable to the parting drilling, parting extraction, 1 seam drilling and 1 seam extraction processes. These processes are all restricted to a single bench. When they reach the end of a strip, they need to wait for the next strip's single bench to be initiated before continuing. The only process that needs to be constrained, however, is the parting drilling operation. If the parting drilling operation cannot proceed, neither can any of the subsequent processes. When the parting drilling operation has completed the last block in a strip, the model checks the first block in the next strip's single bench and determines whether or not the 2 seam has been extracted. If the parting is exposed, the model allows the process to advance. If the 2 seam is still present, however, the process must wait. As soon as the 2 seam extraction process has removed the coal, the parting drilling operation is allowed to proceed.

Multiple 2 seam extraction points: The final process progression restriction is used to control the 2 seam extraction processes. In the model, there are two separate 2 seam extraction processing rates; one for the single bench and one for the double bench. The distinction between the two benches indicates whether the extracted coal is purely 2 seam or has 4 seam coal included. With the assumption that only one 2 seam coal extraction point is allowed, both of these rates cannot operate simultaneously. When the 2 seam coal face advances to a new block, the model determines whether the block is in the single or double bench. According to the new block's bench, the model activates the appropriate 2 seam extraction process and disenables the other.

These constraints embody the interdependencies that exist between the processes, and finalise the model's imitation of Klipspruit Colliery. The auxiliary functions discussed in the next section do not directly contribute to the modelling of Klipspruit Colliery. The purpose of the auxiliary functions is to enhance the user's control over the model's input and improve the resultant analysis capabilities.

3.4 Auxiliary Functions

There are essentially only two opportunities for the user to influence the input into the model. The first is before running the simulation model. Any input defined prior to initialising the simulation will be fixed and unchangeable throughout its execution. These pre-simulation user inputs represent the operating conditions for the model. The second opportunity to control the input is during the simulation. These inputs, signifying the process performance parameters, have a dynamic influence on the model and therefore require constant monitoring. In addition to inputting information, simulation data needs to be recorded and reported. The presentation of the simulation's results forms the final auxiliary function. Each of the auxiliary functions included in the model will now be discussed.

Pre-simulation functions: In terms of the pre-simulation inputs, the user may define: each process' starting strip and block; the ECM drilling, burden blasting and burden dozing processing rates; the Pit Viper, dozer and dragline blasting radii; the average number of overburden and midburden holes to be drilled per block; the average Pit Viper re-drilling percentage; the planned dragline re-handling percentage; the parting and burden swell factors; the expected blast and dozer gain percentages; the initial ROM stockpile level; the desired simulation length; and the normal distribution sampling rate. Most of these variables have been discussed throughout the report. Those that have not been previously mentioned, will be briefly explained.

The Pit Viper re-drilling and the dragline re-handling percentages represent the amount of inventory that normally has to be reworked. The model uses this percentage to increases the total inventory to be processed by the burden drilling and dragline exposing processes. The parting and burden swell factors quantify the expected expansion of material following a blast. All the processes that handle blasted material have their inventories multiplied by this factor. The desired simulation length, expressed in days, controls the duration of the simulation. Once the allotted time has elapsed, the simulation is terminated. The normal distribution sampling rate defines the frequency with which new processing rates should be generated. The default sampling rate is set to be consistent with the daily reports and generate a new processing rate for each day.

To simplify the use of the model and eliminate tedious re-entry of variable values, the model has been equipped with functionality to save the user's preferences. The model also gives the user the option to load predefined, default values. These default values provide a realistic reference point for defining new values.

In simulation functions: To control the process performance parameters throughout the simulation's execution, the model allows the user to manipulate the processing rates. Before the simulation begins, the user needs to specify which processes are to be controlled. The model overrides the relevant process rate values, read in from the daily report analysis spreadsheet, and allows the user to change the rates as required. The user is given the option of adjusting both the processing mean and standard deviation. If the user wants to specify a particular value, a standard deviation of zero will tell the model to use the mean as the processing rate.

Post-simulation functions: The final auxiliary function aids the user when interpreting the simulation's results and is the core of the model's output. The model records each process' processing rate, available inventory and utilisation. When plotted against time, the processing rates and inventories provide a useful, graphical summary of each process' performance throughout the experiment. The utilisation of equipment, especially the dragline, is a good indication of the overall performance of the system. For example, if the Pit Vipers have a high utilisation and are succeeded by a string of poorly utilised processes, this indicates that burden drilling is causing a delay throughout the system and needs to be addressed. Additionally, a fundamental consideration when interpreting a simulation's results is the the compliment of the dragline's utilisation, the idle time. When choosing between alternative solutions, the dragline's idle time coupled with the total amount of coal extracted, are the primary concerns for Klipspruit Colliery.

Incorporation of the abovementioned auxiliary functions, into the already established model, finalises the construction of the Klipspruit Colliery Simulation Model. The combination of the process model, the mining constraints and the auxiliary functions, delivers the fundamental requirement of this project: a model that can imitate the interdependencies that exist between the high level mining processes, allow the user to adjust key process performance parameters, and interpret the effects of these changes on the entire mining process.

Chapter 4

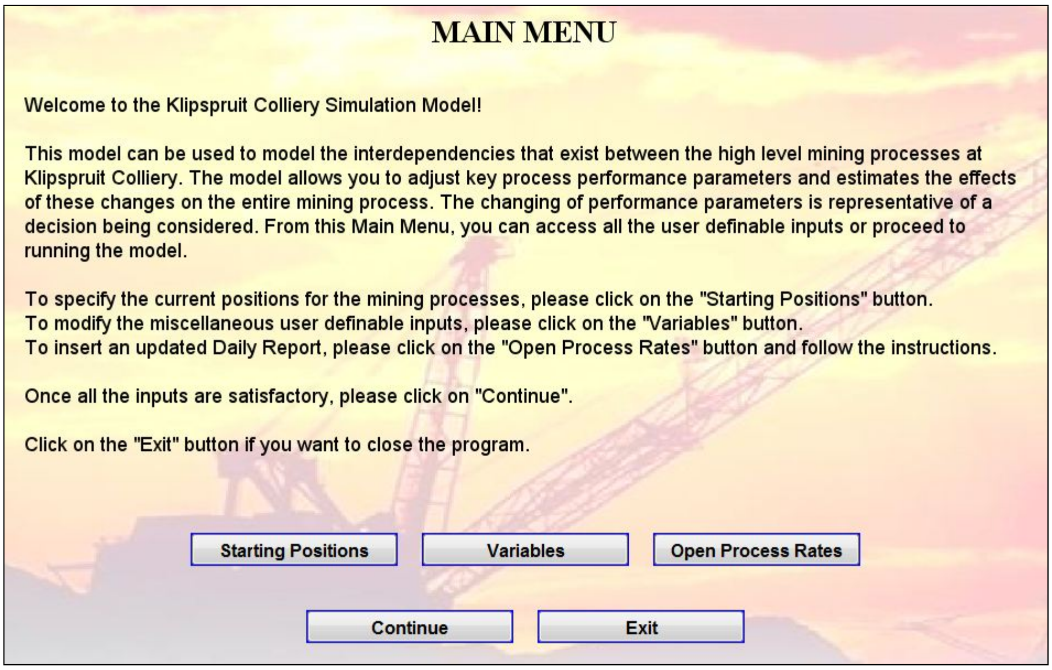
Using the Model

Thus far, the functionality required by and incorporated into the Klipspruit Colliery Simulation Model has been the primary focal point of this report. The rest of the report, however, is directed towards illustrating the value of the model. The value will be demonstrated by evaluating the model's usefulness to the planning department when considering decision alternatives, and furthermore, its ability to adequately imitate Klipspruit Colliery's mining processes. Before demonstrating the value however, it is necessary to understand how the user interacts with the model. This chapter starts with an overview of the model's user interface, followed by a comparison of the model's output to historical data. An example of how the model can be used to analyse decision alternatives will be addressed in chapter 5 before final remarks are made to conclude the project.

4.1 User Interface

According to Mandel (2002), the interface is the only way for a user to communicate with a computer program. Consequently, it is essential to design a user interface that facilitates the collection of all the user definable inputs, and displays all of the necessary output, in an easy to understand and user-friendly layout. To accomplish this, the program needs to be divided into smaller, independent subgroups. The program can then present the user with a centralised menu, that allows him to choose which subgroup to interact with.

In accordance with Mandel's suggestions, when initiated, the Klipspruit Colliery Simulation Model presents the user with the Main Menu window shown in Figure 4.1. The buttons in this menu allow the user to access all of the model's user definable input subgroups, namely the Starting Positions, Variables and Process Rates. Clicking on the Starting Positions button opens a new window in which the user can specify the starting strip and block for each process. The Variables button directs the user to a window containing the miscellaneous simulation inputs. The Open Process Rates button opens the Microsoft Excel spreadsheet that analyses the daily reports and establishes suggested daily processing rates.



MAIN MENU

Welcome to the Klipspruit Colliery Simulation Model!

This model can be used to model the interdependencies that exist between the high level mining processes at Klipspruit Colliery. The model allows you to adjust key process performance parameters and estimates the effects of these changes on the entire mining process. The changing of performance parameters is representative of a decision being considered. From this Main Menu, you can access all the user definable inputs or proceed to running the model.

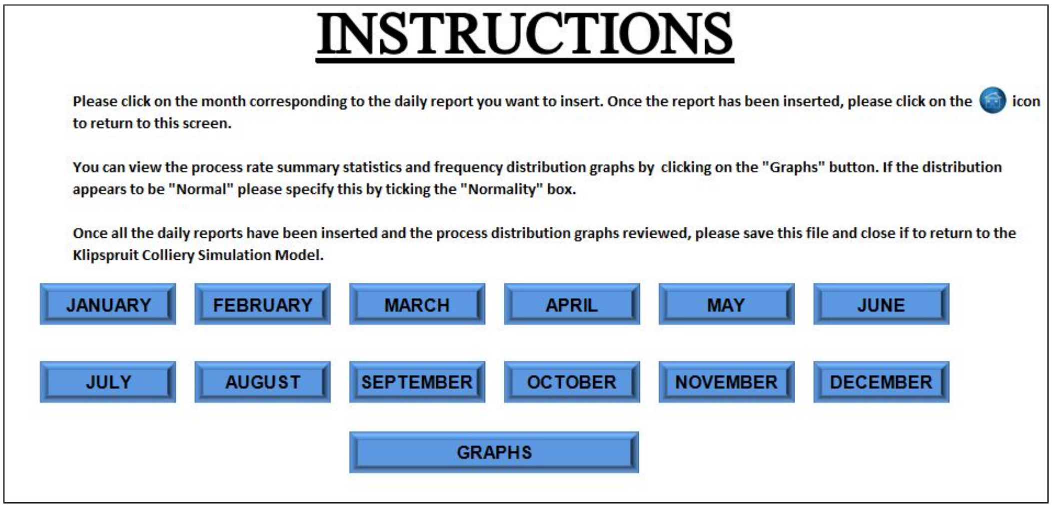
To specify the current positions for the mining processes, please click on the "Starting Positions" button.
To modify the miscellaneous user definable inputs, please click on the "Variables" button.
To insert an updated Daily Report, please click on the "Open Process Rates" button and follow the instructions.

Once all the inputs are satisfactory, please click on "Continue".

Click on the "Exit" button if you want to close the program.

Figure 4.1: Main Menu Window

The analysis spreadsheet once again provides the user with a central menu with links to all the relevant information (Figure 4.2). To insert a specific month's daily report data, the user must click on the corresponding month's button and paste the report in the specified location. Once the user has finished inserting all the necessary reports, or if no new data is available, the user can click on the Graphs button to view the frequency distribution of each process' daily rate.



INSTRUCTIONS

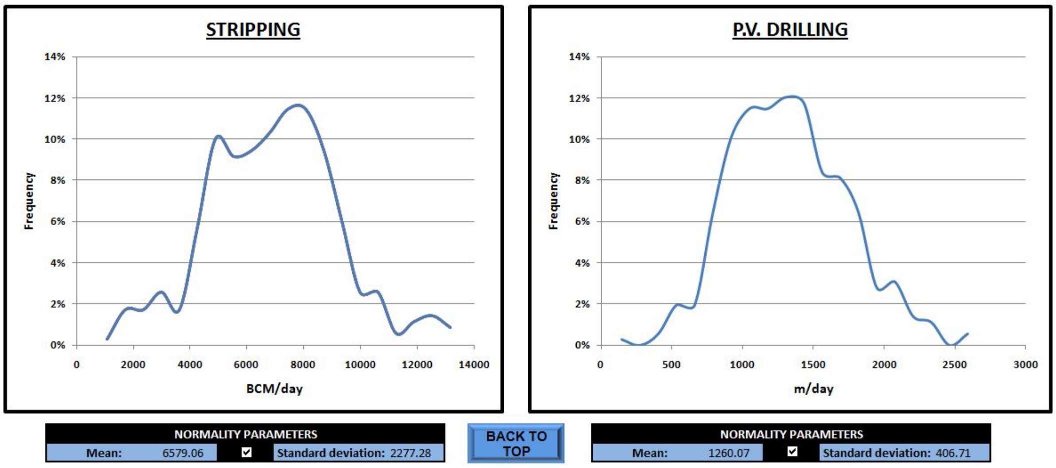
Please click on the month corresponding to the daily report you want to insert. Once the report has been inserted, please click on the icon to return to this screen.

You can view the process rate summary statistics and frequency distribution graphs by clicking on the "Graphs" button. If the distribution appears to be "Normal" please specify this by ticking the "Normality" box.

Once all the daily reports have been inserted and the process distribution graphs reviewed, please save this file and close if to return to the Klipspruit Colliery Simulation Model.

Figure 4.2: Process Rates Spreadsheet

As shown in Figure 4.3, the user is presented with a frequency distribution graph, the mean and standard deviation of the distribution, and a tick-box to indicate if the graph appears to be normally distributed. The Klipspruit Colliery Simulation Model extracts the relevant information from this spreadsheet and model's the processes to match the specified behaviour.

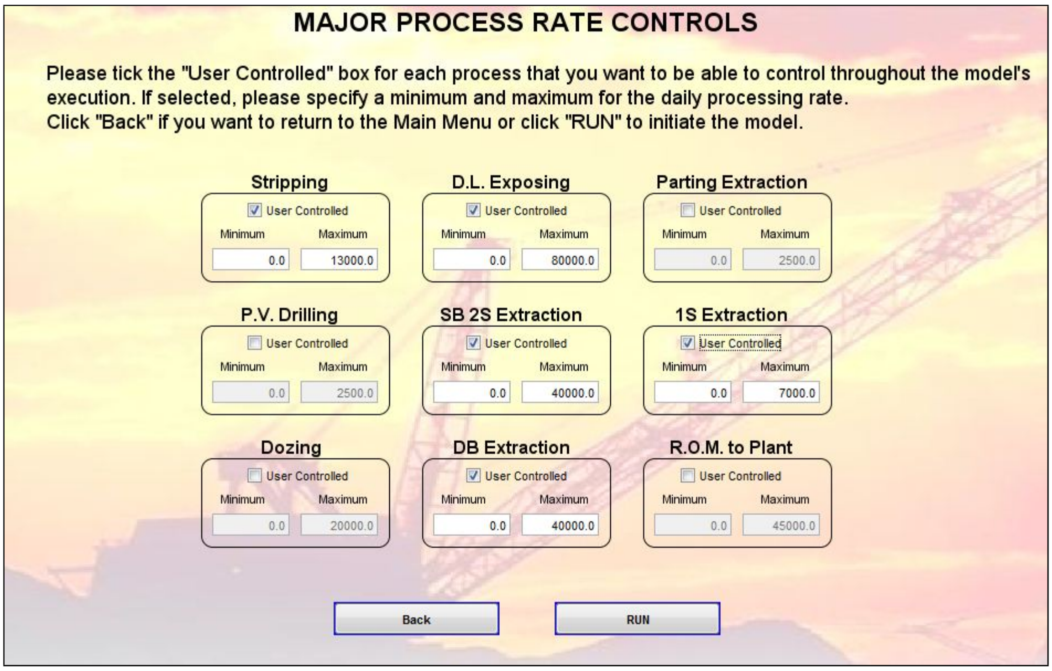


NORMALITY PARAMETERS
Mean: 6579.06 ☑ Standard deviation: 2277.28

NORMALITY PARAMETERS
Mean: 1260.07 ☑ Standard deviation: 406.71

Figure 4.3: Frequency Distribution Graphs

When satisfied with the process rates, the user can save any changes and close the spreadsheet to return to the simulation model's Main Menu. After reviewing and adjusting all the relevant user definable input, the user may click on Continue to proceed to the Process Control window, shown in Figure 4.4.



MAJOR PROCESS RATE CONTROLS

Please tick the "User Controlled" box for each process that you want to be able to control throughout the model's execution. If selected, please specify a minimum and maximum for the daily processing rate.
Click "Back" if you want to return to the Main Menu or click "RUN" to initiate the model.

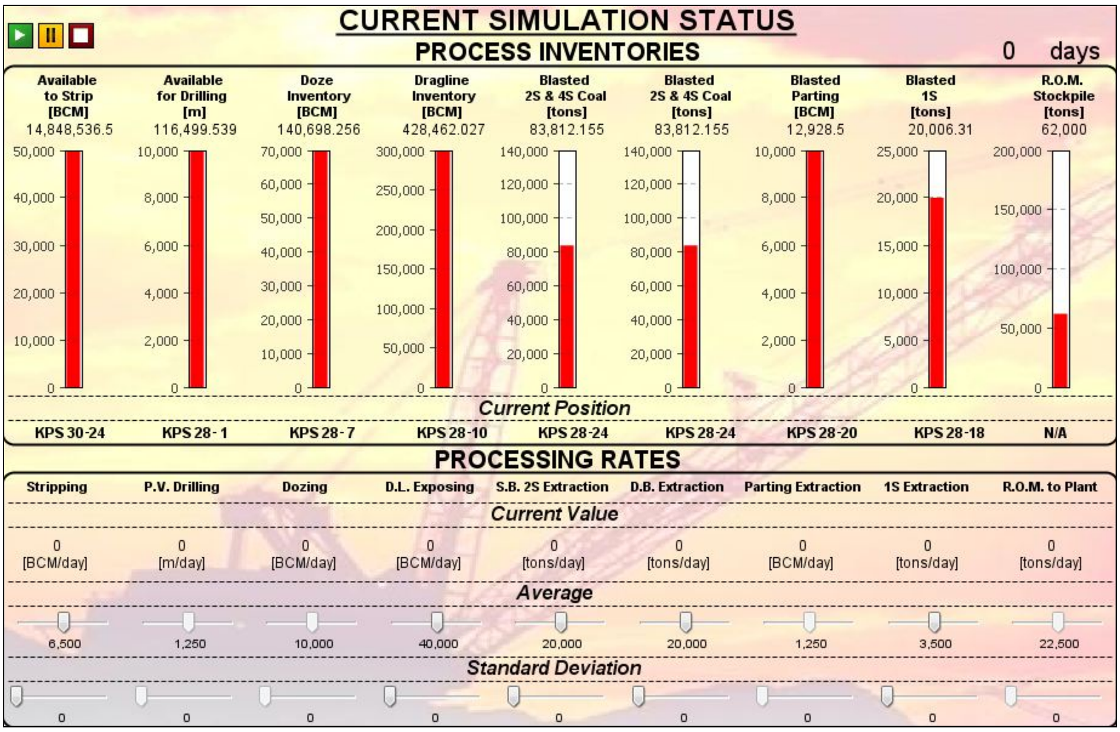
Process	User Controlled	Minimum	Maximum
Stripping	☑	0.0	13000.0
D.L. Exposing	☑	0.0	80000.0
Parting Extraction	☐	0.0	2500.0
P.V. Drilling	☐	0.0	2500.0
SB 2S Extraction	☑	0.0	40000.0
1S Extraction	☑	0.0	7000.0
Dozing	☐	0.0	20000.0
DB Extraction	☑	0.0	40000.0
R.O.M. to Plant	☐	0.0	45000.0

Figure 4.4: Process Control Window

In this window, the user can specify which processes should be controllable during the simulation. The user should take into account the decision under consideration when choosing which processes to control. If the user ticks a process' User Controlled tick-box, he is allowed to specify the minimum and maximum allowable processing rate. If the user does not want to control a process, the model will use the data in the daily report analysis spreadsheet to assign a processing rate. The user may click on Run when he is ready to start the simulation.

Upon initiation, the Current Simulation Status window appears. This window, shown in Figure 4.5, summarises all the relevant information to track the progress of the simulation. The current simulation time is displayed in the top right corner of the screen with the simulation controls situated at the top left. The simulation is initially paused to allow the user to examine the starting simulation scenario before proceeding. The two main areas of interest during a simulation are the processing inventories and the processing rates.

Each process inventory is represented by a bar chart. The height of each bar is set as the amount of inventory that can be processed in one week. In this way, the user can easily notice when a process inventory is nearing its end or if there are excessive quantities to be processed. The exact inventory value is displayed above each bar, with the current position of the process presented below the bar.



Available to Strip [BCM]	Available for Drilling [m]	Doze Inventory [BCM]	Dragline Inventory [BCM]	Blasted 2S & 4S Coal [tons]	Blasted 2S & 4S Coal [tons]	Blasted Parting [BCM]	Blasted 1S [tons]	R.O.M. Stockpile [tons]
14,848,536.5	116,499.539	140,698.256	428,462.027	83,812.155	83,812.155	12,928.5	20,006.31	62,000
Current Position								
KPS 30-24	KPS 28-1	KPS 28-7	KPS 28-10	KPS 28-24	KPS 28-24	KPS 28-20	KPS 28-18	N/A

Stripping	P.V. Drilling	Dozing	D.L. Exposing	S.B. 2S Extraction	D.B. Extraction	Parting Extraction	1S Extraction	R.O.M. to Plant
Current Value								
0 [BCM/day]	0 [m/day]	0 [BCM/day]	0 [BCM/day]	0 [tons/day]	0 [tons/day]	0 [BCM/day]	0 [tons/day]	0 [tons/day]
Average								
6,500	1,250	10,000	40,000	20,000	20,000	1,250	3,500	22,500
Standard Deviation								
0	0	0	0	0	0	0	0	0

Figure 4.5: Current Simulation Status Window

The current value of each processing rate is displayed above a pair of slider bars, one for the average and one for the standard deviation. The slider bars can be used to adjust the processing rate throughout the simulation and are only enabled for the processes specified in the Process Control window.

When all rate modifications are complete, the user can click on the green play button to start the simulation. As the simulation runs, the user can view the progress and make any adjustments to the rates as necessary. Once the specified simulation time has elapsed, the model prompts the user if a summary report should be generated. If the user declines, the simulation terminates and returns to the Main Menu. Alternatively, a summary report is compiled and presented in a Microsoft Excel spreadsheet.

The summary report presents a set of performance characteristics for each individual process, and an overview of the overall system. Amongst other information, the report graphs each process' average utilisation, processing rate and inventory throughout the simulation. An example of the dragline's performance summary is shown in Figure 4.6. The collection of information contained in the summary report forms the basis for comparing decision alternatives. Once all the decisions have been simulated, the planning department can compare the results in the summary reports to choose the most desirable alternative.

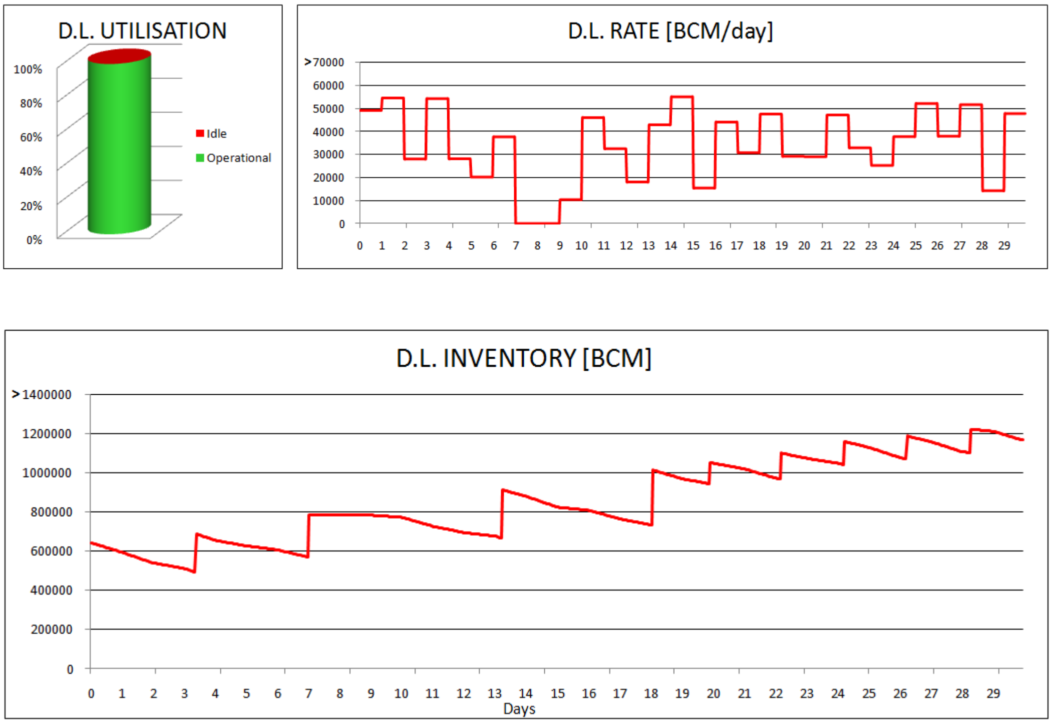


Figure 4.6: Dragline Performance Summary

4.2 Output Comparison

Before using the model to evaluate decision alternatives, it is understandable to question the reliability of the model. If the model is unable to consistently imitate reality, analysing decisions in the unreliable environment would be irrational. To test the model's reliability, the output generated by the model is compared with historical information. This comparison is done for two historical scenarios. The first experiment tests the model's accuracy under "normal" conditions with the second experiment focusing on the model's ability to accurately imitate extraordinary circumstances. In both experiments, the model's inputs are modified to represent a realistic setting. The experiments are executed repeatedly to test the model's consistency and the resultant output compared to the actual results.

For the first experiment, the production results for October 2010, a relatively ordinary month at Klipspruit Colliery, are used as the reference point. These production results are compared to the output generated by the model when only the default values are used as input. The comparison results are tabulated in Table 4.1.

DESIRED OUTPUT

Stripped	Drilled	Dozed	D.L. Handled	2S4S	Parting	1S	Tipped
191 666	38 836	409 905	1 158 203	553 764	12 635	110589.00	763 444

MODEL OUTPUT

#	Stripped	Drilled	Dozed	D.L. Handled	2S4S	Parting	1S	Tipped
1	214028.36	37804.02	436876.99	1098834.64	519009.41	14467.36	101701.23	673352.27
2	206273.22	34973.87	406702.85	1194005.87	537452.28	14467.36	101701.23	673352.27
3	202246.22	37908.92	436876.99	1139536.68	537452.28	14467.36	101701.23	673352.27
4	198633.20	39244.01	451964.06	1105019.64	519009.41	14467.36	101701.23	673352.27
5	194910.01	35200.39	421789.92	1261097.31	537452.28	14467.36	101701.23	673352.27
6	199705.85	34053.68	421789.92	1105681.70	519009.41	14467.36	101701.23	673352.27
7	200163.90	41376.92	451964.06	1136990.22	537452.28	14467.36	101701.23	673352.27
8	195795.75	38918.36	421789.92	1235520.69	537452.28	14467.36	101701.23	673352.27
9	214091.77	38150.75	436876.99	1185977.75	537452.28	14467.36	101701.23	673352.27
10	198683.33	39656.49	451964.06	1089149.02	501009.16	14467.36	101701.23	673352.27
Av.	**202453.16**	**37728.74**	**433859.58**	**1155181.35**	**528275.11**	**14467.36**	**101701.23**	**673352.27**

DIFFERENCE

Stripped	Drilled	Dozed	D.L. Handled	2S4S	Parting	1S	Tipped
-5.63%	2.85%	-5.84%	0.26%	4.60%	-14.50%	8.04%	11.80%

Table 4.1: A Normal Month's Output Comparison

With the exception of the Parting and Tipped values, the model's imitation of reality appears to be acceptable. For the Parting and Tipped values, there is a possible explanation for the calculated differences. At Klipspruit Colliey, the front end loaders and haul trucks used in the coal and parting extraction operations are practically identical to those used at the R.O.M. stockpile. Therefore, if one of the extraction crews are idle for any given reason, it is possible to use that crew to load coal from the stockpiles. This hypothesis is supported by October 2010's production results: the parting value is less than predicted with an increase in the amount of coal tipped from the R.O.M. stockpile. Even if this was not the case, the average difference between reality and the model's output is an acceptable 6.69%.

To evaluate the consistency of the model's output, consider the volume handled by the dragline in each of the experiment's replications (Figure 4.7). The standard deviation over the ten replications is 4.40% of the average value and there is a maximum difference from the average of 7.57%, in replication five. These consistency results combined with the output comparison in Table 4.1, shows that the model is consistently reliable when imitating an ordinary month.

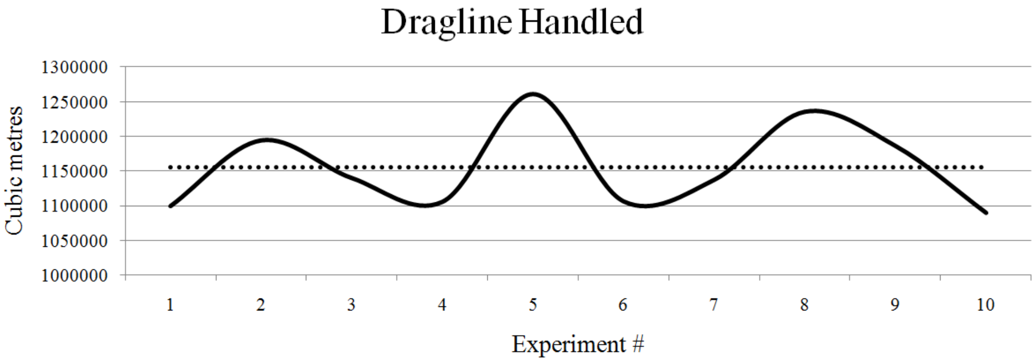


Figure 4.7: Dragline Handled Variation

For the second experiment, the production results from December 2010 are used as a reference point. December 2010 was an extraordinary month for Klipspruit Colliery. The mine experienced 249mm of rain during the third week of December. This was very unexpected considering the average *annual* rainfall in the area is approximately 533mm (SA Explorer, 2011). This excessive rainfall flooded a large section of the mine, inhibiting burden drilling and coal extraction operations. The coal extraction crews were idle during the flooding and were thus instructed to load coal from the interim stockpiles and transport it to the R.O.M. stockpile. Modelling these delays in production requires adjustment of the processing rates and extensive use of the model's functionality.

To model the December 2010 scenario, the starting positions of the equipment are set to match those at the start of the month. The majority of the processes were situated in the double bench and there was no parting or 1 seam available. The miscellaneous variables were adjusted as necessary and the simulation run for one month. On each day that heavy rain was experienced, the drilling and coal extraction rate was decreased proportionally, with an increase in the R.O.M. tipping rate. This experiment was repeated ten times and the results tabulated in Table 4.2.

As expected, there is no 1 seam or parting extraction throughout the month. The stripping, drilling, dragline and coal extraction activities also appear to be acceptably accurate. The dozing and R.O.M. tipping, however, vary by more than fifteen percent from the expected value. The dozing rate is considered a miscel-

DESIRED OUTPUT

Stripped	Drilled	Dozed	D.L. Handled	2S4S	Parting	1S	Tipped
209092.00	26906.00	514143.00	1270711.00	89933.00	0.00	0.00	788183.00

MODEL OUTPUT

#	Stripped	Drilled	Dozed	D.L. Handled	2S4S	Parting	1S	Tipped
1	205002.85	26988.30	425703.50	1199051.19	115118.40	0.00	0.00	628442.66
2	211141.09	26907.30	425703.50	1177552.01	103126.90	0.00	0.00	606526.77
3	179139.63	26546.97	425703.50	1262629.99	95932.00	0.00	0.00	651436.38
4	208143.28	27747.65	425703.50	1157174.86	93318.32	0.00	0.00	647437.38
5	179145.33	26942.27	425703.50	1306891.14	95479.34	0.00	0.00	662438.60
6	200066.20	26640.70	425703.50	1179031.49	96218.03	0.00	0.00	651436.38
7	205428.79	26840.50	425703.50	1250103.46	91807.70	0.00	0.00	702596.53
8	202196.55	27209.02	425703.50	1139923.23	89759.05	0.00	0.00	651436.38
9	194429.20	27857.96	425703.50	1217227.11	95759.73	0.00	0.00	661236.32
10	178687.41	26843.55	425703.50	1258719.58	94607.04	0.00	0.00	712425.89
Av.	**196338.03**	**27052.42**	**425703.50**	**1214830.41**	**97112.65**	**0.00**	**0.00**	**657541.33**

DIFFERENCE

Stripped	Drilled	Dozed	D.L. Handled	2S4S	Parting	1S	Tipped
6.10%	-0.54%	17.20%	4.40%	-7.98%	0.00%	0.00%	16.58%

Table 4.2: An Extraordinary Month's Output Comparison

laneous variable due to the lack of reliable historical information from which to establish a processing rate. The default value is clearly lower than what was experienced in December 2010. If the dozers are performing better than expected at any given time, however, the rate can be easily adjusted.

The tipping rate, on the other hand, is established from the historical data in the daily reports. The deviation can be explained due to the presence of surplus coal in the stockpiles. Towards the end of 2010, Klipspruit Colliery was extracting coal from a small pit known as Mini Pit 3. This mini-pit was not incorporated into the geological model that determines the process progression path. In the simulation, therefore, the coal contained in this area was not accounted for and resulted in a lower than actual R.O.M. stockpile volume.

Despite the two noticeable deviations, this experiment has an average absolute difference of 6.60%, almost identical to the difference calculated in the first experiment. It may therefore be concluded that, even in extraordinary circumstances, the Klipspruit Colliery Simulation Model is reliable in its imitation of reality. The model is therefore ready to prove its usefulness in helping the planning department consider decision alternatives.

Chapter 5

Conclusion

The aim of this project has been to develop a model that can imitate the interdependencies that exist between the high level mining processes, allow the user to adjust key process performance parameters and interpret the effects of these changes on the entire mining process. As illustrated in chapter 3 and chapter 4, the Klipspruit Colliery Simulation Model satisfies each of these requirements. This chapter finalises the proof of concept with a demonstration of the model's ability to aid the planning department in decision making.

To illustrate how the Klipspruit Colliery Simulation Model can be used to evaluate decision alternatives, consider the hypothetical situation of a machine breaking down. Suppose the Caterpillar 993 front end loader, used in the parting extraction operation, malfunctions and will only be operational after two weeks of repairs. For demonstration purposes, suppose there are only three viable decisions to be considered:

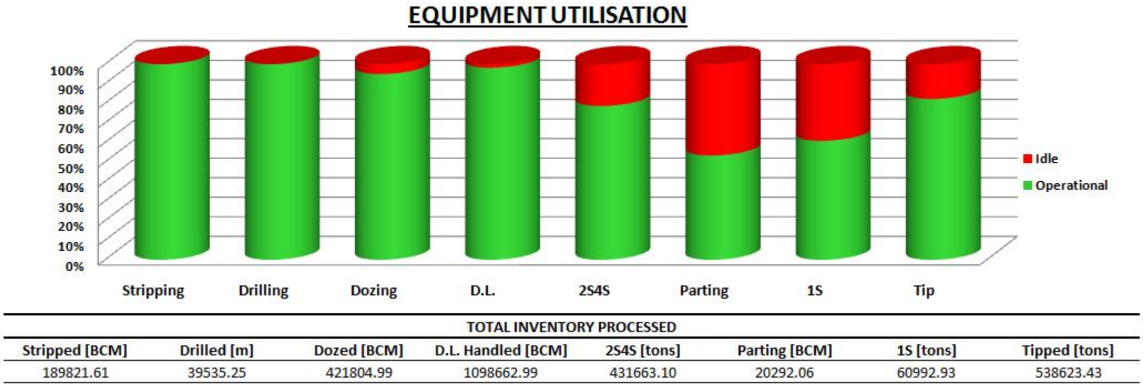
1. **Do nothing:** Wait for the loader to be repaired before resuming parting extraction. This decision is simulated by setting the parting extraction rate to zero for the first fourteen days before returning is to the average for the remainder of the time.

2. **Use the 2 seam extraction loader:** Stop the 2 seam coal extraction process for two weeks and allow parting extraction to continue as usual. This decision is modelled by setting the 2 seam extraction rate to zero for the first fourteen days, before returning it to the average for the remainder of the time. The parting extraction rate remains the average throughout the simulation.

3. **Use the 1 seam extraction loader:** Stop all 1 seam coal extraction for two weeks and allow the parting extraction to continue as usual. This decision is modelled by setting the 1 seam extraction rate to zero for the first fourteen

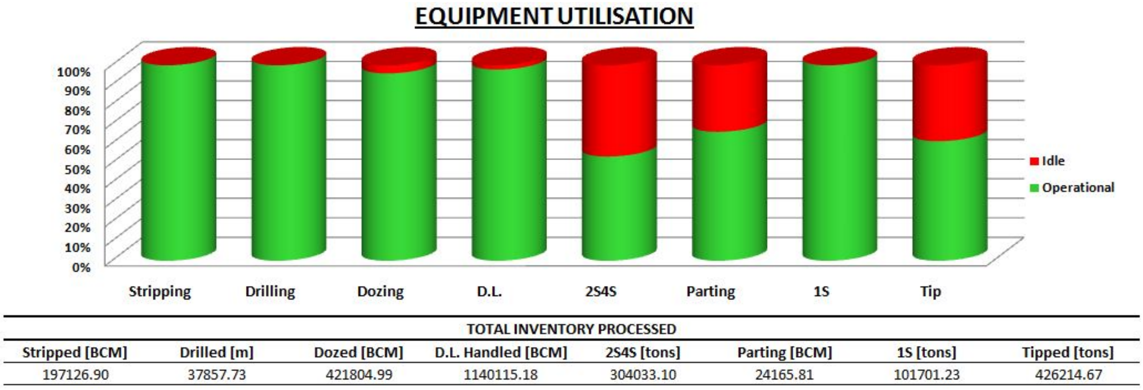
days before returning it to the average for the remainder of the time. The parting extraction rate remains unaffected throughout the simulation.

The same arbitrary starting positions, miscellaneous variable values and historical data are used for all three alternatives. The simulations are conducted for a period of one month to show the impact over a comprehensive interval. An extract from each alternative's resulting summary report is shown in Figures 5(a), 5(b) and 5(c) respectively.



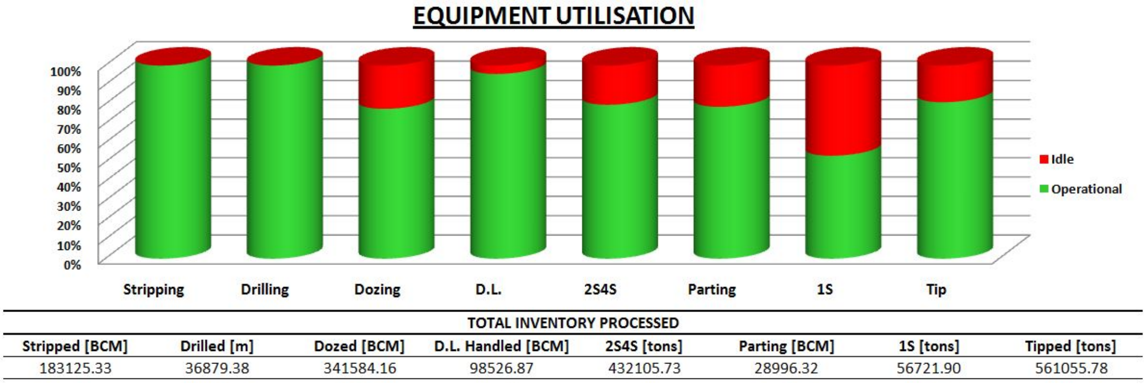
TOTAL INVENTORY PROCESSED							
Stripped [BCM]	Drilled [m]	Dozed [BCM]	D.L. Handled [BCM]	2S4S [tons]	Parting [BCM]	1S [tons]	Tipped [tons]
189821.61	39535.25	421804.99	1098662.99	431663.10	20292.06	60992.93	538623.43

(a) Do Nothing



TOTAL INVENTORY PROCESSED							
Stripped [BCM]	Drilled [m]	Dozed [BCM]	D.L. Handled [BCM]	2S4S [tons]	Parting [BCM]	1S [tons]	Tipped [tons]
197126.90	37857.73	421804.99	1140115.18	304033.10	24165.81	101701.23	426214.67

(b) Use the 2 Seam Extraction Loader



TOTAL INVENTORY PROCESSED							
Stripped [BCM]	Drilled [m]	Dozed [BCM]	D.L. Handled [BCM]	2S4S [tons]	Parting [BCM]	1S [tons]	Tipped [tons]
183125.33	36879.38	341584.16	98526.87	432105.73	28996.32	56721.90	561055.78

(c) Use the 1 Seam Extraction Loader

Figure 5.1: Summary Report Extracts

The results align with what one would expect. The 2 seam is the major coal resource on the mine and as shown in Figure 5(b), interrupting 2 seam extraction has a detrimental effect on the amount of coal that can be tipped from the R.O.M. stockpile. Preventing 2 seam extraction furthermore inhibits the parting extraction and thus negates the reason for relocating the 2 seam loader. Using the 2 seam loader can thus be eliminated as an option.

When comparing the 2 seam, parting, 1 seam and tipping results in Figure 5(a) and Figure 5(c), it is tempting to conclude that these two alternatives are similar and thus either is acceptable. This appearance of similarity is no doubt due to the large interdependence between the parting and 1 seam extraction processes. Upon closer inspection however, one notices that the use of the 1 seam extraction loader impacts the dozing and dragline processes. Considering the nature of the mining process, specifically the blasting restrictions, it makes sense that these processes are influenced. If the 1 seam coal is not extracted, there is no void for the adjacent strip's burden to be blasted into. This blasting delay causes a chain reaction by forcing the dozing process to wait, which in turn causes the dragline to wait. This impact on the dragline immediately disqualifies the use of the 1 seam loader, resulting in the "Do Nothing" option being the best alternative.

Almost any other mine related decision can be modelled and compared using this analysis procedure. It should be emphasised, however, that as illustrated in this example, reasoning and a thorough understanding of Klipspruit Colliery's mining procedures are crucial to interpret the results contained in each summary report. An inexperienced user can easily misrepresent a decision or misinterpret the results, with potentially catastrophic consequences. The Klipspruit Colliery Simulation Model is not an answer to which alternative is best, it is merely a tool to aid the decision maker choose the best option. This being said, the Klipspruit Colliery Simulation Model, as a proof of concept, is undoubtedly a testimony to the usefulness of such a model. It is a valuable foundation upon which to build a full scale, implementable simulation model for Klispruit Colliery.

Understandably there are improvements that can be made. The largest benefit would most likely come from addressing the assumption that the double bench can be processed as a single strip. Dealing with the other assumptions, like the impossibility of a triple bench or multiple 2 seam extraction points, will further refine and improve the model's flexibility to handle exceptional circumstances. In terms of auxiliary functions, a worthwhile improvement would be the development of a graphical interface in which the user can modify the processing route. These improvements will enhance the functionality and accuracy of an already useful tool.

As illustrated in this report, the Klipspruit Colliery Simulation Model is an excellent addition to the planning department's array of mechanisms for achieving the fundamental goal of planning: "To bring the future into the present, so that you can do something about it, *now*!" (Lakein, 2011).

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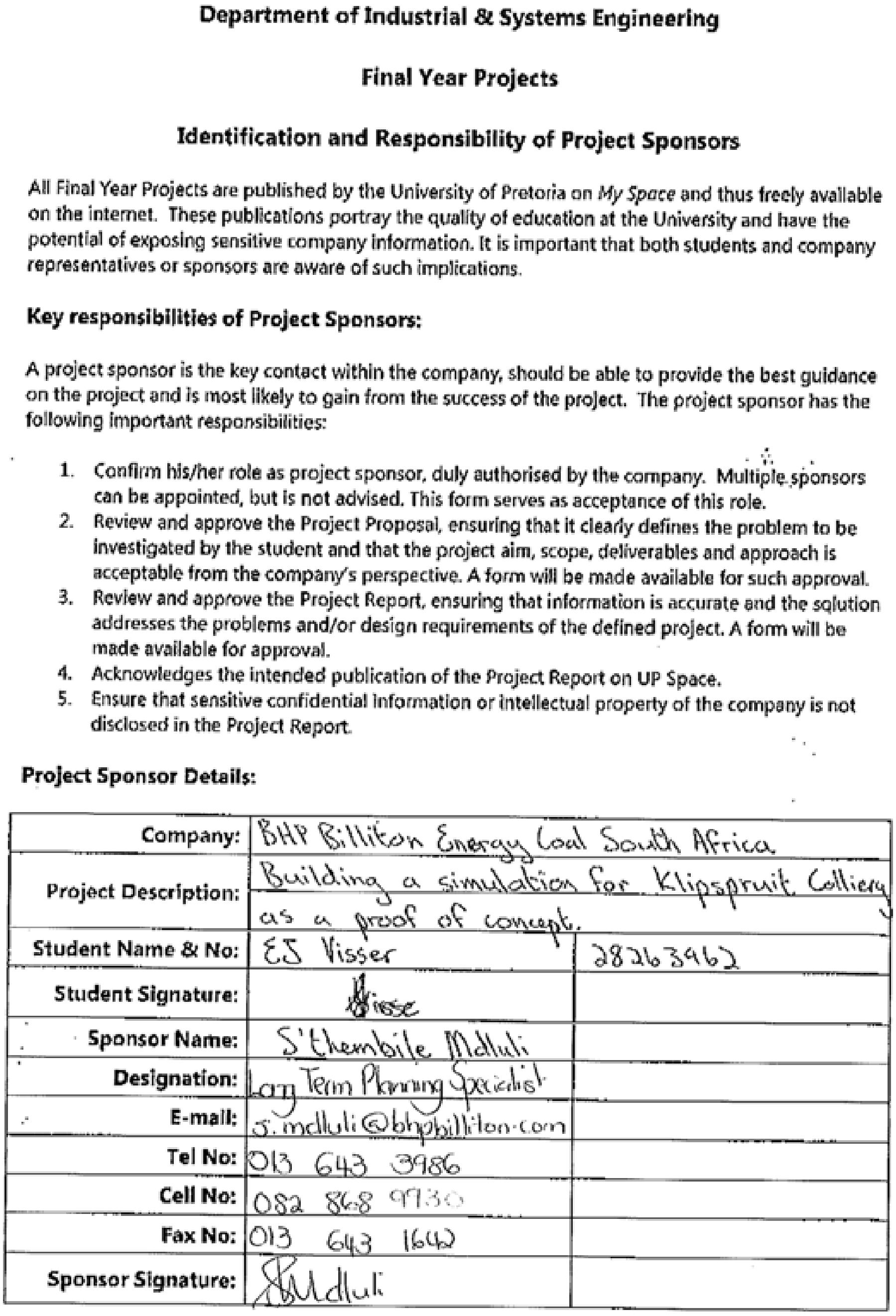
Appendix A

Project Sponsor Form



Department of Industrial & Systems Engineering

Final Year Projects

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2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective. A form will be made available for such approval.
3. Review and approve the Project Report, ensuring that information is accurate and the solution addresses the problems and/or design requirements of the defined project. A form will be made available for approval.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensure that sensitive confidential information or intellectual property of the company is not disclosed in the Project Report.

Project Sponsor Details:

Company:	BHP Billiton Energy Coal South Africa	
Project Description:	Building a simulation for Klipspruit Colliery as a proof of concept.	
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