

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

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# Abstract

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

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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.

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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

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## Abbreviations

**THS** Thermal-hydraulic simulation.

## Nomenclature

**MW** - MegaWatt.

**T** - Tonne.

**kPa** - Kilopascal.

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# CHAPTER 1

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## Introduction and background

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“*Quote.*” - Somebody

## 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 the 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].

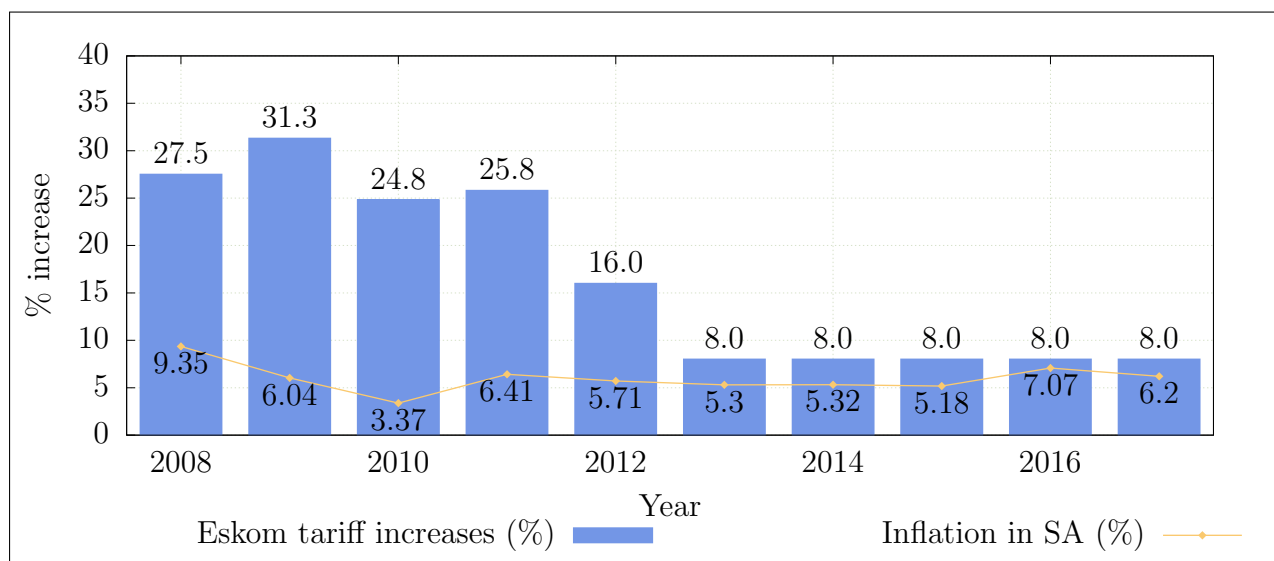


Figure 1.1: Electricity price increases between 2007 and 2017 [2, 3].

In addition to rising electricity cost, 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.

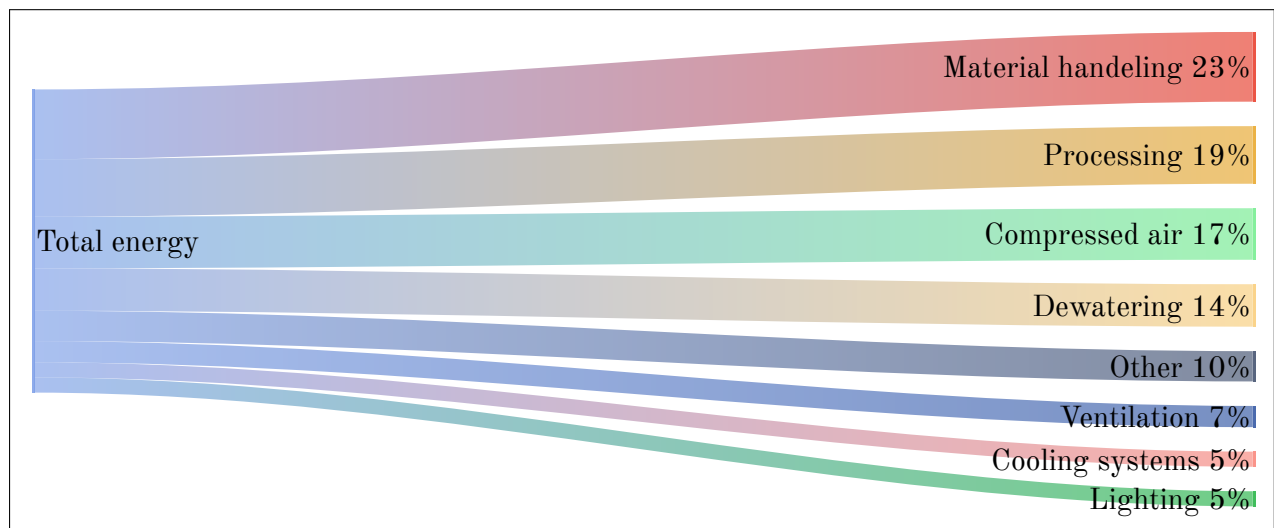


Figure 1.2: The energy split for the south african mining industry [6].

## 1.3 Compressed air systems in mining

### 1.3.1 Compressed air in operation

Due to their reliability, versatility 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 obtained from some systems.

### **Pneumatic rock drills**

Compressed air is used to power pneumatic rock drills within a mine. These drills are heavy, hard to manoeuvre and and inefficient [13]. However mines have widely adopted the use pneumatic drills for there reliability.

Drilling is mainly performed in the production areas or stopes of a mine. The drills are used to drill holes into the rock face. Once the holes have been drilled, explosives are installed to break up the rock.

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. The study showed that reducing pressure delivered to the drills will reduce the efficiency of the drill.[14]

### **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 [15].

Airflow in the refuge bays can be controlled with a manual valve within the chamber. Any

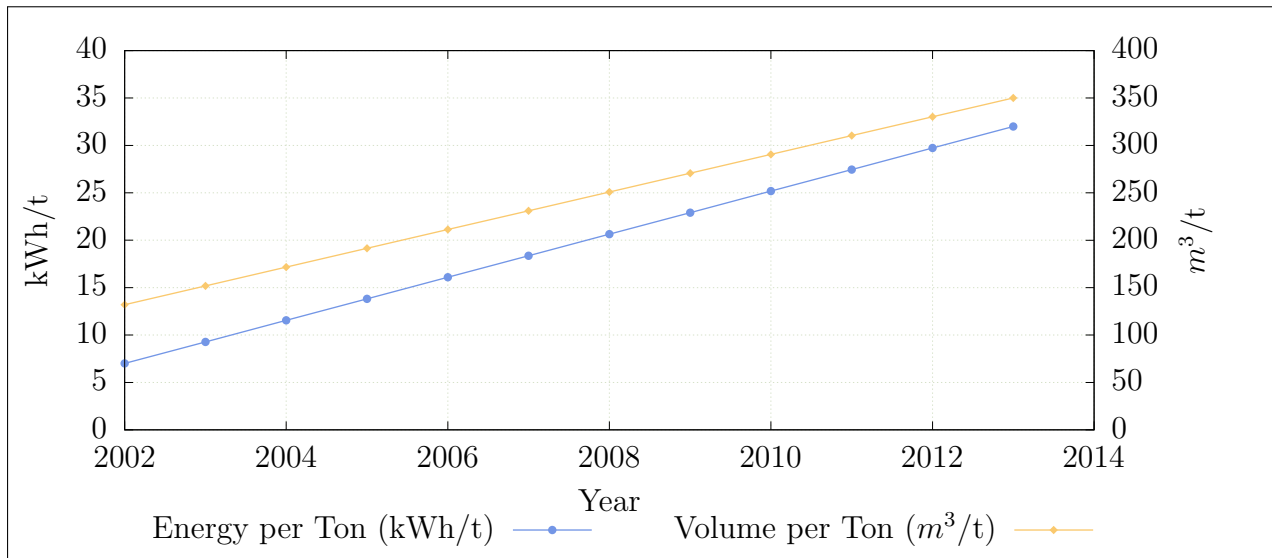


Figure 1.3: The Compressed air energy and flow consumed per T of ore produced. Adopted from Bester *et al.* [14].

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 \*\*\*

### Compressed air control

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

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

### Other components

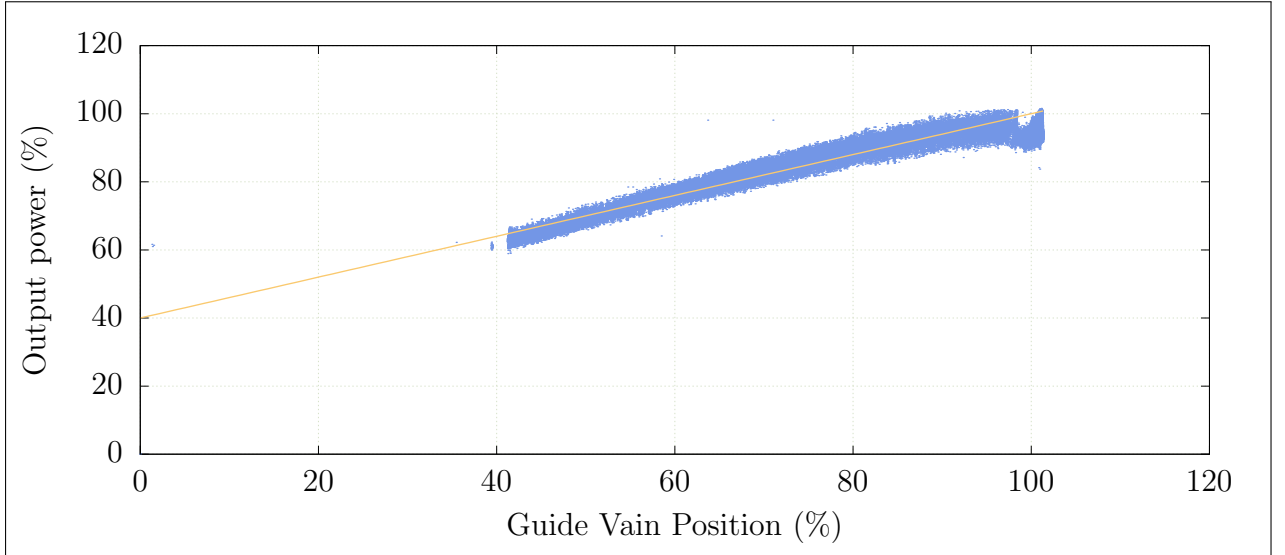


Figure 1.4: The relation between guide vain position and compressor output power.

### 1.3.2 Operation schedules

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 [12, 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 requires the lowest. Schedules and operation philosophies can differ between mines. Different operational schedules require alternative pressure requirement profiles.

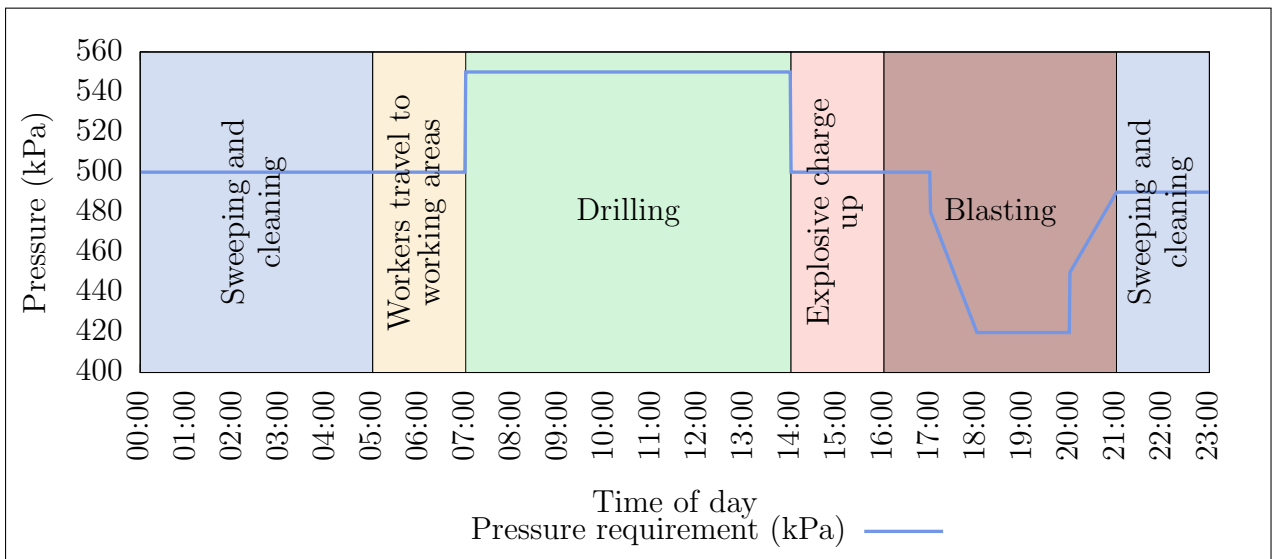


Figure 1.5: The typical operation schedule of a deep level mine [12].

### 1.3.3 Characteristic inefficiencies

As large compressed air distribution networks in the mining industry consist of multiple compressors with working areas up to eight kilometres away from the source [7]. The systems are prone to energy losses due to various characteristic inefficiencies.

Compressed air leakage accounts for as much as 35% of the energy losses of a compressed air network [16]. Other systemic losses include, faulty valves, pipe diameter fluctuations, obstructed air compressor intake filters and inefficient compressors.

### 1.3.4 Instrumentation and measurements

For large industrial systems, instrumentation is necessary in order to monitor the performance and condition of the system. In a mining compressed air network, instrumentation is typically installed on the compressor machine and control valves along the network.

Instrumentation on the compressor machine usually measure flows, pressures, temperatures and guide vain position. Electrical instrumentation is also installed to measure currents, power factors, voltages and power. On the control valves, input/output pressures, flows and valve position are usually measured with instrumentation.

These sensors are usually connected to a Programmable logic controller (PLC). A Supervisory control and data acquisition (SCADA) is installed in order to observe and monitor all of the instrumentation. When instrumentation is not available. Manual measurements are performed at the location required. Need to added a citation or two

### 1.3.5 Inefficiency identification methods

Methods currently used by industry to identify and estimate losses due to an inefficiency

### 1.3.6 Compressed air savings strategies

Methods currently used by industry to identify and estimate losses due to an inefficiency

## 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.[17]

In *Handbook of simulation: principles, methodology, advances, applications, and practice*, the advantages of the use of simulation in industry are discussed as follows [18]:

- 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

Identification of research problem and formulation of objectives should be unambiguous and intelligible



### 1.5.1 Problem statement

### 1.5.2 Research objectives

## 1.6 Dissertation overview

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

## CHAPTER 2

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Literature study

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“*Quote.*” - Somebody

## **2.1 Preamble**

## **2.2 Methods to identify operational improvements**

Johan Marais benchmarking method. Test of bib.

### **2.2.1 Summary**

## **2.3 Review of compressed air energy interventions in industry**

### **2.3.1 Summary**

## **2.4 Use of simulations to identify improvements in mining systems**

### **2.4.1 Summary**

## **2.5 Conclusion**

## CHAPTER 3

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### Developing a simulation methodology

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## 3.1 Preamble

## 3.2 Investigation

3.2.1 Layouts, Data from SCADA Instrumentation, etc.

3.2.2 Manual measurements, audits and approximations

3.2.3 Mining schedule philosophies - (drilling, blasting shifts, etc.)

3.2.4 Summary

## 3.3 Model development and verification

3.3.1 Compressed air component models

3.3.2 Simulation inputs

3.3.3 Verification of model

3.3.4 Summary

## 3.4 Implementation of method

3.4.1 Analyses of data

3.4.2 Quantifying operational improvements

3.4.3 Summary

## 3.5 Conclusion

# CHAPTER 4

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## Results and validation

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“*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

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Conclusion

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“*Quote.*” - Somebody



## 5.1 Conclusion

## 5.2 Limits of this study

## 5.3 Recommendations for future studies

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# APPENDIX A

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# APPENDIX B

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