The use of simulations to identify operational improvements on mining compressed air systems

B.M. Friedenstein

28354516

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Supervisor: Dr Johann van Rensburg

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Abstract

Title:	The use of simulations to identify operational improvements on mining compressed air systems
Author:	B.M. Friedenstein
Supervisor:	Dr Johann van Rensburg
School:	North-West University Potchefstroom Campus
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As operational costs of deep level mines increases and gold ore grades decrease, profitability in the gold mining sector is becoming a challenge. Electricity tariff increases have contributed to a rise in the cost of operating mines. Compressed air systems are utilised on mines as they provide safe, reliable power for various underground machines. Compressed air is also used for emergency oxygen in refuge bays.

Compressed air systems utilise a significant portion of a mine's total energy. It has been shown that many deep level mine compressed air networks have inefficiencies. Improving the efficiency of these systems could result in a reduction of operational costs by reducing the energy required to produce compressed air. Additionally, an improvement in service delivery could be achieved.

Previous studies have shown the usefulness of simulations to develop improvements for deep level mining systems. However, these studies have not followed a structured methodology for developing compressed air simulation for deep level mines. Previous studies have also simplified compressed air models reducing the simulation precision and testable scenarios.

In this study a simulation methodology was therefore developed. Investigations into the compressed air systems are performed. A model is then developed in software to accurately recreate the system operation. Finally a proposed means of improvement is simulated, analysed and quantified in terms of improvements in energy savings and service delivery.

Two case studies were evaluated. For each case study a variety of scenarios were simulated. In case study A by reducing air used by refuge bays in simulation, a reduction of 1 MW E.E. would be achieved with addition to a significant improvement of 18 kPa to system pressure. Drop tests implemented on the case studies validated the simulation with a precision of 5%.

The study showed that simulation is a important tool for identification improvements in large compressed air systems. By utilising a structured methodology to develop detailed compressed air simulations, inefficiencies and operational improvements were identified.

Keywords: Mining, Energy, Compressed air, modelling, Simulation, operational improvements

Contents

Abbreviations

THS Thermal-hydraulic simulation.

Nomenclature

MW - MegaWatt.

T - Tonne.

kPa - Kilopascal.

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CHAPTER 1

Introduction and background

1.1 Preamble

1.2 Background on deep level mining

1.2.1 Mining profitability

Various technical, economic, social and operational challenges are posing a risk to the profitability of the South African mining sector. One of the challenges the sector faces is a rise in the cost of operation [1].

A considerable factor that is contributing to the rise of operational costs in South African gold mines has been the increase in electricity costs. As shown in figure 1.1, the general cost of electricity has increased at a rate greater than inflation since 2008 [2].
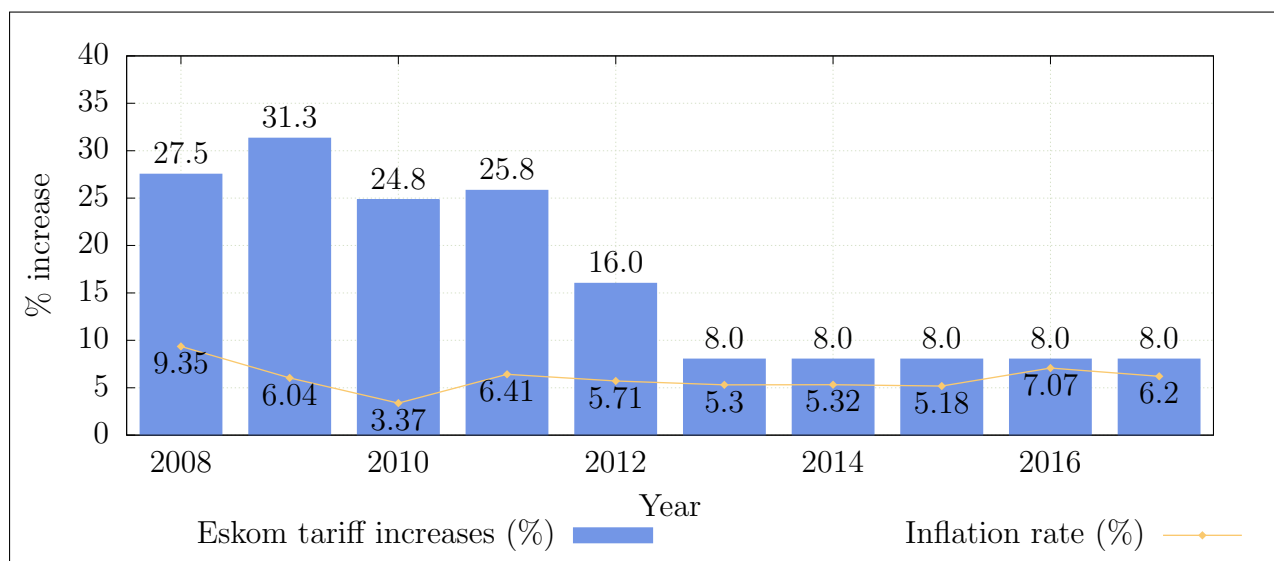
Figure 1.1: Electricity price increases between 2007 and 2017 [2, 3].

In addition to rising electricity costs, gold ore grades of South African mines have fallen substantially over the last few decades[4]. As ore grades decline, the energy utilised per unit of metal increases exponentially [5]. Therefore mines require significantly more energy per unit of metal produced. This combination of tariff increases and increased energy usage per unit have lead to significant rises in mining operation costs.

1.2.2 Mining Process

`Brief description of the mining process`

1.2.3 Mining Services

Energy usage

The mining industry uses extensive amounts of energy. In South Africa, the industry utilizes approximately 15% of the national electricity supplier's yearly output, of which, gold and platinum mines use 80%.[6]

Figure 1.2 shows the division of energy within the mining industry. From the chart it is reasoned that energy can be reduced most effectively through implementing energy interventions on mining material handling, processing and compressed air systems.
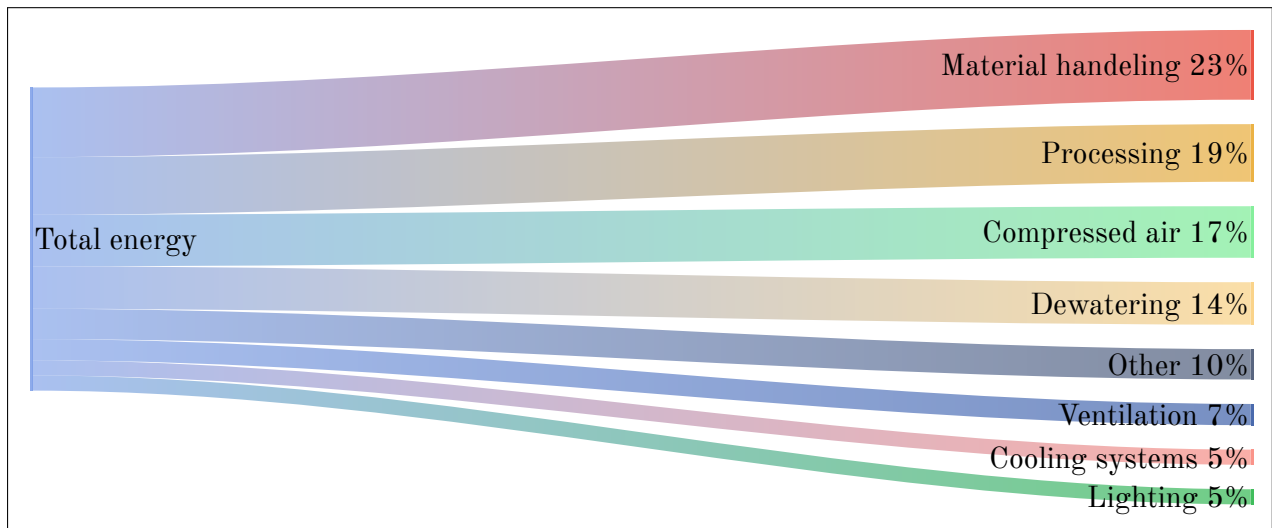
Figure 1.2: The energy split for the south african mining industry [6].

1.3 Compressed air systems in mining

1.3.1 Compressed air in operation

Largely due to their reliability, versatilely and ease of use, the South African mining industry has installed extensive compressed air networks. These systems can have compressors with capacities of up to 15 MW [7].However, the supply of compressed air is a highly energy demanding and costly process [8]. The energy used for compressed air production contributes

to between 9% and 20% of the total mining energy consumption [6, 9].

Large compressed air systems are likely inefficient. Internationally, the expected energy savings potential of a large compressed air network is 15% [10]. Marais [11] showed that energy savings of up to 30% and 40% can be attained through various interventions.

Pneumatic rock drills

Drilling is mainly performed in the production areas or stopes of a mine. Drill machines are used to drill holes into the rock face. Once the holes have been drilled, explosives are then installed to break up the rock [12].

Compressed air is used to power pneumatic rock drills within a mine. Pneumatic rock drills run at an efficiency of 2%. This is low when compared to alternative rock drills such as electric, oil electro-hydraulic and hydro-powered drills that run at an efficiency of between 20-31% [13, 14].

Reduced pressure to the drill will cause it to run even less efficiently. A study by Bester *et al.* showed that between 2002 and 2013 compressed air and energy consumption per tonne of ore produced had steadily increased as shown in figure 1.3. The increase in consumption per T was a result of a reduction in air pressure at the mining stopes. Measurements indicated that the pressure was as low as 300 kPa. This reduced the efficiency of the rock drills. Before 2002 pressure was maintained above 500 kPa at the stopes. .[15]

Refuge bays

Refuge bays are installed in mines to provide safety to miners during emergencies. Most mines will utilise compressed air to deliver safe, cool air to the refuge bay. The provision of 1.42 l/s of air per person at a pressure between 200 and 300 kPa is required to provide oxygen and prevent any poisonousness gas entering the refuge [16].

Airflow in the refuge bays can be controlled with a manual valve within the chamber. Any many cases, this valve is often misused by mine workers who open the valves fully in order to cool the bay through the decompression of the air. `*** need source ***`
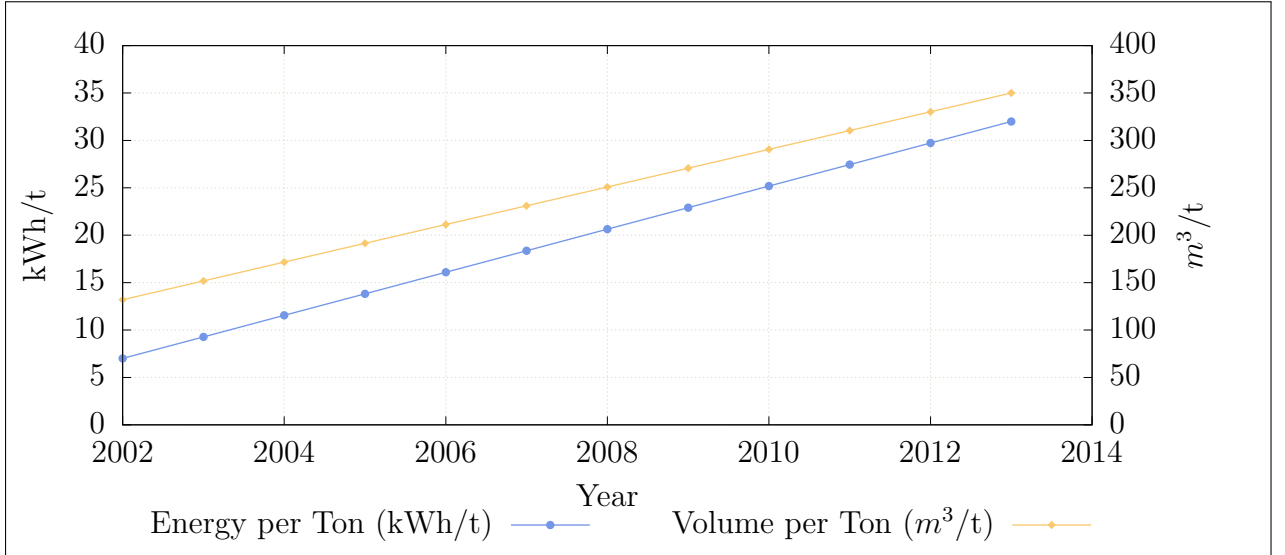
Figure 1.3: The Compressed air energy and flow consumed per T of ore produced. Adopted from Bester *et al.* [15].

Compressed air control

On many large compressed air networks, the intake guide vain position on a compressor is manipulated in order to obtain the air flow and pressure requirements. Typically, guide vains are opened and closed to increase and decrease the compressors discharge pressure. When more pressure is required than can be obtained with the guide vains fully opened, another compressor is needed to operate.

As shown in the figure 1.4, showing guide vain positions vs power for a typical mining compressor, the guide vains are controlled between 40% and 100% of their fully open position. Reducing and increasing the guide vain position will effect the power output of the compressor.The relationship between power and guide vain position of a compressor can be approximated as a linear function. A guide vain position of 40% will relate to an output power of about 60% of maximum power.

Operation schedule

On a typical mine, various operations will take place at different times of the day. Depending on the activity taking place, many mines will control the pressure to meet the requirements [17, 7]. Figure 1.5 shows the schedule and pressure requirement on a typical deep level mine.

As shown in the figure, the pressure requirement changes depending on the activity taking place. The drilling shift typically has the highest pressure requirement whilst blasting shift
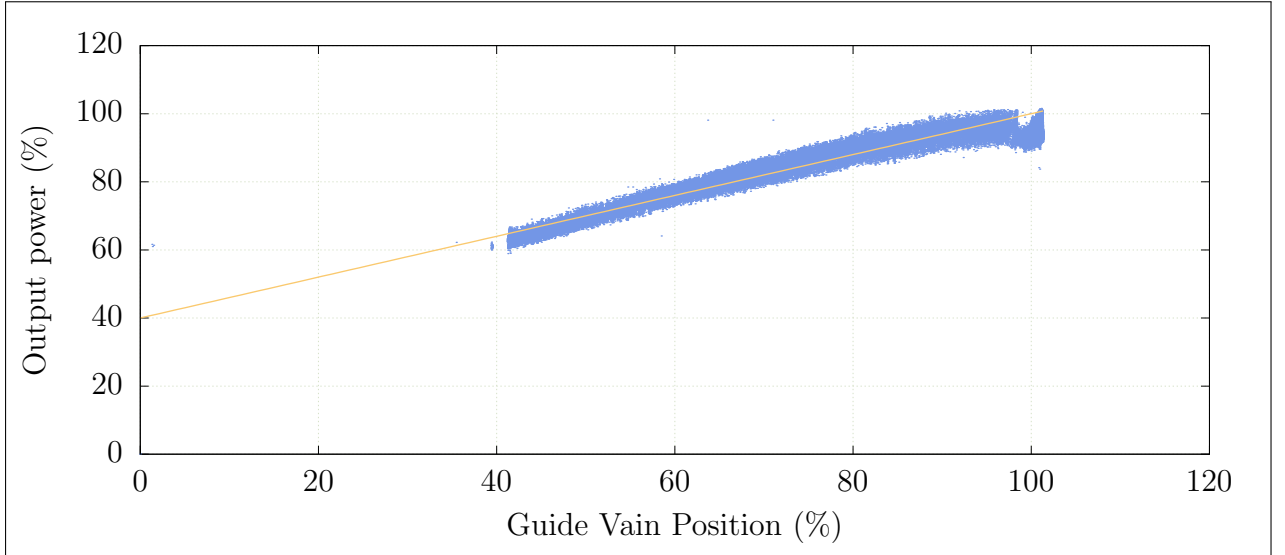
Figure 1.4: The relation between guide vain position and compressor output power.

requires the lowest. Schedules and operation philosophies can differ between mines. Different operational schedules require alternative pressure requirement profiles.
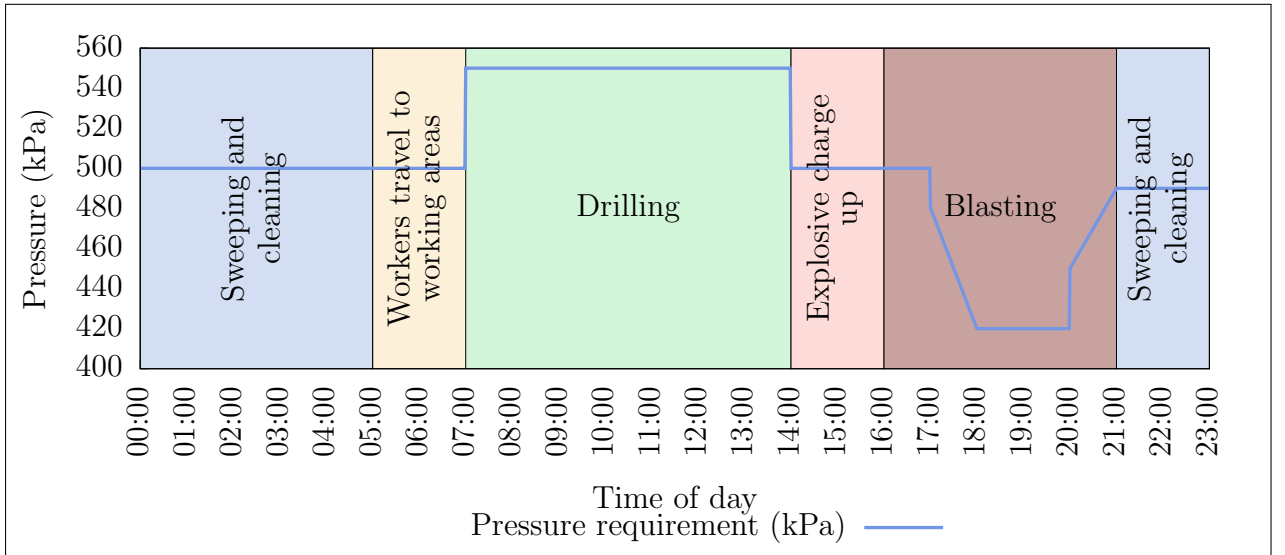
Figure 1.5: The typical operation schedule of a deep level mine [17].

1.3.2 Characteristic inefficiencies

Compressed air distribution networks in the mining industry consist of multiple compressors and working areas up to eight kilometres away from the source [7]. Due to their size and complexity, these systems are prone to large energy losses.

Compressed air leakage accounts for as much as 35% of the energy losses of a compressed air network [18]. Other systemic losses include, faulty valves, pipe diameter fluctuations, obstructed air compressor intake filters and inefficient compressors.

1.3.3   Inefficiency identification methods

Leakage and inefficiency detection strategies is not often pursued in the South African mining industry [14]. Many mines do however perform leak inspections either internally or by a outside company. In these inspections, an ultrasonic detector is used to locate the leak. Alternatively, some mines employ the 'walk and listen' method to identify leaks from the audible sound that it produces [14]. Once the inspection is completed, the findings, including the locations and estimated costs of all identified leaks, are reported.

1.3.4   Instrumentation and measurements

For large industrial systems, thorough instrumentation is necessary in order to monitor performance and condition throughout the system. In a mining compressed air network, instrumentation is installed on the compressor to monitor flows, pressures, temperatures and guide vain position. Electrical instrumentation is also installed for sensing currents, power factors, voltages and power. On control valves, input/output pressures, flows and valve position are usually measured with instrumentation.

Programmable logic controllers (PLCs). A Supervisory control and data acquisition (SCADA) system is is used to observe and monitor all of the instrumentation.

When instrumentation is not installed. Manual measurements are performed... `Need to added a citation or two`

1.3.5   Compressed air savings strategies

The main strategies fo reducing energy on compressed air systems are summarised as follows [19]:

- Reducing leaks.
- Reducing demand.
- Reducing unauthorised usage.
- Increasing supply efficiency.
- Optimising supply.

1.4 Simulations in industry

Continuous improvements in computing hardware has led to major advancement in software technology. Consequently the use of computational simulation has become an increasingly valuable tool for many industries.[20]

In *Handbook of simulation: principles, methodology, advances, applications, and practice*, the advantages of the use of simulation in industry are discussed as follows [21]:

- The ability to test new policies, operating procedures and methods without causing a disruption to the actual system.
- The means to identify problems in complex systems by gathering insight in the interactions within the system.
- The facility to compress or expand time to investigate phenomena thoroughly.
- The capability to determine the limits and constraints within a system.
- The potential to build consensus with regard to proposed designs or modifications.

1.4.1 Thermal-hydraulic simulation

Thermal-hydraulic simulation (THS) is the modelling and computational analysis of Thermal-hydraulic systems. THS models can be developed large mining systems such as cooling ,compressed air water reticulation etc..

1.4.2 Use in mining

In industry, various software packages are used for modelling and simulating these systems. Two such packages are KY-pipe and Simulation Toolbox.

1.5 Problem statement and objectives

1.5.1 Problem statement

Rising costs and falling ore grades are driving in the mining industry to reduce operational inefficiencies. Large energy savings can be made in Compressed air systems in the mining

industry. However manual testing of interventions can be cumbersome.

Computer modelling and simulation of compressed air systems can be used to quantify and prioritise operational interventions that improve efficiency. The simulations would allow scenarios to be evaluated with minimal risk.

1.5.2 Research objectives

The main objective of this dissertation is achieve energy savings and identify operational improvements in mining compressed air systems. A simulation process to will be developed to achieve this goal.

1.6 Dissertation overview

```
Describe (in approximately one sentence each) the contents of
each of the dissertation chapters.  No results here.
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CHAPTER 2

Literature study

2.1 Introduction

2.2 Methods to identify operational improvements

2.2.1 Preamble

2.2.2 Identifying areas for improvement

(Kriel Masters) -Investigation

-Measurements

-Simulated impact of the proposed intervention

2.2.3 Leakage detection

(Van Tonder masters) - Inspections

- Audible sounds (by ear)

- Ultrasonic

- Intelligent leakage detection (instrumentaion SCADA)

- Alternatives (pigging, soap water, Dyes load/unload test)

- CALDS (Compressed air leakage document system)

2.2.4 Estimation techniques

- Snyman estimated improvements using historical data.[19]

- Marais estimation through simplified estimation, simulation [7, 11].

2.2.5 Summary

2.3 Review of compressed air energy interventions in industry

2.3.1 Preamble

(Kriel Masters) - Supply and demand strategies (improving compressor efficiency vs reducing/improving demand)

Marais et al investigated increased energy savings through the use of Compressed Air Leakage Documentation System (CALDS) [22].

2.3.2 Strategies to improve compressed air supply

- Control Strategies

- Relocating compressor. reconfiguring networks - Bredenkamp

- Compressor schedules

- Variable speed drives

- Compressor selection

- Marais showed compressed air saving potential through an expert control system.[23]

2.3.3 Strategies to reduce/optimise compressed air consumption

- Reducing leaks

- Control Valves - Pascoe

- Marais PhD

- Snyman - investigated various Compressed air demand reduction and efficiency optimisations [19].

2.3.4 Summary

2.4 Use of simulations to identify improvements in mining systems

2.4.1 Preamble

2.4.2 Value of simulation in DSM projects

(Van Niekerk M)

- Compressed air

- Cooling systems

- Dewatering

- Design optimisations using simulation

- KYPipe's gas simulation engine

- De Coning - simulations to investigate the opportunity to optimise the control strategy of a compressed air network by rescheduling the compressors.

2.4.3 Simulation procedure

-Kriel masters

-Pascoe

2.4.4 Verifying simulations

- Holman - van Niekerk masters

- Kriel masters (validation)

- Calibrating -pascoe - determining accuracy - pascoe - Du2015Development

2.4.5 Shortcoming of previous simulations

2.4.6 Summary

2.5 Conclusion

CHAPTER 3

Developing a simulation methodology

"Quote." - Somebody

3.1 Introduction

3.2 System investigation

3.2.1 Preamble

Developing a detailed simulation model of a compressed air requires thorough comprehension of the inner workings of the network. This section will discuss the investigations required to obtain this understanding.

3.2.2 Data acquisition

-Layouts, data from SCADA Instrumentation, etc.

3.2.3 Manual measurements

- When instrumentation isn't available

- locate leaks etc.

- Estimate/ measure typical flows to sections

- Audits

- Manual measurements required

3.2.4 Mining schedule

- Identify typical mining procedures and philosophies that influence the consumption of compressed air.

- eg. Drilling throughout the day or shift, diferent types of shift, air requirements

3.2.5 Summary

3.3 Model development and verification

3.3.1 preamble

- This section will discuss the development of a simulation model.

3.3.2 Compressed air component models

- Modelling components (Pipes, leaks, compressors, ambient conditions, after coolers, controllers(guide vain vs VSD) etc.)

Compressors

Pipes

Demand/leak

Ambient conditions

Controllers

Cooling

3.3.3 Simulation inputs

-Discuss inputs of the simulation, (compressor setpoints, ambient conditions, demands)

3.3.4 Verification of model

- Steps to validate the model accuracy .

- Compare parameters to actuals

3.3.5 Summary

3.4 Implementation of method

3.4.1 preamble

- This section will discuss the implementation and analysis of the simulation.

3.4.2 Analyses of data

- Baseline vs Optimised comparison

3.4.3 Quantifying operational improvements

- Estimating cost savings

3.4.4 Summary

3.5 Conclusion

CHAPTER 4

Results and validation

"Quote." - Somebody

4.1 Preamble

4.2 Case study: Mine A (Kusasalethu)

4.2.1 Background

4.2.2 Scenario 1. Refuge bay simulation

tested scenario where all excessive leaking valves are removed. refuge bays savings 1MW E.E.

4.2.3 Scenario 2. Closing off levels/stopes

4.2.4 Scenario 3. Periodic simulation

4.2.5 Summary

4.3 Case study: Mine B (Beatrix 123)

4.3.1 Background

4.3.2 Compressor set points

4.3.3 Control valves set points

4.3.4 Summary

4.4 Validation of results

4.5 Conclusion

CHAPTER 5

Conclusion

5.1 Conclusion

5.2 Limits of this study

5.3 Recommendations for future studies

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APPENDIX A

1

APPENDIX B

2