DOCUMENT

BF-Chapter2

SCORE

62 of 100

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BF-Chapter2

2.1 Introduction

2.2 Background on mining compressed air networks

2.2.1 Preamble

Compressed air is used extensively in a mine in surface and underground operations. In this section, background on compressed air systems is provided 1 through discussion of component 2 that make 3 up the system.

1 Passive voice
2 [the component or a component]
3 [~~make~~ → makes]

2.2.2 Compressor air network components

Compressors

Compressed air in mining is most commonly supplied by a centrifugal-type dynamic 4 compressor [20],[21]. Compression in these machines is achieved 5 as a result of the centrifugal force from the high speed 6 rotation of impellers in air 7. Impeller rotation powered by a large electric motor. A higher pressure ratio is obtained 8 through multi-stage impeller designs [20]. The compression process is inefficient. Only about 5% to 10% of the input energy of the process is converted 9 into energy that is used [22].

4 Unusual word pair
5 Passive voice
6 [~~high speed~~ → high-speed]
7 [the air or an air]
8 Passive voice
9 Passive voice

Pneumatic rock drills

Drilling is mainly performed 10 in the production areas or stopes 11 of a mine. Drill 12 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 [23].

10 Passive voice
11

Compressed air is used to power pneumatic rock drills within a mine. Pneumatic rock drills run at an efficiency of 2%. This 14 is low when compared to alternative rock drills such as electric, oil electro-hydraulic and hydro-powered drills that run 15 at an efficiency of between 20-31% [24], [14].

Refuge bays

Refuge bays are installed underground in deep level mines to provide safety to miners in the event of an emergency. To satisfy the safety criteria 16, most mines will utilize 17 compressed air to deliver cool 18 air to the chamber [25]. g. 2.1 shows an example of a compressed air inlet at an underground refuge bay. A muffler is installed to the end of the inlet air pipe to reduce noise.

The provision of 1.42 l=s of air per person at a pressure between 200 and 300 kilopascals is

Figure 2.1: An example of compressed air inlet in an underground refuge bay chamber of a mine.

required to provide oxygen and prevent any poisonousness gas entering the refuge 19 [25].

Air flow in the refuge bays can be controlled 20 with 21 a manual valve within the chamber. Often, this valve is often misused 22 by mine workers who open the valves fully in order to 23 cool 24 the bay through decompression of the air.[CitationNeeded]

Processing plants

Processing plants are constructed 25 near gold and mines. They are used 26 when extracting metal from the ore that is

12 Repetitive word / Possibly confused word

13 Passive voice

14 Unclear antecedent

15 Repetitive word: *run*

16 Dangling modifier

17 Possible Americanism

18 Overused word: *cool*

19 Repetitive word: *refuge*

20 Passive voice

21 [controlled ~~with~~ → controlled **by**]

22 Passive voice

23

obtained 27 from the mining operation. These plants use compressed air for various systems, processes and equipment.

To save costs 28, processing plants often share compressed air network with mine [8]. The plants use relatively low 29 amounts of air compared to mines, however 31 30 plant processes have pressure requirements that di er from the rest of the air network. If the plant is not isolated from the mine 32 air network 33, compressed air optimizations 34 on the mine 35 can be complicated.

Other compressed air users

Due to the availability underground, compressed air is utilised 36 for a number of 37 other applications. These usages include, 38 pneumatic loaders or rock shovels, pneumatic cylinders, dam sediment agitation, cooling and ventilation and many other applications. This vast variety of of 39 applications also leads to misuse of compressed air this leads to inefficient operation.

2.2.3 Operation schedule

On a typical mine, various operations 41 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

[26],[8]. g. 2.2 shows the schedule and pressure requirement on a typical deep level mine.

As shown in the figure, the pressure requirement 42 changes depending on the activity taking place. The drilling shift typically has the highest pressure requirement

24 [~~in order to~~ → to]
Overused word: cool

25 Passive voice

26 Passive voice

27 Passive voice

28 Dangling modifier

29 Overused word: low

30 [mines~~, however~~ → mines. However]

31 [however,]

32 Repetitive word: mine

33 Repetitive word: network

34 Possible Americanism

35 Repetitive word: mine

36 Passive voice

37 [~~a number of~~ → some]

38 [include~~,~~]

39 [of ~~of~~]

40 [this,]

41 Repetitive word: operations

whilst 43 blasting shift 44 requires the lowest. Schedules and operation philosophies can differ between mines. Different operational schedules 45 require 46 alternative pressure 47 requirement profiles.

Figure 2.2: The typical operation schedule 48 of a deep level mine [26].

2.2.4 Instrumentation and measurements

For large industrial systems, thorough instrumentation is necessary in order to 49 monitor performance and equipment condition throughout the system. In a mining compressed air network, instrumentation is installed to monitor flows, pressures, temperatures ,etc 50. Electri-cal 51 instrumentation is also installed 52 for sensing currents, power factors, voltages and power. On control valves, input/output pressures, ows 53 and valve position are usually measured 54 with instrumentation.

A Supervisory 55 control and data acquisition (SCADA) system is 56 used to monitor and control processes throughout the mine from a control room. The SCADA centralises instrumentation data from Programmable logic controllers (PLCs) throughout the mine 57. The SCADA can also be used to control 58 machines and instrumentation by sending control signals to the relevant PLC. Communication to the underground PLCs is achieved using a substantial 59 bre 60 optic network.[27]

2.2.5 Summary

2.3 Review of compressed air energy interventions in

42 Repetitive word: *requirement*

43 [~~whilst~~ → while]

44 Repetitive word: *shift*

45 Repetitive word: *schedules*

46 Repetitive word: *require*

47 Repetitive word: *pressure*

48 Repetitive word: *schedule*

49 [~~in order to~~ → to]

50 [, etc]

51 [~~Electri-cal~~ → Electrical]

52 Passive voice

53 Unknown word: *ows*

54 Passive voice

55 [~~A Supervisory~~ → Supervisory]

56 [~~is~~ → are]

industry

2.3.1 Preamble

Compressed air improvement can be obtained 61 through intervention in either the supply or demand of compressed air [26]. Improvements in supply interventions 62 are achieved 63 by increasing the efficiency of compressed air supply. Examples of this type of intervention include Dynamic Compressor Selection (DCS), compressor maintenance, etc.

Due to the size of mining compressed air networks, there is often a larger scope for improvement in air demand. Improving the demand 64 is achieved by optimising air flow consumers, reducing leaks, etc.

This section will review compressed air supply and demand interventions that have improved energy or operation efficiency the mining industry. From the, 65 successes and shortcomings in studies will be discussed and analysed with regard to 66 this study.

2.3.2 Strategies to improve compressed air supply

Optimising compressor control

Compressors types and numbers can differ widely from mining compressed air systems. Compressor selection is crucial in these systems to match the correct compressors with the requirements of the system [28].

In a study by Booysen et al 67 [21] on optimising compressor control, [21] found that many mines control

57 Repetitive word: *mine*

58 Repetitive word: *control*

59 Unusual word pair

60 Unknown word: *bre*

61 Passive voice

62 Repetitive word: *interventions*

63 Passive voice

64 Repetitive word: *demand*

compressors using xed 68 target pressure points that are much higher that 69 required. In one system, compressors were set to a target 650 kilopascals to ensure pressure underground did not fall below 500 kilopascals. Using high pressure 70 set-points can lead to excessive 71 wasteful blow-o flow when the pressure exceeds a maximum points 72.

Booysen [29] showed that through dynamic pressure setpoint control, matching the supply pressure with the demand, and optimal compressor selection, energy savings can be achieved. In a case study, an average power reduction of 1.07 MW was achieved 74. The lead to an estimated energy cost saving of R3M.

Optimising control of compressors to match the demand of the system can be complicated.

Variable Speed Drives (VSDs) and guide vain 75 are used to control the capacity of the system 13. More effective 76 power reductions can be achieved 77 through the use of VSD control. Running compressors at part load reduces 78 efficiency. From literature 79 it shown electric motors will typical use 60-80% of there 80 rated power when running at <50% load [30].

Reconfiguring compressed air networks

A number of 81 old mining compressed air systems have not been adequately maintained 82 and improved. Often they cannot suficiently 83 supply air to meet the demand or air is provided from non 85 optimal 84 sources. In a study by Bredenkamp [31], reconfiguring of the air network was investigated to improve these systems.

65 [the,]

66 [~~with regard to~~ → about]

67 [al.]

68 [~~xed~~ → fixed]

69 Possibly confused word

70 [~~high pressure~~ → high-pressure]

71 [excessive,]

72 [~~a maximum points~~ → maximum points]

73 Preposition at the end of a sentence

74 Passive voice

In the study, Bredenkamp investigated 86 interconnecting the compressed air systems of two mining shafts and relocating of a compressor. This strategy lead 87 to an average power reduction of 1.7 MW and an estimated annual energy cost saving of R8.9M at the time.

2.3.3 Strategies to reduce compressed air demand

As illustrated in g 89. 88 2.2 - Reducing leaks

- [8]

- [15] - investigated various Compressed air demand reduction and efficiency optimisations . 90

Leakage detection

Air leaks are a major 91 inefficiency in mining compressed air systems. Improving leaks is relatively 92 easier method to reduce air demand and improve the efficiency of the system [32]. Air leaks occur as a result of open pipes, fissure and breaks. Losses depend on the size of the leak and pressure in the network. g. 2.3 shows the theoretical 93 air ow of through a pipe orifice as a function of leakage area and pressure1. [32] showed that the system power consumption linearly increases with the amount of air leakage. Therefore, energy savings can be achieved 94 through either reducing pressure or detecting and xing 95 leaks.

Leaks are often not easily detected through visual methods. In industry, a number of 96 techniques are employed to detect air leaks. Pascoe [33] and van Tonder [14] summarised these strategies as follows:

75 Possibly confused word

76 Overused word: *effective*

77 Passive voice

78 [~~reduces~~ → reduce]

79 [the literature]

80 Possibly confused word

81 [~~A number of~~ → Some]

82 Passive voice

83 [~~suficiently~~ → sufficiently]

84 [~~non optimal~~ → non-optimal]

85 [~~non~~ → an]

86 Repetitive word: *investigated*

87 [~~lead~~ → leads]

88 Sentence fragment

89 [~~in g~~ → in g]

Audible detection (Walk and report)

1 efunda, "Ori ce Flowmeter Calculator." [Online] http://www.efunda.com/formulae/fluids/calc_ orifice_flowmeter.cfm, [Accessed 18 October 2016].

Figure 2.3: The leakage flow 97 as a function of inlet pressure and leakage area1.

Ultrasonic detection

Detection 98 through intelligent systems Pigging

Soap water and dyes

These methods are time and resource intensive 99 and many mines do not actively employ dedicated leakage detection and repair teams. Marais et al 100 [34] investigated streamlining the leakage detection and repair process to increase energy savings through the use of Compressed Air Leakage Documentation System (CALDS 101). The system was developed to allow centralised mobile leakage reporting. Usage of CALDS in mines resulted in an increased leak detection rate. One mine 102 reporting 24 leaks in a single month. It was noted 103 in the study that there di culty quantifying the actual energy savings of the leakage repairs due to other intervention occurring simultaneously 104.

Underground control valves optimisation

Many mines utilise automated valves at critical locations or levels in the compressed air network. These valves control the pressure, restricting air ow from that point in

90 [~~optimisations .~~ → optimisations.]

91 Overused word: *major*

92 [a relatively or the relatively]

93 Unusual word pair

94 Passive voice

95 Possibly confused word

96 [~~a number of~~ → some]

the air network 105. Restricting air ow reduces losses resultant from network 106 inefficiencies and leaks.

Kleingeld 107 and Marais [35] found that optimising control valve control on mining levels can conservatively lead to between 20% on mines where no control valves are installed 108. For systems that already have some form of network control, between 10 and 15% savings can conservatively be achieved.

From literature, the advantage of control 109 valve optimisation is the signi 110 cant savings that can be achieved 111 with relatively short set-up up time. Savings can be achieved 112 incrementally with each control valve installation. Studies did not look at accurate estimations of savings or the shaft pressure improvements that result from control valve optimisation.

Improving pneumatic rock drill efficiency

Pneumatic rock drills are on 113 of the largest air consumers in a mine. However Pneumatic drilling systems convert energy very inefficiently. Replacing pneumatic drills with more efficient alternatives such as hydraulic or pneumatic drills would lead to large energy savings

[33]. Alternatively improving the eficiency 114 of pneumatic drilling can have a significant energy impact on the system, without the cost and safety concerns of alternative drilling technologies.

In a study by Bester et al. [36] looking at the effect of compressed air pressure on energy demand. 115 Bester showed that between 2002 and 2013 compressed air and energy consumption per tonne of ore produced had steadily increased. This 116 is illustrated 117 in g. 2.4. The

97 [~~leakage flow~~ → leakage flow]

98 Repetitive word: *detection*

99 [intensive,]

100 [al.]

101 [~~CALDS~~ → CDS]

102 [mine **is** or mine **was**]

103 Passive voice

104 Weak verb

105 Repetitive word: *network*

106 Repetitive word: *network*

increase [118] of air consumption per Tonne was a result of reduced air pressure at the mining areas. This [119] caused a drop in the drilling rate, leading to higher air consumption. Pressure measurements as low [120] as 300 kilopascals were recorded [121] in these areas [122]. Before 2002 the drilling pressure at the mining section (stopes [123]), was maintained above 500 kilopascals at most mines.

Figure 2.4: The Compressed air energy and flow consumed per T of ore produced. Adopted from Bester et al. [36].

From literature, it is shown [124] that lowering the pressure reduces the effciency [125] and drill rate of rock drilling, leading to higher air consumption. Interventions that reduce systemic air losses or optimise supply can increase the pressure operating pressure. Increased pressure, during

the drilling shift, [126] may add more value than the energy cost savings that can be achieved [127] at a lower pressure.

2.3.4 Summary

2.4 Use of simulations to identify improvements in min-

ing systems

2.4.1 Preamble

The value of simulation in the mining industry has been shown [128] through its use in Demand Side Management (DSM) initiatives. Simulation has been used to identify savings strategies for water reticulation cooling,

107 [~~Kleingeld~~ → Kleinfeld]

108 Passive voice

109 Repetitive word: *control*

110 [~~signi~~ → sign]

111 Passive voice

112 Repetitive word: *achieved*

113 Possibly confused word

114 [~~eficiency~~ → efficiency]

115 [intensive,]

compressed air and ventilation. This section will summarise the the work 129 that has been done 130 in industry. From this 40 the successes and shortcomings of previous work will be discussed.

2.4.2 Estimating techniques used for energy savings on mining

systems

Estimation of energy savings has been used in literature to obtain the potential energy impact that can be achieved 131 for a system. Before new tools allowed for quick 132 development of simplified simulation models, estimation techniques were frequently used to determine the feasibility of energy interventions on mining systems. The problem with an estimation 133 approach is that they typically rely on simplified 134 system model that lead to high prediction error.

Snyman, [15] used mathematical estimation techniques to determine the expected power savings from initiatives on mining compressed air systems. Due to uncertainty in the estimations, [15] predicted results were provided 135 as a range between conservative and best-case estimates. The actual achieved energy impact would fall between these estimations.

Benchmark modelling

Cilliers, [37] developed \best practice models" using the Corrected Ordinary Least Square (COLS) benchmarking method. These models provide an energy benchmark 136 that can be used to identify the scope for energy improvements on a system. An example of a benchmark 137 model for a mining compressed air system is shown 138

116 Unclear antecedent
117 Passive voice
118 Repetitive word: *increase*
119 Unclear antecedent
120 Overused word: *low*
121 Passive voice
122 Repetitive word: *areas*
123 Possibly confused word
124 Passive voice
125 [~~effciency~~ → efficiency]
126 [shift~~,~~]
127 Passive voice

in 73 ??. The model shows 139 that energy required is dependent on the quantity of ore mined and the depth of the mine 140. [37] also developed benchmark models for mine cooling, water reticulation and ventilation systems.

128 Passive voice

2.4.3 Value of simulation in mining DSM

Van Niekerk [38],[39] investigated the value of simulation models in mine DSM projects. Van Niekerk developed simulation models for compressed air and water reticulation systems

129 [~~the~~ work]

130 Passive voice

Ecomp = 1:51 Z + 33:36 T 1930:21

Figure 2.5:

using KYPipes's 142 gas simulation engine. 141

Mine cooling systems

131 Passive voice

132 [the quick]

Simulation has been used 143 in studies as a tool to improve mine cooling. Holman [40] investigated improvements to mine cooling systems that improve 144 performance and effciency 145. In the study [40] used simplified PTB simulation models to investigate cooling interventions.

133 Repetitive word: *estimation*

134 [a simplified or the simplified]

The scenario Holman simulated showed potential average power reduction of 136 kW which would lead to an annual energy cost saving of R0.55M. The study could be improved 146 by increasing accuracy of the simulation. Power difference of as high as 31% between the simulation and actual were 148 observed 147 for some time periods.

135 Passive voice

2.4.4 Simulation procedures

- Philip - Kriel masters

2.4.5 Simulation model veri cation strategies

Due to lack of instrumentation, measurement inaccuracies and other non-ideal aspects of mining systems. It is impossible for a simulation model to match the actual system's performance perfectly. From literature, methods of verifying simulation precision were investigated 149. The verification techniques identified from literature 150 were Mean 151 residual difference, Mean Absolute Error (MAE), coeficient 152 of determination or correlation and Mean Square Error (MSE).

136 Repetitive word: *benchmark*

137 Repetitive word: *benchmark*

138 Passive voice

139 Repetitive word: *shows*

140 Repetitive word: *mine*

Mean residual di erence 153 method

The average difference method looks at the average for 155 154 the data points in the actual and simulated time series. The error is then calculated 156 with eq. (2.1). The simulation percentage error in relation to 157 the actual series is then calculated 158 by dividing the error by the Actual datapoints 159, eq. (2.2).

A major 160 disadvantage of this method is that for transient simulation, the positive and negative errors for individual points can cancel out. This 161 leads to a smaller resultant error than would be expected. The resultant error measurement therefore 162 can not lead to any 163 conclusive 164 statements regarding the accuracy of the model [41]. This strategy is not recommended 165 if used alone to verify transient simulation precision.

141 Sentence fragment

142 [~~KYPipes's~~ → pipes's]

143 Passive voice

Yu-jie 166 Xu et al 167 [42] developed a simulation model for an absorption chiller. In the study [42] utilised residual difference to measure the relative steady state error of the absorber model 168.

21

The accepted margin of accuracy in the study was a relative 169 steady state error of 5 %. Mean absolute error method

The MAE verification method 170 follows a similar calculation as in the Average residual di er-ence 171 method. However, as shown in eq. 172 (2.4), the error is calculated individually for each point in the series. The average of the individually 173 errors is the resultant error, eq. (2.3). To obtain the relative error percentage 174, each error is divided by the Actual value at that time step as in eq. (2.4).

A Actual 175 system time series S Simulation time series

n Data point

N Number of Data point in simulation period

Coe cient 176 of determination

The Coeficient 177 of correlation is the measure of how accurately a data series (x) can be represented 178 in a linear relationship with Data series (y), i.e. y = mx 179 + c. The value for the coeficient 180 ranges between 1 and 1 181 where a value of 1 indicates a perfect linear relationship

144 Repetitive word: *improve*

145 [~~effciency~~ → efficiency]

146 Passive voice

147 Passive voice

148 [~~were~~ → was]

149 Passive voice

150 [the literature]

151 [the Mean or a Mean]

152 [~~coeficient~~ → coefficient]

153 [~~erence~~ → Terence]

154 Repetitive word: *average*

155 Possibly confused preposition

156 Passive voice

between the series and a value of -1 represents a perfect negative linear relationship. A value of 0 indicates 182 that there is no relationship 183 between the data series. The correlation coeficient 184 can be calculated using equation eq 185. (2.5).[41]

Kurnia et al 186 [43],[44] developed a simulation for a novel underground mining ventilation system. [43],[44] selected the mathematical model with the highest precision when compared with historical data points. The chosen model had an R-Square value of 0.96 and a relative error 30 %, using the mean absolute error method.

Mean squared error

In statistics, the MSE or Root Mean Square Error (RMSE) is the average of the square of the error between the actual and estimated value. The value is always positive. A smaller value relates to a more accurate model.1

dominic 187 [45]

Comparing verification methods

The difference between the verification strategies is best shown using an example. Figure g. 2.6 shows the simulation model's output power 188 and the actual power 189 of the system over a 24 hour period. In a study by [18], the mean residual percentage difference method, eq 190. (2.2), was used to calculate the accuracy of a simulation model. The average of the two power profiles were 191 similar, leading to a calculated relative error of 1.17%. Using the Relative error method, eq 193. 192 (2.4),

157 [~~in relation to~~ → about]
158 Passive voice
159 Possibly confused word
160 Overused word: *major*
161 Unclear antecedent
162 [measurement, therefore,]
163 Repetitive word: *lead*
164 [~~conclu-sive~~ → conclusive]
165 Passive voice
166 [~~jie~~ → Jie]
167 [al.]
168 Repetitive word: *model*
169 [~~relative~~ → relatively]
170 Repetitive word: *method*
171 Unknown word: *ence*
172 Sentence fragment
173 [~~individually~~ → individual]
174 Dangling modifier

applied to the same data the results in a relative error of 15.2%. The results of the verification strategies on the example is 195 provided 194 in section 2.4.5.

175 [~~A~~ Actual → An Actual]

1 University of Kentucky Department of Mathematics, "Estimators, Mean Square Error, and Consistency" [Online] http://www.ms.uky.edu/~mai/sta321/mse.pdf, [Accessed 3 March 2017].

176 [~~cient~~ → cent]

Figure 2.6: Example of simulation error calculations. Data adapted from Mare [18]

177 [~~Coeficient~~ → Coefficient]

178 Passive voice

Table 2.1: Results of the comparison of verification methods.

179 [~~mx~~ → MX]

180 [~~coeficient~~ → coefficient]

181 [~~1~~ → one]

Willmott, [46] studied the Advantages of the use of mean absolute error MAE over the RMSE method in assessing model accuracy. In the study,[46] concluded that the MSE measure is a function of MAE and therefore does not describe average error alone. From the analysis 196 MAE was described 197 as the most natural and unambiguous measure of average error magnitude.

182 Repetitive word: *indicates*

183 Repetitive word: *relationship*

184 [~~coeficient~~ → coefficient]

185 Possibly confused word

Veri cation usage in previous simulation studies

186 [al.]

Previous studies verified there 198 simulations through different methods and varying degrees of precision.

2.4.6 Summary

Table 2.2: Simulation verification methods that were implemented 199 in previous studies.

2.5 Use of simulation in mining compressed air optimisation

2.5.1 Preamble

This section will discuss literature where simulation was used to optimise mining compressed air systems.

2.5.2 Compressed air simulation models

Simplified vessel model

Before new tools allowed model [200] development for complex mining compressed air simulation models, Marais [8],[12] created a simplified model to estimate and quantify the performance of potential interventions. [8] simplified the mining compressed air system, comparing the network to an air source and a vessel with many leaks. This [201] is illustrated [202] in g. 2.7.

Figure 2.7: Simplified compressed air network model. Adapted from Marais [8].

A simplified calculation methodology was developed to quickly estimate the expected energy savings impact on the system [203]. From this, energy saving [204] estimations rules were developed [206] [205] as shown in table [207] 2.3.

The accuracy of this approach is not very high as the specifics of the network are not taken into account. The simplified approach [208] cannot be used [209] for more complex

187 [~~dominic~~ → Dominic]

188 Repetitive word: *power*

189 Repetitive word: *power*

190 Possibly confused word

191 [~~were~~ → was]

192 Sentence fragment

193 Possibly confused word

194 Passive voice

195 [~~is~~ → are]

scenarios for example compressor relocation. The study also does not estimate other potential benefits of

an intervention 210 such as pressure delivery improvements.

Intervention 211	Estimation rule
Reducing compressor deliver pressure	x% pressure reduction / (1.6 to 1.8) x% power reduction
Reduce control valve pressure	x% pressure reduction / p x% power reduction. Where p is the valves percentage flow contribution to the system
Reduction of ow	x% flow reduction / x% power reduction

Table 2.3: Summary of energy saving estimation rules[8].

Simpli 212 ed system model

Kriel [26] used simulation to estimate project performance on compressed air. The KYPipe software tool was utilised to develop simulation 213 model for compressed air systems. [26] simplified the system for the simulation such that a single compressor and a flow 214 to each level represented the system. The model is shown graphically in g. 2.10

Figure 2.8: Simpli ed system model. Adapted from Kriel [26].

Simulation 215 was performed to quantify the savings from underground network interventions. The interventions were deigned 216 to reduce flow to the network 217. The simulated

196 [analysis,]

197 Repetitive word: *described*

198 [~~there~~ → their]

199 Passive voice

results varied between 10 and 25% from the actual performance of the interventions. The simulation procedure in this study could be improved using a more precise model verification method.

200 Repetitive word: *model*

Compressor relocation

Bredenkamp [31] developed a simulation model to test compressor relocation scenarios. The model, as visualised in g. 2.9

201 Unclear antecedent

202 Passive voice

Figure 2.9: Compressor relocation simulation model. Adapted from bredenkamp 218 [31].

Compressed air ring

- Pascoe

203 Split infinitive

Figure 2.10: Simplified compressed air ring model. Adapted from Kriel [33].

204 Repetitive word: *saving*

205 Passive voice

206 Repetitive word: *developed*

207 Possibly confused word

- Bredenkamp -Mare et al

208 Repetitive word: *approach*

209 Passive voice

- van Tonder

- De Coning

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

210 Missing verb

211 Repetitive word: *intervention*

2.5.3 Summary

212 [~~Simpli~~ → Simple]

213 [a simulation or the simulation]

214 [~~a~~ flow]

215 [~~Simulation~~ → The simulation]

216 Possibly confused word

217 Repetitive word: *network*

218 [~~bredenkamp~~ → Breden Kamp]