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

B.M. Friedenstein

28354516

Dissertation submitted in fulfilment of the requirements for the degree *Magister* in Electrical and Electronic Engineering at the Potchefstroom Campus of the North-West University

Supervisor: Dr Johann van Rensburg

April, 2017

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

It all starts here ™

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
Degree:	Masters in Electrical and Electronic Engineering

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.

List of Figures

List of Tables

CHAPTER 1

Introduction and background

“*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 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].

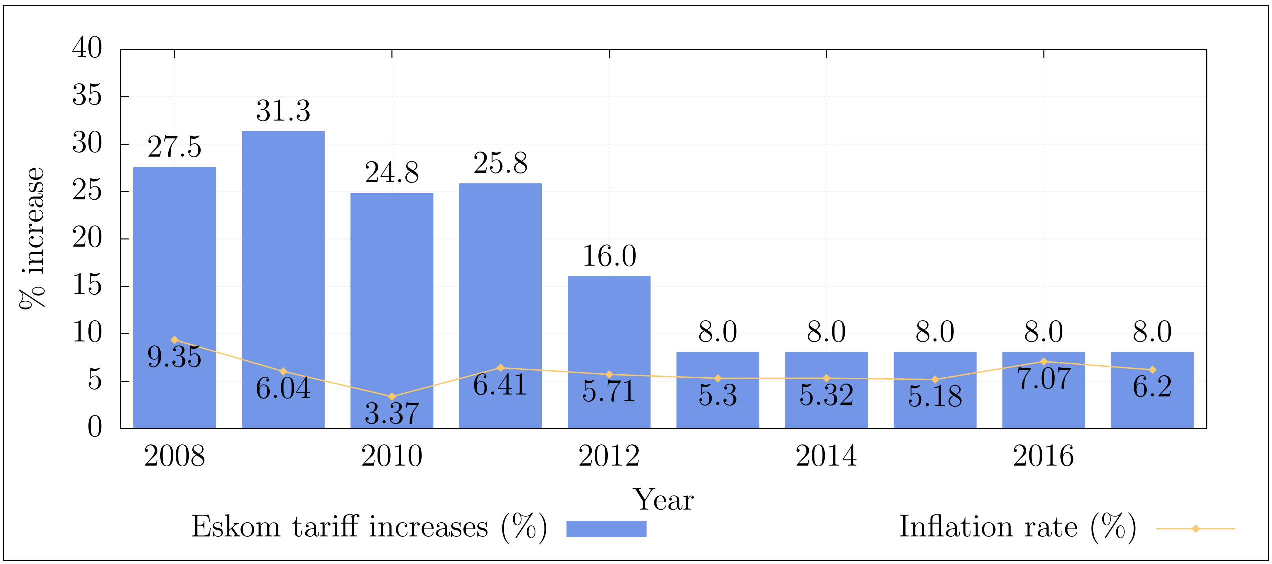

Figure 1.1: Electricity price increases between 2007 and 2017 [2, 3].

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.

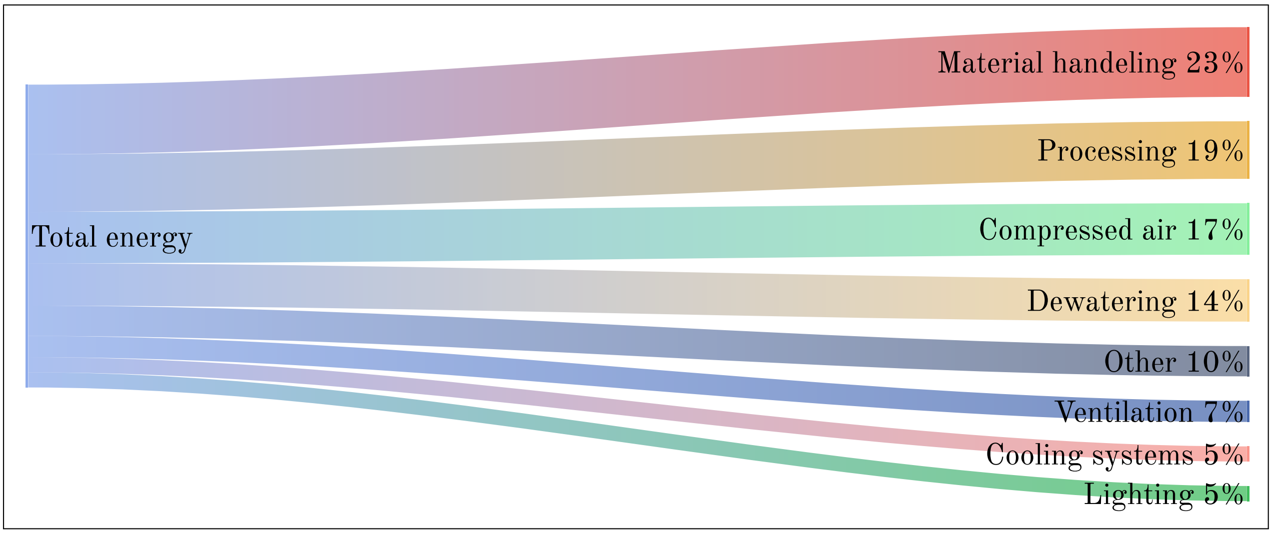

Figure 1.2: The energy split for the south african mining industry [6].

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. Compressed air is used to power pneumatic rock drills within a mine. Pneumatic rock drills utilise energy at an efficiency of as low as 4%. However, alternative power sources for rock Drilling, such as hydro-power and electrical power, were set aside by high costs and potential hazards[12].

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.[13]

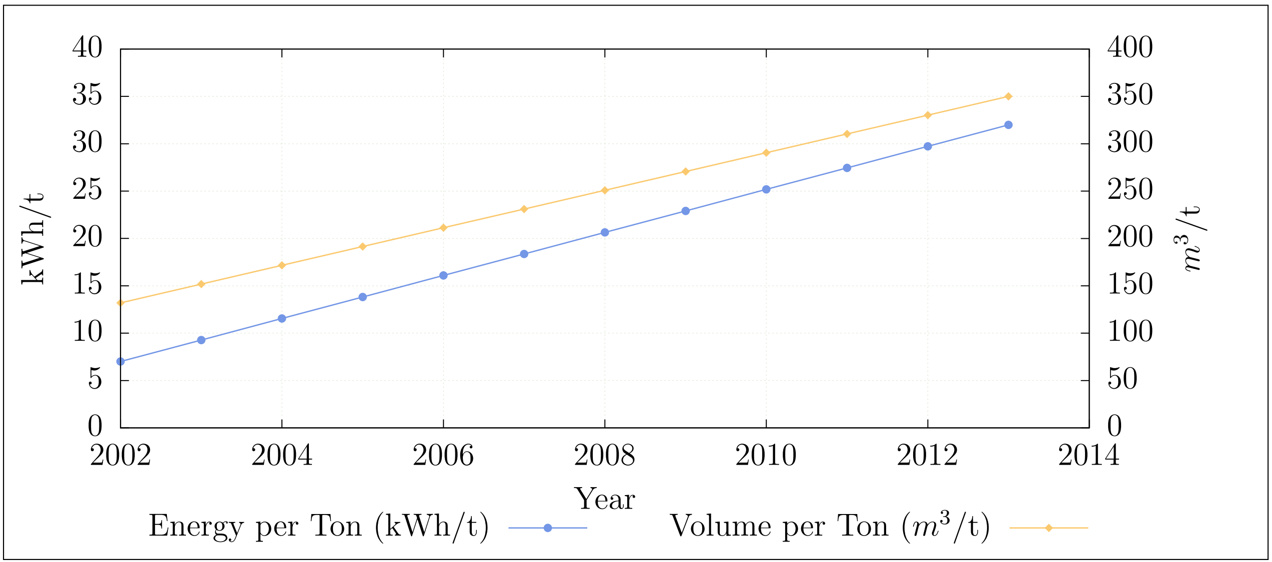

Figure 1.3: The Compressed air energy and flow consumed per T of ore produced. Adopted from Bester *et al.* [13].

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 [14].

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 ***`

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 [15, 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.

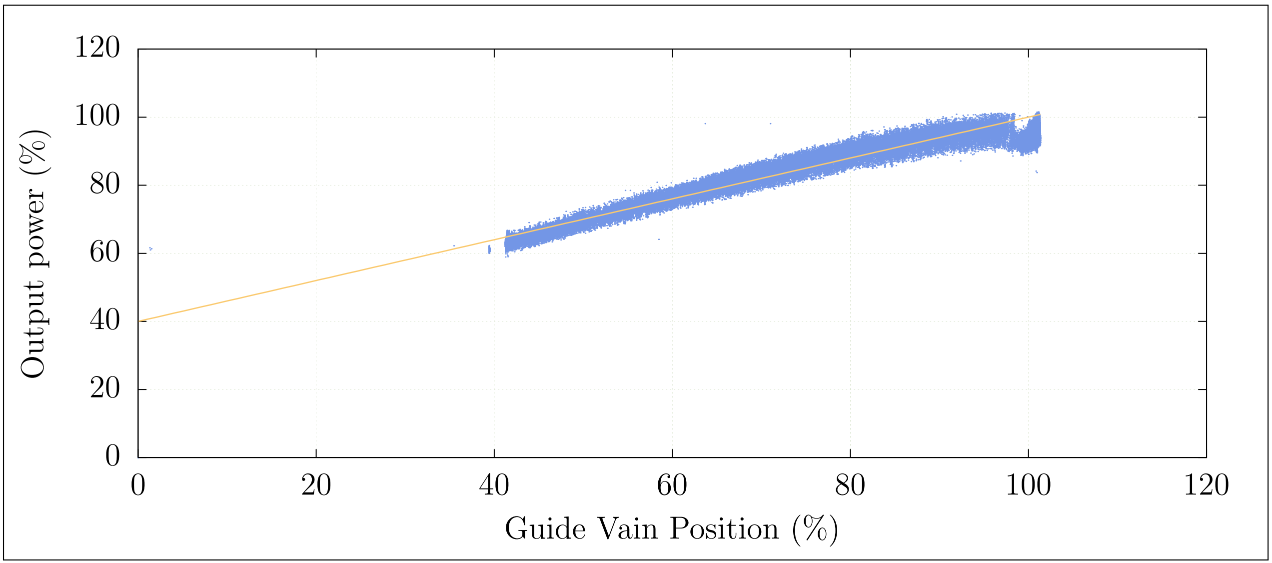

Figure 1.4: The relation between guide vain position and compressor output power.

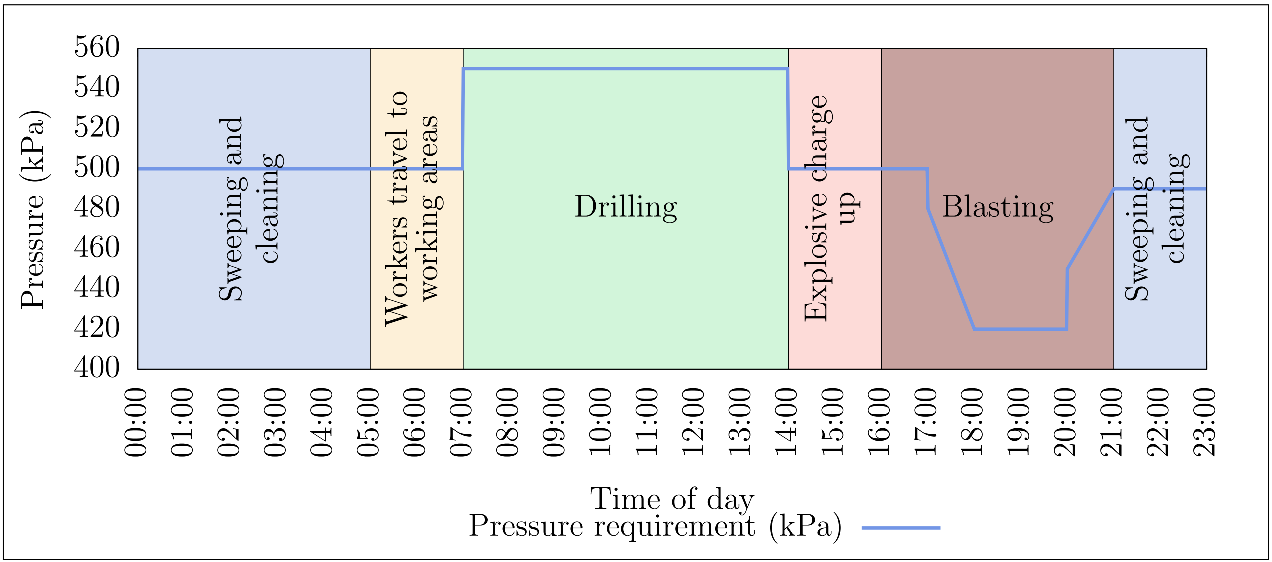

Figure 1.5: The typical operation schedule of a deep level mine [15].

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 [16]. 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 [17]. 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 [17]. 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 [18]:

- 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.[19]

In *Handbook of simulation: principles, methodology, advances, applications, and practice*, the advantages of the use of simulation in industry are discussed as follows [20]:

- 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

Literature study

"*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

Developing a simulation methodology

"*Quote.*" - Somebody

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

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

"*Quote.*" - Somebody

5.1 Conclusion

5.2 Limits of this study

5.3 Recommendations for future studies

Bibliography

[1] P. Neingo and T. Tholana, "Trends in productivity in the south african gold mining industry," *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 116, no. 3, pp. 283–290, 2016.

[2] Eskom, "Revenue application - multi year price determination 2013/14 to 2017/18 (mypd3)," [Online] http://www.eskom.co.za/CustomerCare/MYPD3/Documents/NersaReasonsforDecision.pdf, 2013, [Accessed 22 March 2017].

[3] inflation.eu, "Historic inflation south africa - cpi inflation," [Online] http://www.inflation.eu/inflation-rates/south-africa/historic-inflation/cpi-inflation-south-africa.aspx, 2017, [Accessed 25 March 2017].

[4] G. M. Mudd, "Global trends in gold mining: Towards quantifying environmental and resource sustainability," *Resources Policy*, vol. 32, no. 1, pp. 42–56, 2007.

[5] J. Müller and H. Frimmel, "Numerical analysis of historic gold production cycles and implications for future sub-cycles," *The Open Geology Journal*, vol. 4, no. 1, pp. 29–34, 2010.

[6] Eskom Demand Side Management Department, "The energy efficiency series - towards an energy efficient mining sector," [Online] http://www.eskom.co.za/sites/idm/Documents/121040ESKD_Mining_Brochure_paths.pdf, February 2010, [Accessed 19 March 2017].

[7] J. Marais, "An integrated approach to optimise energy consumption of mine compressed air systems," Ph.D. thesis, North-West University, 2012.

[8] L. Padachi *et al.*, "Energy efficiency through the integration of compressed air supply control with air network demand control," in *Proceedings of the Sixth Conference on the Industrial and Commercial Use of Energy*. Citeseer, 2009, pp. 77–80.

[9] J. Du Plessis and R. Pelzer, "Development of an intelligent control system for mine compressor systems," in *Industrial and Commercial Use of Energy (ICUE), 2011 Proceedings of the 8th Conference on the.* IEEE, 2011, pp. 59–63.

[10] J. Neale and P. Kamp, "Compressed air system best practice programmes: What needs to change to secure long-term energy savings for new zealand?" *Energy Policy*, vol. 37, no. 9, pp. 3400–3408, 2009.

[11] Marais *et al.*, "Simplification of mine compressed air systems," in *Industrial and Commercial Use of Energy Conference (ICUE), 2013 Proceedings of the 10th.* IEEE, 2013, pp. 1–8.

[12] A. van Jaarsveld, S. Ebben, and A. Ashanti, "Development and implementation of an electrically powered stope rockdrill for tau tona mine," in *SAIMM Narrow Vein and Reef Conference, Sun City, South Africa*, 2008.

[13] Bester *et al.*, "The effect of compressed air pressure on mining production and energy demand," in *Industrial and Commercial Use of Energy Conference (ICUE), 2013 Proceedings of the 10th.* IEEE, 2013, pp. 1–4.

[14] D. Brake and G. Bates, "Criteria for the design of emergency refuge stations for an underground metal mine," in *AusIMM Proceedings*, vol. 304, no. 2. The Australian Institute of Mining and Metallurgy, 1999, pp. 1–8.

[15] C. Kriel, "Modernising underground compressed air dsm projects to reduce operating costs," Masters dissertation, North-West University, 2014.

[16] L. B. N. Laboratory, *Improving Compressed Air System Performance: A Sourcebook for Industry.* Washington DC: US Department of Energy.

[17] A. van Tonder, "Sustaining compressed air dsm project savings using an air leakage management system," Masters dissertation, North-West University, 2011.

[18] J. Snyman, "Integrating various energy saving initiatives on compressed air systems of typical south african gold mines," Masters dissertation, North-West University, 2010.

[19] Kocsis *et al.*, "The integration of mine simulation and ventilation simulation to develop a 'life cycle' mine ventilation system," *Application of Computers and Operations Research in the Minerals Industries, South African Institute of Mining and Metallurgy*, pp. 223–230, 2003.

[20] J. Banks, *Handbook of simulation: principles, methodology, advances, applications, and practice*. John Wiley & Sons, 1998.

APPENDIX A

1

APPENDIX B