UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Overall improvement in production drilling efficiency at Grootegeluk Coal Mine, to meet current and future drilling demand

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Science in Engineering (Mining).

Lephalale, 2019

DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the degree of Master of Science in Engineering (Mining) to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

I confirm that there is no plagiarism in the report.

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(Signature of Candidate)

26.......................**day of**...08...............**year**..2020

ABSTRACT

Production drilling capacity at Grootegeluk mine needs to be sustained to ensure that the required floor stock levels of blasted material is maintained. Drill rig availability, utilisation and cycle time (hole to hole movement) of the drill rigs have an impact on the drilling output. Without blasted floor stock (blasted material which must be loaded by shovels into the haul trucks, mining operation will not be able to reach planned production target.

Root cause analyses is utilised to address the question why production drill rigs at Grootegeluk mine are not performing as planned. It is also used to determine how Grootegeluk mine can avoid having the same problem in the future.

Since 2014 the drilling fleet size at Grootegeluk increased to seven (three additional drill rigs procured) without adjusting the maintenance strategy. This resulted in the artisan/technician to equipment ratio decreasing from 1.5 to 0.86 and without the corresponding increase in supervision (Foreman and pit worker).

There are multiple inefficiencies in the drilling section which lead to the poor performance of the section. To minimise or fully eliminate inefficiencies it is necessary to consider autonomous drilling. With autonomous drilling, operators are removed from the drill rigs and they are controlled remotely from a control room.

Findings from the project indicted that, Grootegeluk maintenance and operational structures are not aligned to the number of drill rigs currently on the mine. Drill rigs were increased from four to seven, the maintenance team remained the same resulting in insufficient manpower to service and maintain the drill rigs. UoA dropped mainly due to the increase in a number of drill rigs on the mine without substantial increase in supervision.

It is therefore, recommended that Grootegeluk take a phased approach in improving drill rig utilisation by correcting organisational structure first then replace the current drilling fleet with an autonomous fleet over a period of three years (2020 to 2022), this will improve utilisation from the current 49% to 72%.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AT	Available Time
AV	Availability of Machine
BDT	Breakdown Time
CAT	Caterpillar
DMR	Department of Mineral Resources
DPS	Drilling Piling System
ER	Employee Relations
GG	Grootegeluk Mine
GPS	Global Positioning System
LCD	Liquid Crystal Display
Ltd	Limited
MRM	Mineral Resource Management
MWD	Measure While Drilling
OEM	Original Equipment Manufacture
OEE	Overall Equipment Effectiveness
PME	Planned Mining Elevation
POT	Planned Operating Time
Prod	Productivity of a Machine
PSDT	Planned Shutdown Time
Q	Quality of Work Done by a Machine
RCS	Remote Control Station
ROM	Run-of-mine
SWP	Strategic Workforce Planning
SAP	Systems, Applications and Products
TT	Total Calendar Time
TV	Television
UoA	Use of Availability
USB	Universal Serial Bus
Wits	University of Witwatersrand
YTD	Year to Date

LIST OF SYMBOLS

%	Percentage
Gbps	Gigabits per seconds
h	Hour
km	Kilometer
Ltd	Limited
Mbps	Megabits per seconds
mm	Millimeter
m	Meter
Rd	Relative density
t	Metric tonne

1 INTRODUCTION

This chapter will introduce the research topic by giving a general overview of Grootegeluk mine and the performance of the production drill rigs. The problem statement, research motivation, objectives/purpose and justification of the research report will also be covered in this chapter.

1.1 Background Information

Grootegeluk Mine is part of Exxaro Resources Ltd and is situated in the Waterberg Coal-field in Limpopo province within the Magisterial District of Lephalale. Grootegeluk is the flagship of Exxaro contributing more than 90 percent of the company's profit. The mine has the largest coal beneficiating complex in the world, beneficiating more than 13 000 tonnes of coal per hour from its nine beneficiating plants (Van Heerden, 2016).

The mine is situated 40 km south of the Botswana border. Lephalale has four neighbouring towns which are, Thabazimbi (130 km to the south), Vaalwater (90 km to the south-east), Mokopane (160 km east-south-east) and Polokwane (210km east) (Van Heerden, 2016).

The mine is currently the only one operating in the vast coal resources of the Waterberg coalfield. Exxaro Resources own the property rights pertaining to the mining rights area and prospecting rights. Exxaro is in the process of establishing another coal mine called Thabametse in the Waterberg Coalfield to supply power station coal. Figure 1 shows the locality of Grootegeluk mine.

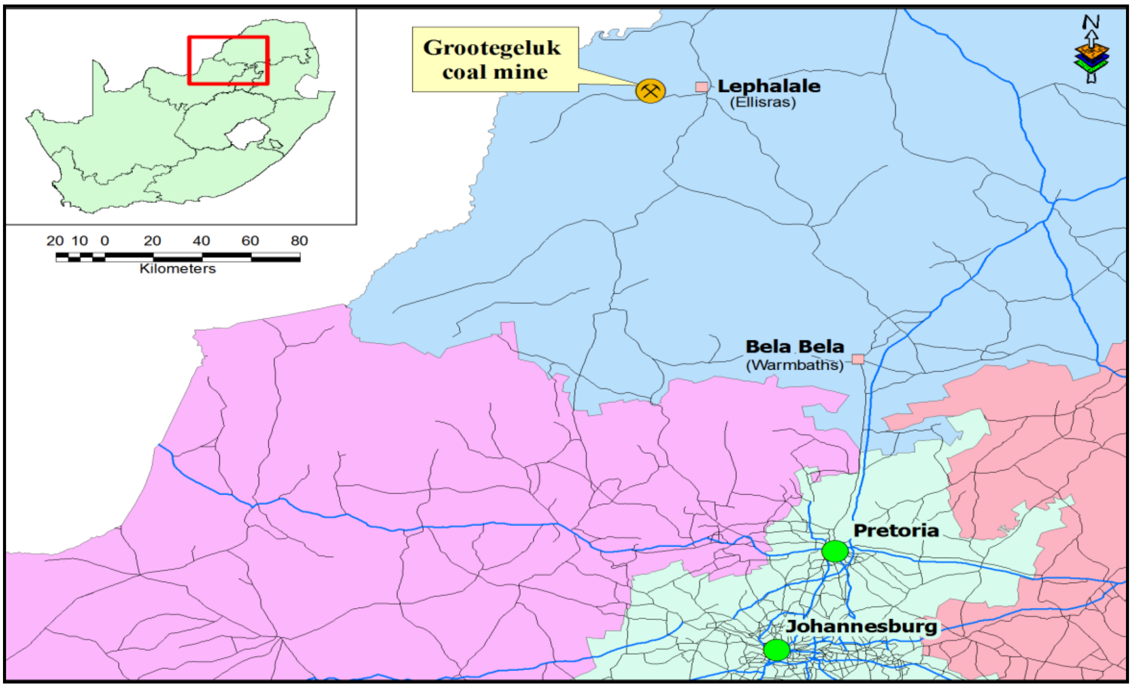


Figure 1: Grootegeluk coal mine location map (Heerden, 2016)

The mine is a multi-bench surface coal mine operation where a series of parallel benches are mined progressively across the deposit. Mining activities employed include drilling, blasting, loading and hauling with trucks delivering ROM to five different tipping areas to feed nine beneficiation plants which produce a variety of coal products.

Four of the tipping areas (three fixed and one semi-mobile) are outside the pit and the other three are semi-mobile crushers located in the pit. This results in shorter hauling distance saving the number of trucks required to feed the beneficiating plants. The nine beneficiating plants produce thermal coal (80.4%), semi-soft coking coal (10.7%) and metallurgical coal (8.9%) of the total product (Venter, 2017) and monthly ROM of 5,5 million tonnes.

Overburden material is mined and transported back into the pit at a suitable location to build a platform for the waste conveyor that takes the discarded material from the beneficiating plant back into the pit. Overburden material is also used outside the pit for construction projects and to seal discarded material to avoid spontaneous combustion of coal. The mine is in the process of assessing the possibility of installing a semi-mobile crusher to enable transportation of overburden by conveyor belt to reduce the number of haul trucks required to remove overburden. Top soil is removed and placed on the Northern side of the Pit for rehabilitation.

1.2 Problem Statement and Research Motivation

Grootegeluk mine is currently at risk of not achieving budgeted drill metres for 2019 and beyond because of poor drilling performance and this risk will always be present if the mine does not improve the performance of the drill rigs. For the year 2019 till the end of October the mine was over 5 million tonnes down on ex-pit tonnes, However, despite being behind on production drilling still struggled to keep up with this reduced production. Based on 2020 business plan, the budgeted tonnes will increase by over 10 million tonnes as compared to 2019 without any increase in number of drill rigs on the mine.

Blasted floor stock tonnes were supposed to be more than planned in 2019 because the mine was 5 million tonnes down on Ex-pit by end of October, but the opposite happened, where a loan drill rig was procured to close the gap created because of poor performance by Grootegeluk drill rigs. Figure 2 shows the production performance for Grootegeluk for the year 2019 and a five-year production forecast (Witt, 2019).

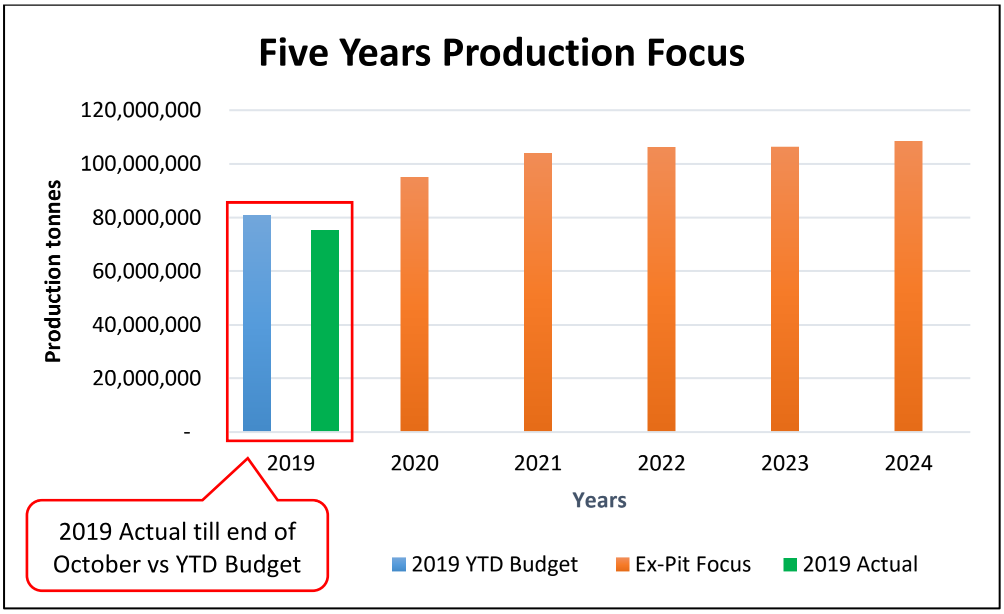


Figure 2: Five years blasted tons focus (Witt, 2019)

Fourie (2016) states that the industry best performance for drill rigs is at 74% utilisation. Grootegeluk is currently budgeting on 51% and the mine struggled to achieve the low utilisation within the budget. To optimise drill rig efficiency, availability, use of availability and drill rate must be considered. Availability and use of availability are interdependent under normal operational conditions and combined gives overall utilisation. Figure 3 indicates drill rig overall utilisation at

Grootegeluk. Drill rig utilisation dropped drastically from 2017 to 2019 mainly due to manpower which is not aligned to the number of drilling rigs on the mine and drilling rigs with more than 20 000 running hours without being rebuilt; rebuilding is supposed to take place at 15 000 running hours.

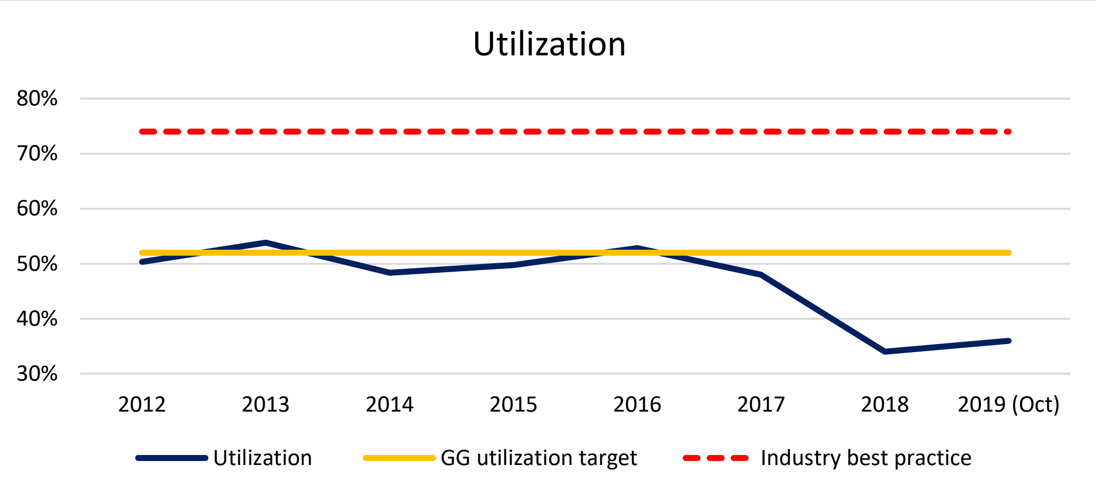


Figure 3: Grootegeluk drill rigs overall utilisation

Currently, Grootegeluk has seven drill rigs operating. They are aligned to the five years drilling strategy, (Table 1). The total drill fleet is made of four caterpillars 6290 (45 ton) and three Sandvik Pantera DP150i (25 ton) drill rigs. Caterpillar (CAT) drill rigs are used mainly to drill the top benches with a hole diameter of 149 mm and the Pantera (P) drill rigs are used mainly to drill the lower benches with a hole diameter of 115 mm. Figure 4 indicates Grootegeluk coal mine benches.

Table 1: Five year drill rigs rebuild and replacement strategy (Mare, 2017)

Drill Type	Drill Number	Hours	2019	2020	2021	2022	2023	2024
Caterpillar MD6290 (45 Ton)	CAT 1		Replaced with Pantera 3					
	CAT2	37 498	Replace			Rebuild		
	CAT 3	22 846	Rebuild			Replace		
	CAT 4	25 231	Rebuild			Replace		
	CAT 5	21 619		Rebuild			Replace	
Pantera DP1500i (25 Ton)	P 1	19 559	Replace			Replace		
	P2	13 130		Replace			Replace	
	P3	5 887			Replace			Replace

Top benches start from bench 1 to bench 5 with a mining height of between 16.9 metres and 13.5 metres. The lower benches start from bench 6 to bench 11 with a mining height of between 8.2

metres and 1.4 metres. Figure 4 shows Grootegeluk mining benches for the top and lower benches.

Bench	Hole depth (m)	Ø (mm)
B1A	16,5	149mm
B1B	4	
B2	13,5	
B3	16,1	
B4	16,9	
B5	16,7	
B6	4	149/115mm
B7A	4,9	
B7B	5,8	
B8		
B9A	4	
B9B	4	115mm
B10	6	149/115mm
B11	4	115mm

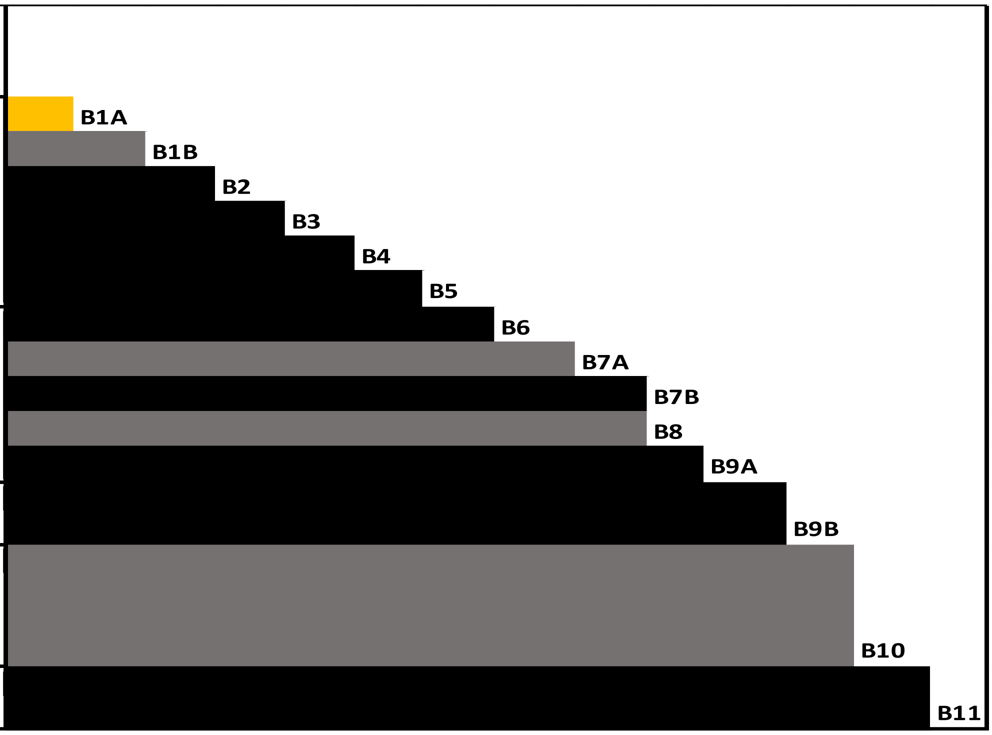


Figure 4: Grootegeluk mine's coal mining benches (Heerden, 2016)

At the beginning of 2019, the mine had to loan a drill from Epiroc (DM30) to close production gap created by poor performance of Grootegeluk drill rigs. The drill was on loan for six months and it was subsequently removed from service in September 2019.

This study will identify the inefficiencies in the drilling section which lead to the sub-optimal performance of the section. The study will also consider autonomous drilling to minimise or eliminate inefficiencies identified.

1.3 Objectives/Purpose of the Study

The main objectives of this project are to investigate various elements that contribute to poor overall utilisation of the drill rigs and low productivity/tempo (hole to hole cycle time) at Grootegeluk mine. The report will present recommendations to address the challenges to get drill rigs overall utilisation above industry benchmark of 74%. Elements which will be investigated are:

- Operational efficiency
    - Overall drill utilisation. This is critical to ensure that drill rigs are utilised within budget with no impact on production of blasted material availability.

    - Availability. This is the time that engineering makes the drill rig available to operations.
    - Use of availability. This is the time mining operations use the drill after it was made available by engineering.
- The hole to hole cycle time.
- Mining losses as a result of poor-quality drilling and
- Monitoring System. To get information for management and to give real-time information to operators.

This project will also explore the opportunity to transition to an autonomous drilling fleet. It will focus on the concept of transitioning all drill rigs over to a full autonomous drilling fleet. With autonomous drill rigs, the overall drill rig utilisation and efficiency should improve at Grootegeluk mine.

1.4 Justification and Relevance

Mining is a series of activities that include drilling, blasting, loading, hauling and dumping. (Elevli & Elevli, 2010). The sequence of mining cannot be changed around, therefore, blasting depend directly on drilling, loading depend on blasting, hauling depend on loading and dumping depend on hauling. This places drill rigs at the start of the mining value chain and failure to achieve planned performance will affect the entire mining value chain.

Grootegeluk, when fully ramped up, will supply more than 80% of its product to two Eskom power stations (Matimba and Medupi) which will produce more than 20% of South African electricity (Witt, 2019). This place Grootegeluk as an important mine critical to Eskom coal supply. The mine is in a contract with Eskom on a “take or pay basis”, therefore, if the mine fails to supply the agreed tonnages to Eskom the mine will have to pay penalties for the shortfall. Grootegeluk also sells a portion of its coal on the spot market and cannot afford to miss the opportunity to sell more product because the mine failed to produce the planned tonnages due to poor drilling.

Improved drill utilisations will eliminate the risk of shovels standing without blasted material. The benefit of improved drill utilisations is increased production tonnages with the same number of drill rigs or same production tonnages with fewer drill rigs. Taking into consideration that production is expected to increase in the next five years at Grootegeluk, it is important for the mine to increase production tonnages with the same number of drill rigs. Findings from this project to improve drill rig utilisation will play a vital role in realising production increase.

1.5 Contents of the Research Report

Chapter 1 introduces the research topic by giving a general overview of Grootegeluk mine and performance of the drill rigs. The problem statement, research motivation, objectives/purpose and justification of the research report are also covered in Chapter 1.

Chapter 2 covers the literature review where reasons for poor drill performance in the mining industry are identified. In Chapter 3 a study method used for the project, resources and a process which was followed are discussed. In Chapter 4 various elements that contribute to poor overall utilisation of drill rigs and low productivity at Grootegeluk will be investigated and analysed. Chapter 4 also explores the opportunity to transition to an autonomous drilling fleet.

Chapter 5 covers solutions considered in resolving Grootegeluk drilling inefficiency. Solution 1 is to increase manpower in both mining operation and maintenance. Solution 2 is translating Grootegeluk drilling into autonomous drilling over a period. Chapter 6 is the concluding chapter where the outcome of the study report is summarised. Chapter 7 is the last chapter where the appropriate recommendations to improve overall drilling efficiency at Grootegeluk mine, to meet current and future drilling demand is made.

2 LITERATURE REVIEW

2.1 Method of Investigation (Root-cause analysis)

Rooney and Heuvel (2004) say root cause analysis can be used to find a solution when there is a production problem. A process which is known or suspected to have a problem must be addressed and prevented from affecting downstream processes. Root cause analysis helps to address the question of why the process is not performing as planned and how do we avoid having the same process of giving problems in the future. For this to happen considerable investigation and investment in time is crucial. Rooney and Heuvel (2004) concluded that when investigating the cause of the problem using root cause analysis the focus should be more on the quality of the process. How did the process not happen as planned and where the weakness in the process is?

Using root-cause-analysis the report will address why drill rigs performance is not reaching the planned target. We will do that by unparking availability and use of availability of the drill rigs. Drill rig cycle time (Hole-to-hole) will be analysed focusing on five main steps.

Productivity of the drill rigs will be analysed focusing mainly on operational delays, drill accuracy, and drill rig monitoring. We will further investigate the possibility of using technology to optimize drill rig performance.

Grootegeluk mine in consultation with Boston consulting group (BCG) applied root-cause analysis to determine what cause haul trucks not to achieve planned direct operational hours per day. The process identified six improvement levers to be addressed (Boston Consulting Group , 2018).

2.2 Overall Equipment Utilisation

More often poor blasting is attributed to inadequate or faulty explosives or initiation systems. However, a study conducted by Rorke (2016) found that poor blasting can be traced back to poor drilling. This is because of a shortage of drill rigs for the planned production or poor performance of the drill rigs resulting in drilling sections being under pressure and does not hand over quality drill holes to the blasting team. This is the case with Grootegeluk, drill rig utilisation is poor and it results in poor quality drilling.

Kalra, et al (2015) sates that, to be able to measure how drill rigs are performing the mine needs to understand overall equipment effectiveness (OEE) on the drill rigs. Fourie (2016) described OEE as a category of metrics that focuses on the process of effective utilisation of equipment. He further describes the OEE of an equipment as an outcome of its operational availability, utilisation of the available time, the productivity of the equipment when in use and quality of the operation. Below is the formula that Fourie (2016) used to calculate OEE.

OEE = Av × UoA × Prod × Q x 100……………………………………………………………………………………… (1)

Where

OEE = Overall equipment effectiveness in percentages

Av = Availability of machine or fleet of machines

UoA = Use of availability of a machine or fleet of machines

Prod = productivity (expressed as operating tempo) of a machine or fleet of machines

Q = Quality of work done by a machine or fleet of machines.

The next step is to compare OEE to the industry benchmark and work towards achieving it. For the effective use of equipment all four parameters must achieve high levels since they all have an impact on overall equipment efficiency.

2.3 Availability

Kansake and Suglo (2015) state that availability is one of the key performance indicators of equipment performance. The rate of production in mining is directly linked and sensitive to availability. Drill rigs are capital intensive machines, it is, therefore, important to achieve and sustain planned availability. Mohammadi, et al., (2015) closely studied the pertinent literature and conducted field studies on different mines across the world to define availability (see Figure 5)

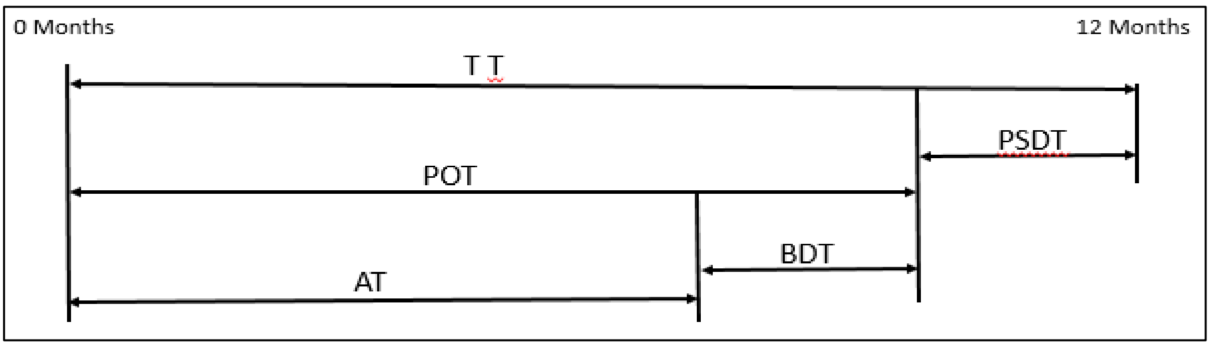


Figure 5: Breakup of total calendar time (Mohammadi, et al., 2015)

Where:

TT = Total calendar time

PSDT = Planned shutdown time or non-scheduled time for operation

POT = Planned operating time or drilling time

BDT = Breakdown time

AT = Available time

Availability in the mining industry can be expressed in various forms. The two forms which will be discussed are operational availability and inherent availability.

Operational availability can further be divided into two approaches (Mohammadi, et al., 2015).

- The first approach is expressed as a calendar time. It can be expressed mathematically as the ratio of available time and total calendar over the same period; and
- The second approach is expressed as drilling time. It can be expressed mathematically as the ratio of available time and operating time over the same period.

The difference between the two approaches is the total accountable time used for evaluating the availability.

The formula for both approaches can be expressed mathematically as follows (Mohammadi, et al., 2015).

$$A_o = \frac{AT}{TT} = \frac{TT-(PSDT+BDT)}{TT} \quad \text{.......................} (2)$$

Where A_o is operational availability (Calendar time based)

$$A_o' = \frac{AT}{POT} = \frac{POT-BDT}{POT} \quad \text{.......................} (3)$$

Where A_o' is operational availability (Drilling time based)

The drilling time based approach will provide a higher operational availability as compared to the calendar based time approach. This is because the calendar-based approach is bigger than drilling time based. Before evaluating availability, it is crucial to understand the selection and application of each approach.

Inherent availability considers the equipment's built-in characteristics including its parts and disregards downtimes caused by other sources like network, two-way radio, diesel and water which are obviously not part of equipment design. These downtimes are beyond the control of the original equipment manufacturer (OEM.) Inherent availability can be expressed mathematically as follows (Mohammadi, et al., 2015):

$$A_i = \frac{MTTF}{MTTF+MTTR} \qquad (4)$$

Where A_i = Inherent Availability

MTTF = Mean Time to Failure

MTTR = Mean Time to Repair

Mean Time to Failure basically means how often a drill rig fails, which can also be referred to as reliability. To decide how often a drill rig should be maintained it is important to understand drill rig reliability. The reliability allows a maintenance team to plan spare parts consumption and a pattern thereof.

Meantime to repair refers to how quick the machine can be fixed after going down on a breakdown which can also be referred to as maintainability. Equipment's inherent availability can be increased by improving its reliability and maintainability, by either reducing length of breakdowns or reducing number of breakdowns (Mohammadi, et al., 2015).

Inherent availability considers the equipment's built-in characteristics including its parts. Inherent availability disregards downtimes caused by other sources which are not part of equipment design such as, network, two-way radio, diesel, water, etc. These down-times are beyond the control of the original equipment manufacturer (OEM).

2.4 Use of Availability

Most managers constantly fight against under-utilisation of heavy equipment. Mond (2015) considers a machine underutilised if it is used less than 4 000 hours per year.

Mond (2015) suggested the following 4 ways to improve equipment utilisation:

- Track every move of your equipment;
- Record engine hour metre at the fuelling station;
- Reward employees with high drill rig utilisation; and
- Estimate based on fuelling amounts.

Equipment can be monitored remotely to give managers insight into the utilisation of the equipment as well as tracking long-term trend analyses (Case Construction, 2015). Data from the equipment monitoring system can be used to make better decisions about the equipment. The utilisation of the equipment can be analysed by adding critical thinking to the data captured from the equipment. Case Construction (2015) states that equipment can better be utilised as follows:

- Identifying under-utilised pieces of equipment;
- Understand how a machine is used and the rate of component wear;
- Right-sizing equipment based on utilisation;
- Benchmarking productivity and performance; and
- Know your operators and how they use the equipment.

Use of availability represent productive use of available hours from maintenance teams. Maintenance teams make equipment available for use by operation teams. Use of availability can be calculated as used time over available time (Case Construction, 2015).

$$\mathrm{UoA} = \frac{\mathrm{UT}}{\mathrm{AT}} \quad (5)$$

Where UoA is Use of availability in percentages

UT is actual drilling time

AT is machine engineering available time

Utilisation represent productivity of drill rig. Utilisation can be calculated by multiplying availability by use of availability (Case Construction, 2015).

$$\mathrm{Ut} = \mathrm{A} \times \mathrm{UoA} \times 100 \quad (6)$$

Where Ut is Utilisation in percentages

A is drilling operational availability.

UoA is use of availability

2.5 Cycle Time (Hole-to-Hole)

Drilling rig productivity can be directly linked to cycle time, therefore, every second for a drill rig is precious to improve productivity. Drill rig performance can be increased by minimising cycle time and improving operator's performance (Mohammadi, et al., 2015). Drilling cycle time, from one hole to the next, can be defined in five main steps; Tramming between drill holes and positioning the drill rig, Levelling the jack to provide stability during drilling, Drilling the hole, Steel Change to drill the hole to the correct depth and Idling.

2.6 Equipment productivity

Strong, et al (2006) advocated that it is not about the machines but how they are utilised. Utilisation improvement of mechanised mining fleets can be achieved when supplier and customer jointly analyse information gathered from the mining system. When presentations are made to management requesting capital and operating expenditure for new drill rig, the basis is usually based on the manufacturer stated productivity outputs. When the new drill rig does not meet the targets as presented when requesting capital approvals, the blame for the poor performance is on availability.

Strong, et al., (2006) conducted a study at Modikwa mine with the aim of improving productivity by practically measuring the role played by availability and maintenance in drilling. He also measured what the equipment does when made available. The study found that if they interrogate the data more thoroughly and objectively, apart from the breakdowns, a lot of valuable time is lost due to the longer drill cycle time. Longer drill cycle time can result in more hours lost than the hours lost due to breakdowns.

Strong, et al., (2006) Concluded that mining equipment productivity is about achieving what you purchased the drill rig for and for the drill rig to achieve key performance indicators that were promised when motivating capital to purchase the drill. The challenge to the mining industry is, therefore, to put the machines to work within a system that will allow it to perform and to align employees who will be operating the drill rig with what the fundamentals issues are.

2.7 Assets Optimisation

Johnson (2013) applied the theory of asset optimisation derived from the concept of lean manufacturing technique first introduced by Taiich Ohno (manager at Toyota who introduced lean manufacturing technique). Johnson (2013) made a fundamental adjustment to the technique so that it can be applied in the mining operation. Taiich Ohno identified a problematic machine and he placed people on that specific machine for the entire shift. They recorded the actual performance of the problematic machine and compared it to the planned performance. They recorded the performance every 15 minutes for the entire shift. He then developed a chart where all the losses and actual reasons for the losses could be identified at the end of the shift.

Johnson (2013) observed that effort is placed more on stops and delays that takes longer to fix. He concluded that stops, irrespective of how small the delays, can accumulate to a bigger loss over time if not attended to as those that take longer to fix. Consideration should be made to accommodate mining because of its unique environment. In mining production is continuous throughout the shift, however, slow running of the machine can equally be taken as a stoppage. In mining, losses can come from different sources such as material, people, machine, poor operating practices and even weather. Therefore, it is critical to have an automatic control system to automatically detect issues causing losses. It is difficult to visually identify processes causing delays on all machines due to geographically spread out teams in mining.

2.8 Operational Delays

Adams and Bansah (2016) studied operational delays in surface mining equipment. They were of the view that productivity in mining decreases because of operational delays which result in production shortfall. They reviewed factors that contribute to operational delays in surface mining fleet systems. Adams and Bansah (2016) classified operational delays into fixed delays, where the time of occurrence and duration is known like shift change and variable delays, where the time of occurrence and duration is unknown like extreme weather.

They identified factors that contribute to the operational delay, which include but not limited to the following:

- Fixed (planned delays)
    - ✓ Shift change
    - ✓ Equipment refuelling
    - ✓ Equipment inspection
    - ✓ Blasting
    - ✓ Lunch/breaks
- Variable (Unplanned delays)
    - ✓ Drill block preparation by the mining operation

- ✓ Equipment breakdowns
- ✓ Waiting for drill pattern and staking from the survey
- ✓ Tramming drill rigs on an uneven floor
- ✓ Drilling extra hole (Because another hole was lost)
- ✓ Extreme weather conditions
- ✓ Wireless network down.

2.9 Drilling Accuracy

Neale (2010) says drilling must be accurate for any blasting to be successful. Deviation on drill plan will lead to poor blast results. Managers end up calling for a blast design to be re-evaluated when fragmentation did not come out as expected. More often the theoretical design is correct and no need to change the design. Neale (2010) calculated that a hole drilled at least 0.5 metres away from the planned position can reduce the explosive power by 35 percent at a certain point.

2.10 Drill Rig Monitors

Raaths (2001) during the study at Optimum Colliery on maximising coal exposure by dragline found that there were processes that were impacting directly on the dragline performance. Raaths installed the Aquila (DM2/5) navigating and monitoring system on the overburdened drill rigs to monitor drill rig performance. His initial intention was to eliminate manual staking and positioning thereby ensuring that a regular pattern is drilled. He realised that drill holes drilled to correct depth reduces drill metres and it minimises coal losses and contamination.

Minescape software was used to create drill patterns on the computer and the information will be uploaded on the drill's on-board computer and the operator will follow the moving map display on MD5 navigation system to position the drill rig to exact hole position. Each hole is assigned unique identification where the XYZ coordinates of each hole get captured by the system after drilling each hole.

The DM2 system that was installed at Optimum drill rigs had the capability to identify various rock formations enabling the system to notify the operators when the drill bit touched coal. The system uses change in back pressure, pulldown pressure, torque, revolution per minutes (RPM) and the rate of penetration to identify rock formations. According to Raaths (2001) Aquila (DM2/5) navigating and monitoring system improved drill rig performance at Optimum colliery by:

- Reducing survey work (no drill rig standing due to no stakes available);
- Accurate hole positioning;
- Less re-drill;
- Reduced over drills;
- Reduced coal losses; and
- Improved blasting performance.

2.11 Use of Technology to Optimize Drill Rig Performance (autonomous drilling)

Epiroc supplied drill rigs to BHP Billiton in Western Australia to optimize drilling on the mine. The drill rigs were operated from a control room 1 300 km away from the mine. BHP reported a 20% improvement in the optimization of its drill rigs. According to Julian Turner, automation of drill rigs can boost operational efficiency (Turner, 2017).

Network communication is key to a successful autonomous drilling. For an autonomous system, contact between the machine and control must be seamless. According to Epiroc the autonomous technology has matured, and most mines are moving in that direction to improve key efficiency for mining operations (Turner, 2017).

BHP reported improvement in digging condition, fragmentation, loading condition and increased payload on the trucks because of automation on the drill rigs. The autonomous drill rig can work 11.5 hours in a 12 hours shift with the capability of one operator controlling a maximum of three drill rigs at once from a control room as compared to 8.5 hours in 12 hours shift with human operators. Automating drilling and eliminating delays experienced when human operates drill rigs and replacing them with technology capable of maintaining consistency thought the shift will improve productivity (Turner, 2017).

Epiroc reported an improvement in the overall speed of the drill per cycle of 16% because of automation. The autonomous drill rig can maintain consistency which human operators struggle with. Epiroc says the autonomous drill rig is guaranteed to be where is supposed to be and drill the exact depth that is designed to drill to (Turner, 2017).

A visit was made by Grootegeluk coal mine team to Goldcorp Penasquito mine in Mexico. The mine reported 25% increase in operating hours per calendar year and 12% increase in metre drilled per operating hour. Penasquito mine indicated that the drill rigs are able to maintain consistence drill rate. The drill rigs were observed operating during blasting and shift change.

3 INVESTIGATIVE PROCEDURE

In this chapter, a study method used for the project, resources and a process which was followed will be discussed. The project scope was finalised by interacting with drilling teams both in mining operations and maintenance. After the interaction changes were systematically introduced from the initial project scope to ensure that it would be beneficial to the mine.

The root-cause analysis was used in this study to ensure that the project provides long-term solutions for the mine. The root-cause analysis helped in identifying whether the problem in drilling was systemic rather than individual. With root-cause analysis, it is important to distinguish between the immediately apparent cause of the problem and the underlying root causes. Below are the steps followed to determine the appropriate action to be taken to optimize drilling and minimize the likelihood of the challenges in drilling recurring.

3.1 Data gathering and analysis

Method for data collection and analysis is important for root-cause analysis. It is critical that the method selected is correct and is well implemented to give accurate results.

- Conduct detailed analysis of available data from both Dispatch and Trimble;
- Conduct time studies;
- Conduct value stream mapping;
- Analysis of current performance;
- Identify bottlenecks within drilling and focus on areas for improvement;
- Study Grootegeluk drilling strategy;
- Analyse and benchmark existing data in focus areas to identify areas for assessment;
- Participate in meetings and conduct interviews with operators, supervisors and management; and
- Conduct lean maturity assessment for each focus area.

3.2 Identify improvement opportunity

Continuous improvement can be achieved if planning put in place is implemented. Data gathered after implementation should be checked for positive differences. Below are the improvement opportunities identified:

- Provide industry best practice;

- Sketch a potential solution for each improvement opportunity; and
- Transition to an autonomous drilling.

3.3 Apply Strategic Workforce Planning

Strategic workforce planning (SWP) is a tool used by Exxaro to determine an efficient number of operators per machine and supervisors per section. The tool is also used to determine the number of engineering personnel required per machine and per section. This tool is used to minimize instances where a section can end up understaffed or overstaffed. The SWP tool will be used in conjunction with a recommendation from OEM when determining organisation structure.

3.4 Consult Original Equipment Manufacturer

Three OEMs' were consulted for this study (Epiroc, Caterpillar and Sandvik), however, in this report where these OEMs' are compared, they will be referred to as OEM A, B and C in no particular order. The reason for this is because this report is not about comparing OEMs' rather understand the capabilities of OEMs'.

4 FINDINGS

The main objectives of this project are to investigate various elements that contribute to poor overall utilisation of drill rigs and low productivity at Grootegeluk. Elements identified as contributors to low utilisation and productivity will be discussed in this chapter.

This chapter will also explore the opportunity to transition to an autonomous drilling fleet. The autonomous drilling will focus on the concept of transitioning all drill rigs over to a full autonomous drilling fleet to improve the overall drilling utilisation and efficiency at Grootegeluk.

It is also important to note that during the study it was identified that mining and engineering organisational structures are major contributors to low drilling utilisation and efficiency at Grootegeluk. The organisational structures are not aligned to support the number of drill rigs on the mine. The mine has been in the expansion process for the last ten years resulting in drill rigs increasing from four to seven. Table 2 discuss problems, observation and production challenges identified in drilling and their root causes. The root causes were arrived at by obtained information from the mine and analysing it. It must be mentioned that only information for 18 months was analysed, and field visit over a period of three months was conducted to observed how the drilling section was operated and also identify improvement opportunities in the section.

Table 2: Problems identified

Problems Identified	Root Cause(s)
1. Low drill availability	
	Increase in number of drill rigs without increasing maintenance teams
	Drill rigs running longer hours than originally designed for
	Critical components not readily available
	No lowbed to take drill rigs from the pit to the workshop for services resulting in drill rigs tramming for more than 8 km to the workshop
	No service truck to service drill rigs in the pit
	Not following current drill rig strategy for rebuild and replacement
2. Low UoA	
	Area too large – only one foreman and three pit workers
	Shift change taking longer
	Bench not properly signed off prior to long walks to next bench
	The current shift cycle is not optimised and thus time is not optimally utilised. Grootegeluk does not operate on Sunday's.
	Delay in transportation of operators
3. Monitoring System	
	No system to measure cycle time
	Therefore, drilling cycle not optimised when tramming between holes due to lack of reliable data

4.1 Drill Rigs Availability

As shown in (Figure 6) target drill rig availability at Grootegeluk is 80%, the mine saw an increase in availability from 2013 to 2016 where 80% was achieved in 2016. The increase in availability was mainly due to new drill rigs arriving on the mine. Table 3 shows the arrival dates of new drill rigs at Grootegeluk where two new CAT drill rigs arrived in 2013 and another CAT drill rig in 2014 respectively. Pantera drill rigs arrived in 2014 and 2016 respectively.

Table 3: Drill rigs arrival dates at Grootegeluk

Drill Type	Drill number	Arrival dates
Caterpillar MD6290 (45 ton)	CAT 1	Jul-08
	CAT 2	Jul-08
	CAT 3	Feb-13
	CAT 4	Jan-13
	CAT 5	May-14
Pantera DP1500i (25 ton)	P 1	Dec-14
	P 2	Nov-16
	P3	Jan-19

The availability dropped in 2017 to 73% which is a concern for the mine. It is critical that drill rigs are operating at an acceptable level all the time when operated and maintained according to OEM recommendations. Availability is the amount of time the equipment is made available to be used by operation and perform as planned. The only year in the past six years where Grootegeluk managed to achieve more than the planned availability of 80% was in 2016.

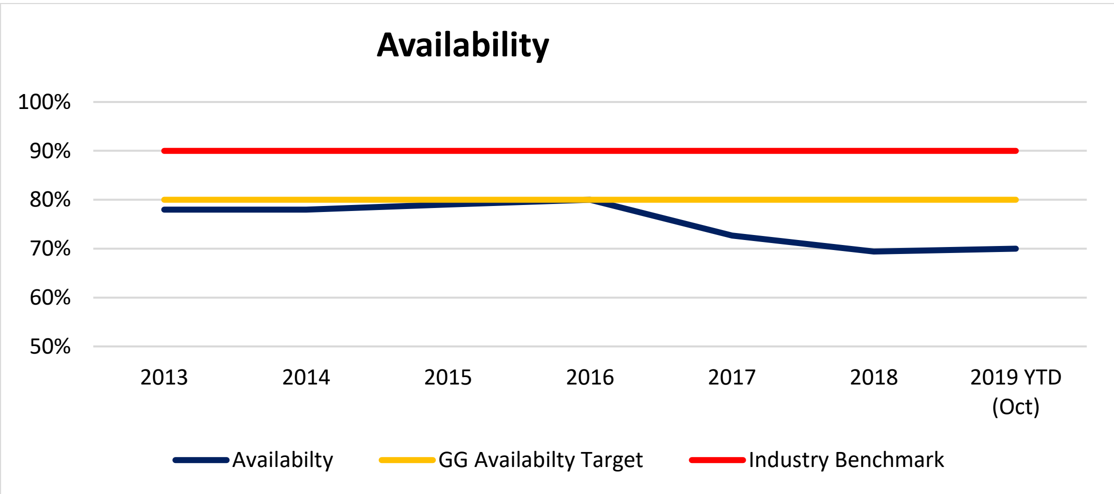


Figure 6: Drilling fleet availability

Caterpillar did an audit on Grootegeluk drill rigs and found that the main contributor to low availability is the maintenance organisational structure which is not aligned with the number of drill rigs currently on the mine. When drill rigs were increased, the maintenance team remained the same resulting in insufficient manpower to service and maintain the drill rigs. Figure 7 indicates an increase in the number of the drill rigs at Grootegeluk.

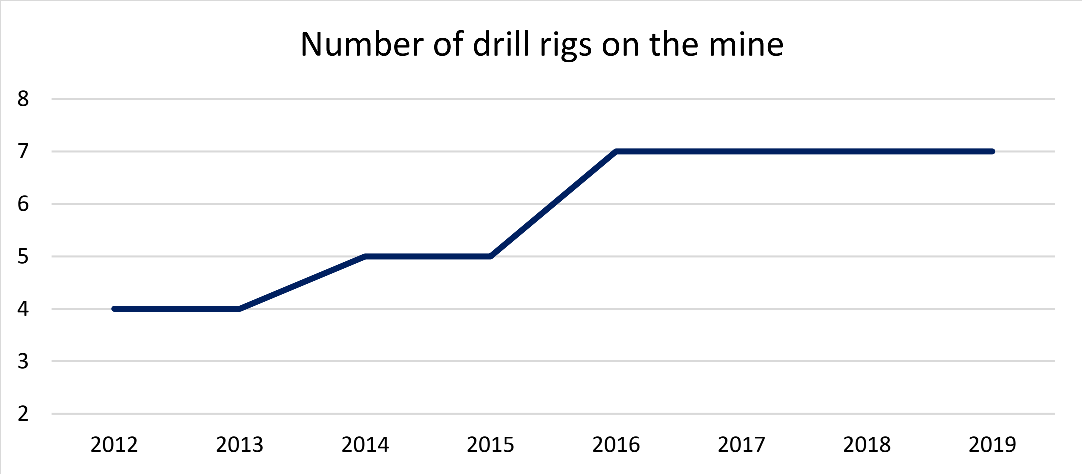


Figure 7: Increase in number of drill rigs

4.1.1 Planned Maintenance

Planned maintenance at Grootegeluk is scheduled per hour interval, executed and recorded with the assistance of SAP Planned Maintenance system.

- Scheduled Services
    - 250/500 hours intervals;
    - 1 000, 2 000, 5 000, 7 500, 12 500 hours services, each containing different additional tasks over standard 250/500 hours service; and
    - Service time differ per each scheduled service interval and it is dependent on the type of service planned.
- Rebuilds
    - Drill rig rebuilds are executed at 15 000 hours intervals for CAT drill rigs. Pantera drill rigs do not get rebuilt but get replaced at 15 000 hours. (It is important to indicate that this is based on the rebuild and replacement strategy which is not followed currently) and
    - Rebuilds are executed by changing components which have reached their life span and repair structures where applicable.
- Other Maintenance
    - Scheduled components change on norm (which is not part of the rebuild and scheduled services) and
    - Condition-based maintenance (condition monitoring and component changed on condition).

4.1.2 Unplanned Maintenance

During field study it was observed that unplanned maintenance shutdowns affect the availability and can partly be attributed to machine abuse and human error. It is expected that if the human error is eliminated by technology, availability will increase resulting in more uptime. During the study it was found that the maintenance team is not sufficient in number.

Barloworld did the audit on Grootegeluk mine drill rigs. The findings from the audit report was that unplanned maintenance could be reduced by 50% if the maintenance team is increased to align to the number of drill rigs on the mine. Part of the audit report is included in appendix 9.4.

4.1.3 Maintenance Organizational Structure

Currently, there is no dedicated drill rig maintenance team and the maintenance personnel for the drill rigs that form part of the secondary equipment maintenance structure. The structure only caters for one foreman who is responsible for the drill rigs, rubber wheel dozers, track dozers and cable handlers (List of all equipment under the foreman is listed in Appendix 9.1). Figure 8 indicates the positions from the secondary equipment structure allocated for the maintenance of the drill rigs. The positions for maintenance of the drill rigs are inadequate considering the fleet size increase from four to seven.

Since 2014 the drilling fleet size increased (three additional drill rigs procured) without adjusting the maintenance structure resulting in the artisans/technicians to equipment ratio decreasing from 1.5 to 0.86. Based on Barloworld recommendation, at least 1.5 to 2 artisans/technicians are required per drill rig. The ratio only looks at the artisan and technicians, it does not include supervisors and helpers.

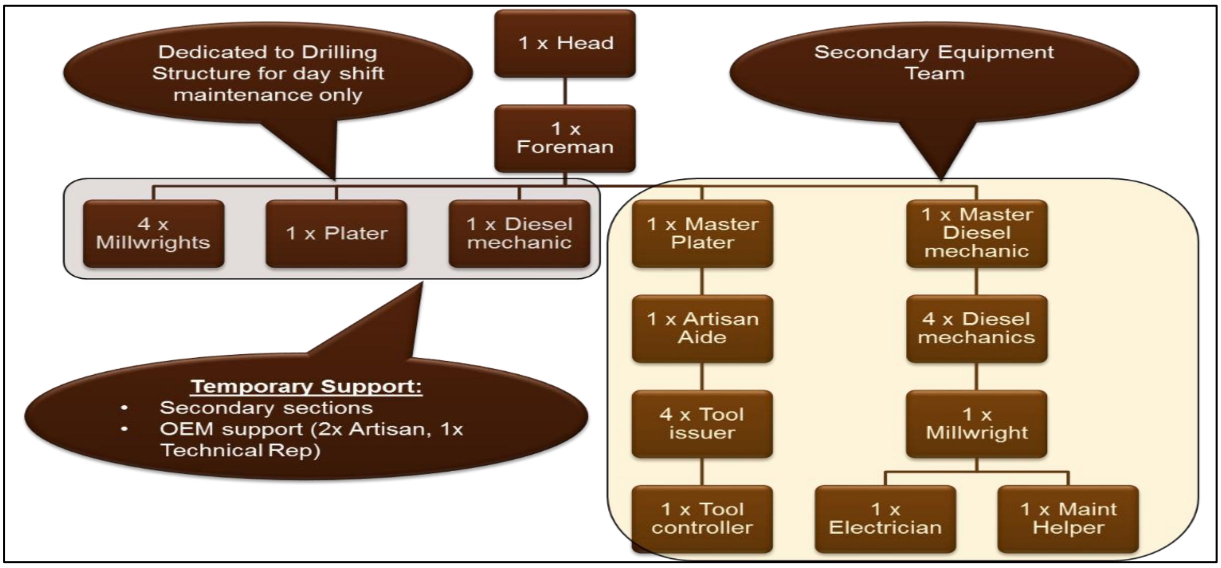


Figure 8: Secondary equipment structure

Currently, the budgeted availability of 80% is not being realised even with the support from the other sections. There are also two additional artisans and one technical representative that is contracted in to assist with the drill rig maintenance. Artisans/technicians to equipment ratio remains 0.86, however, due to help from other sections and the contractors, drill rigs are able to operate. The ratio does increase during the period when additional artisans/technicians are requested from other section to help.

4.1.4 Drill Rig Replacements and Rebuilds strategy

The current drill rig strategy recommends that the 45 ton drill rigs be rebuilt at 15 000 hours and replaced at 30 000 hours and that the 25 ton drill rigs be replaced at 15 000 hours without a rebuild. As shown in Table 4, the current rebuild and replaced strategy is not followed as planned. This results in poor availability and reliability of the drill rigs. Reliability is the failure rate of the drill measured in hours. CAT maintenance availability and MTTF is included in appendix 9.2.

Table 4: Current drilling fleet rebuild and replacement schedule

Drill Type	Drill Number	Hours	2019	2020	2021	2022	2023	2024
Caterpillar MD6290 (45 Ton)	CAT 1		Replaced with Pantera 3					
	CAT2	37 498	Replace			Rebuild		
	CAT 3	22 846	Rebuild			Replace		
	CAT 4	25 231	Rebuild			Replace		
	CAT 5	21 619		Rebuild			Replace	
Pantera DP1500i (25 Ton)	P 1	19 559	Replace			Replace		
	P2	13 130		Replace			Replace	
	P3	5 887			Replace			Replace

4.1.4.1 CAT 2 Replacement Requirement

Despite the drilling hours that have been exceeded well beyond 30 000 for the drill rig. The drill rig shows a significant amount of structural deterioration, declining in reliability and availability. Based on the structural deterioration and poor performance of the drill rig, it must be replaced to prevent inadvertent critical failure.

4.1.4.2 CAT 3, 4 and 5 Rebuild Requirement

CAT 3, 4 and 5 were scheduled to be rebuilt in June 2017, October 2017 and July 2018, respectively. However, the three drill rigs have exceeded their rebuild hours. As a result, neither of the three drill rigs are reaching their availability and reliability targets as shown in Figure 9 and Figure 10 respectively.

Table 5: Drill rig operational hours

Drill Rig	Operating Hours	Rebuild Norm	Engine	Compressor
CAT 3	22 846	15 000	C27	HP
CAT 4	25 231	15 000	C18	LP
CAT 5	21 619	15 000	C27	HP

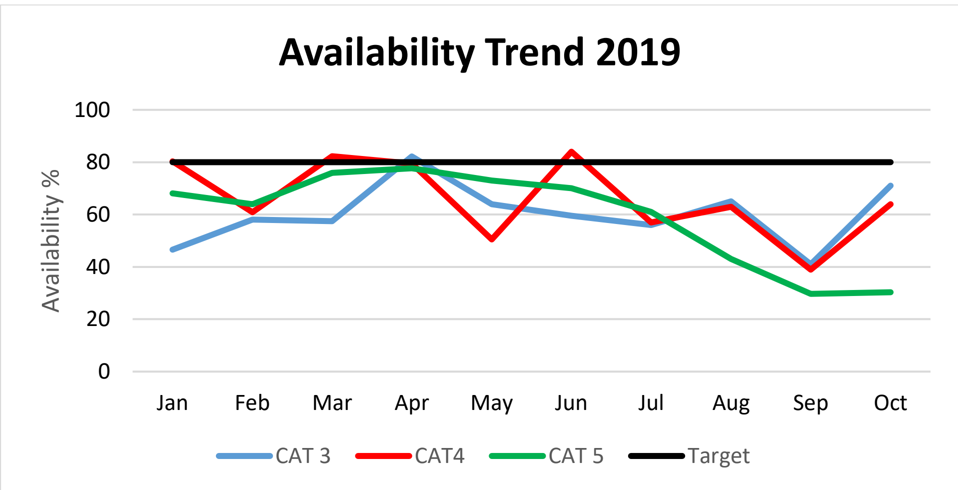


Figure 9: Availability trend

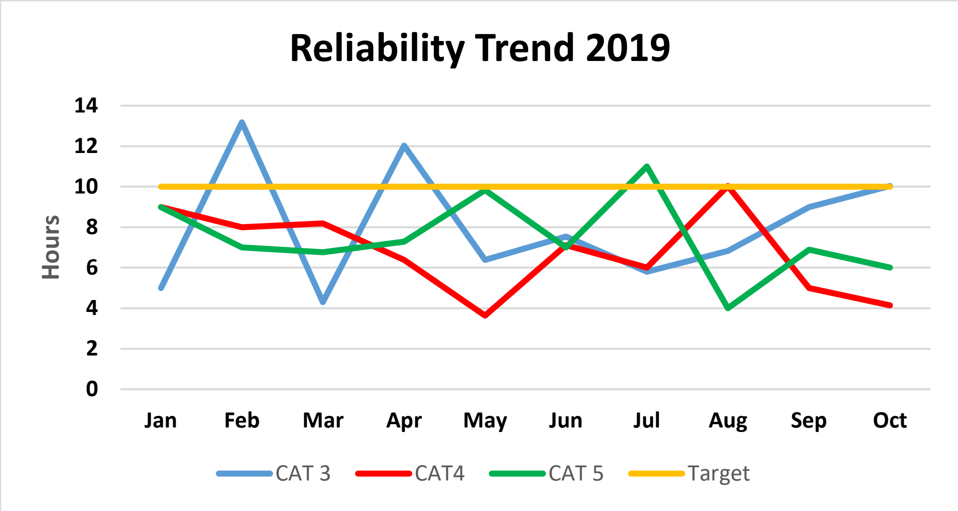


Figure 10: Reliability trend (Mean time between failure)

Figure 9 and 10 shows that the availability and reliability of all three drill rigs are erratic and thus replacing either of the three drill rigs would have a significant improvement on the standards and norms. It is also important to highlight that CAT 3 and CAT 5 are both high-pressure drill rigs and have C27 engines compared to CAT 4 which has a low-pressure compressor and C18 engine. This cause difficulties in standardizing spares for the drill rigs resulting in spares shortage.

4.2 Drill Rig Use of Availability

In Figure 11 the UoA dropped from 69% in 2013 to 63% in 2014 primarily due to increase in number of drill rigs without the substantiating increase in supervision (Foreman and Pit worker). The use of availability has increased slightly in 2019 due to the mine working most of the Sundays and holidays.

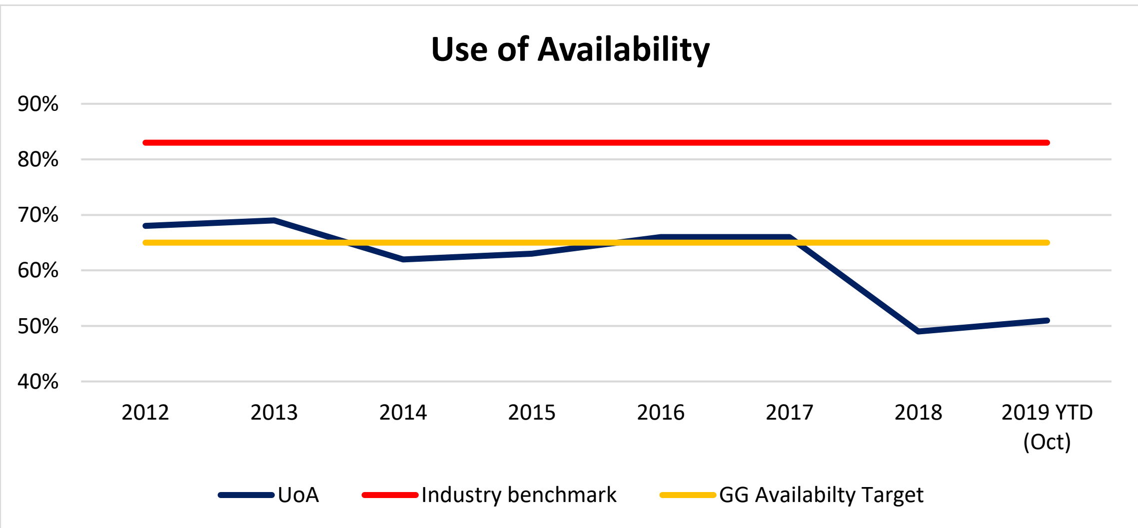


Figure 11: Drilling fleet UoA

A big drop from 2017 to 2018 is mainly due to the requirements by inspectors of mines where a drilling block must be declared safe by a supervisor before drilling can commence. Each drill rig operator must complete pre-use check list before putting the drill rig into operation. Pre-use check list does not have to be signed by the supervisor before drilling can commence. Currently, drilling section has one pit worker in the afternoon and night shift to transport operators to the drill rigs. Some of the drill rigs start working four hours into the shift.

Pit worker is a 2.9.2 appointee as per Mine health and safety act No. 29 of 1996 and regulations. The pit worker is responsible for the development, implementation and maintenance of production standard, health and safety in his/her area of responsibility.

4.2.1 Mining Operation Organizational Structure

The current mining operational structure only caters for one drilling foreman for the section working only day shift and one pit worker per shift. This lack of supervision negatively affects the performance of the section. The two organizational structures in Figures 12 and 13 show the people ratio per equipment and shift, and the total number of positions currently in the structure. Figure 12 illustrates ratios per equipment per shift. Each drill rig has one general worker and one operator. The shift has one relief operator and one multi-purpose vehicle operator. The multi-purpose vehicle is used to refill water in the drill rig, change drill rods and for demarcation of drill blocks.

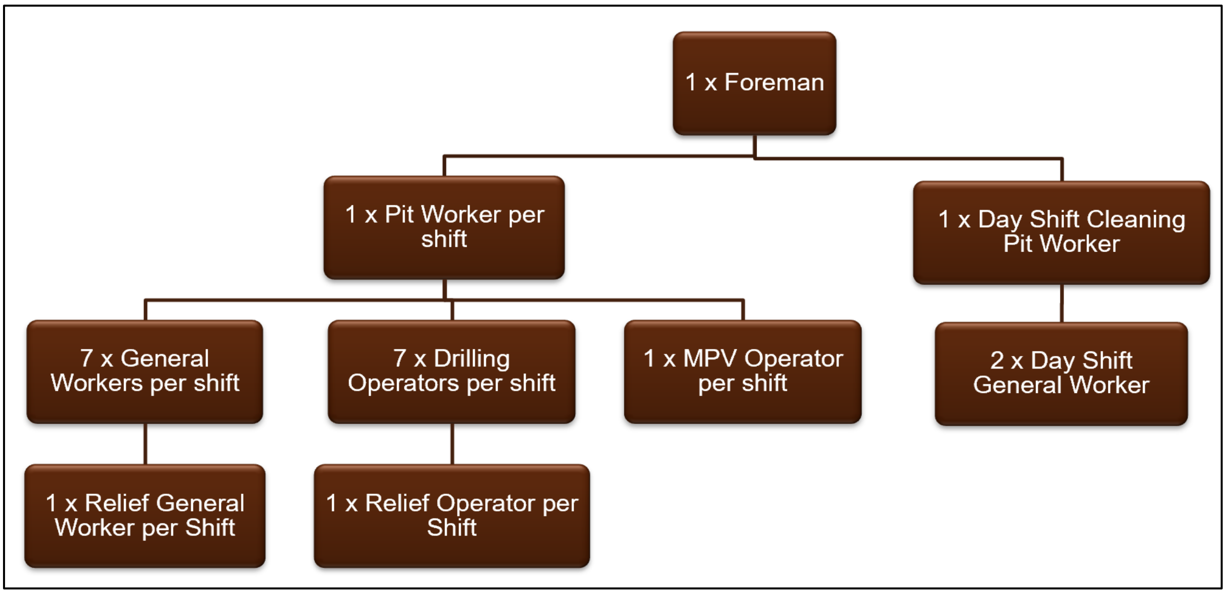


Figure 12: Drill rig section positions per shift

Figure 13 illustrates positions in the operational organisation structure. In total, the drilling section has 59 employees made of, 26 general workers, 22 drill rig operators, 3 relief operators, 3 multi-purpose vehicle operators, 4 pit workers and one foreman. Block cleaning team works only day shift.

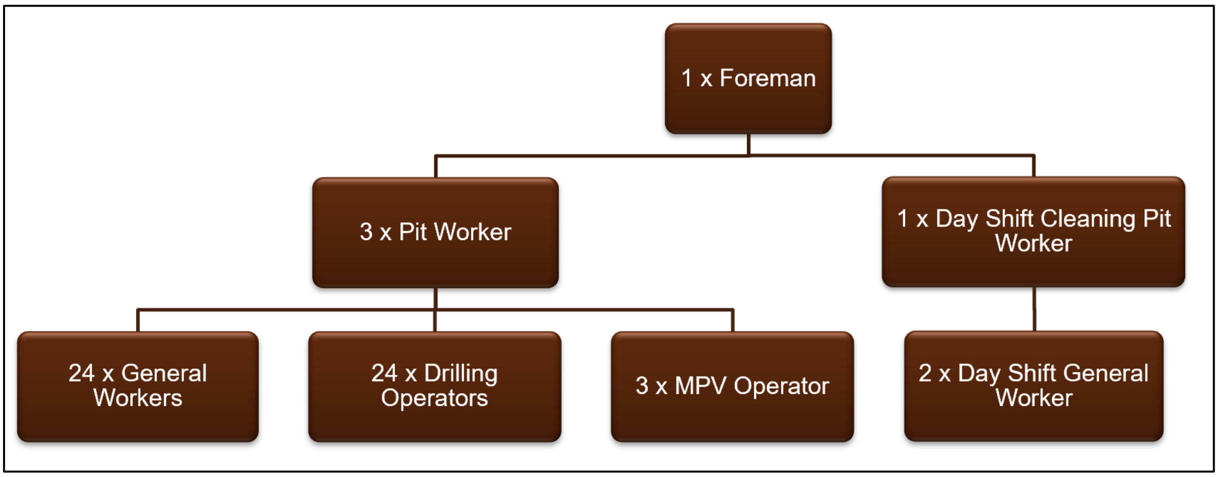


Figure 13: Positions in the drilling operational organizational structure

4.2.2 Operational Downtime which Lead to a Low UoA

Operational downtime which have an impact on the use of availability were identified, they are; shift change, standby no operator, blasting, lunch, toilet breaks, fatigue break, transport, meeting, training, long walk and accident. The biggest single contributor to the operational downtime impacting UoA is standby followed by shift change as shown in Figure 14.

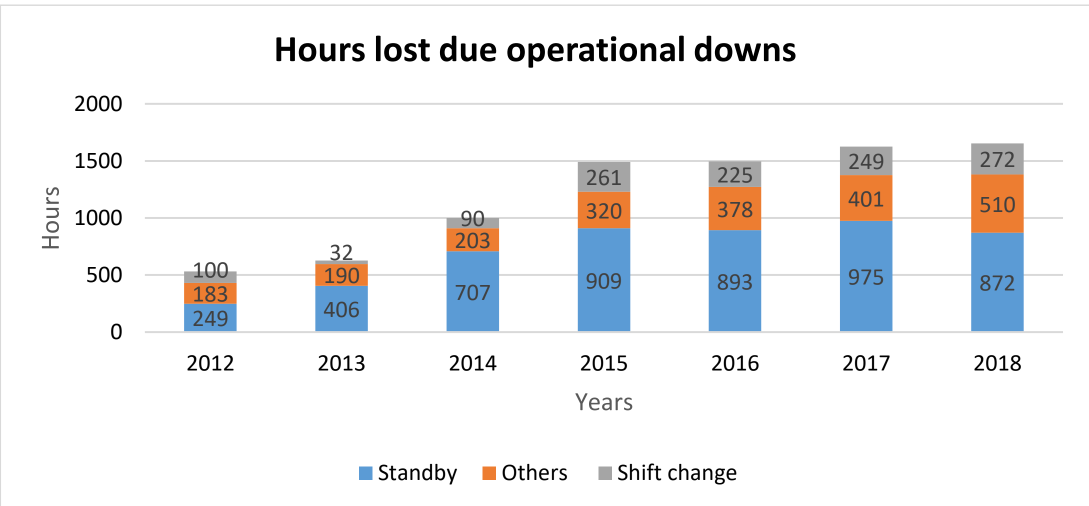


Figure 14: Hours lost due to operational downs

Standby is high mainly due to drill rigs waiting for operators after shift change, this is because of transport and the fact that one pit worker in the afternoon and night shift must take in seven drill rig operators and their assistants to the drill rigs. The pit worker stops on each drill block to conduct safety declaration as per DMR instruction before moving to another drill block to offload operators. Figure 14 shows hours lost due to operational downtime increasing. The increase is mainly due to the number of drill rigs also increased from four to seven. Drilling section has one foreman who works only day shift, the foreman helps the pit worker to conduct safety declaration on day shift, however, night and afternoon shift does not have a foreman to help the pit worker.

4.2.3 Damages

As shown in Figure 15, human error is an inherent factor that cannot be completely removed unless the human interference with drill rigs is removed from the system. Based on damage incident of the last 6 years, we can factor in the damages going into the future to be around 14. Damage incident caused by human are expected to remain around 14 per year if human interference is not removed from the drill rigs.

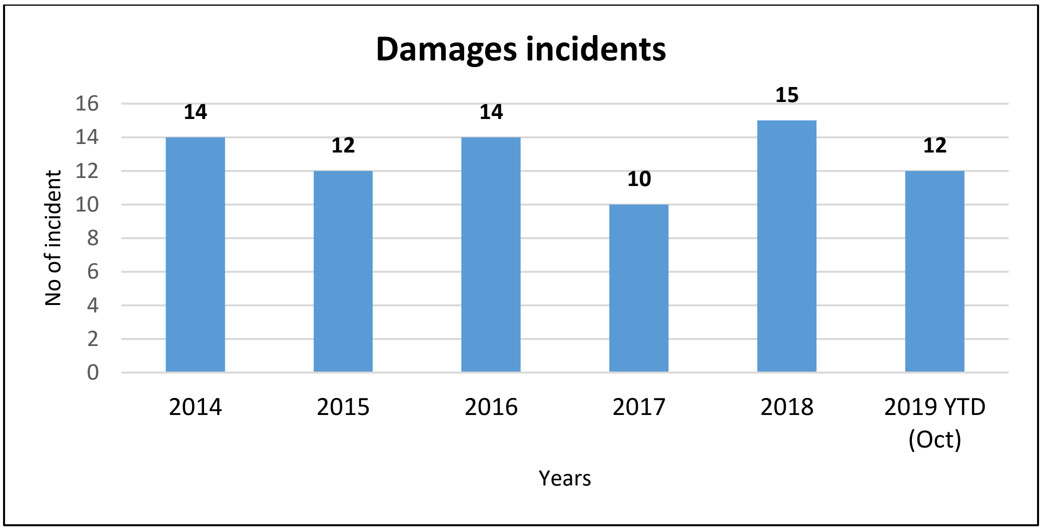


Figure 15: Number of damage incident caused by operators

Safety department record incident per section and store the information. After every incident, the investigation is conducted where the root cause can be determined and share a lesson learnt with other operators. Every time a drill rig stands due to accident or incident it is booked against operational activity or event which has impact on the UoA.

4.2.4 Lowbed

Grootegeluk procured a new 170 ton lowbed (Figure 16) early in 2018 and it was expected to be used in the second half of 2018. However, by January 2019 it was still not yet in use due to the design problem where drill rigs could not get onto the lowbed. The ramps at the back of the lowbed were too steep for the drill rig to get onto the lowbed. The levelling jacks of the 45 ton drill rig were touching the ramp. In February 2019 the ramps were redesigned and fixed, this allowed the 45 ton drill rigs to use the lowbed.

Figure 16: New 170 ton lowbed

The design challenges were resolved and the new lowbed resulted in a huge decrease in the number of long walk hours, below are the benefits of the new 170 ton lowbed:

- The new 170 ton lowbed is able to also transport the Pantera drill rigs which could not be transported on the old lowbed;
- The lowbed is reliable and easy to operate;
- The new lowbed does not need to uncouple the horse and trailer to load/offload equipment as with the old lowbed; and
- No person needed to operate the hydraulics for uncoupling/coupling

The Pantera drill rigs could not be transported on the old lowbed due to the design not aligned to small size drill rigs. The old 120 ton lowbed required two operators, the first one operate the hydraulics for coupling and uncoupling and the second operates the engine to give power to the hydraulics.

Figure 17: Old 120 ton lowbed

4.3 Hole to Hole Cycle Time

The drilling cycle time, from one hole to the next, can be defined in five main steps, tramming, levelling, drilling, steel change, and idling between holes. A time study was conducted for these main steps and the results can be seen in Figure 18. This information was gathered manually in the field by doing a time study, and a system can be used in the future to get the data with high level of accuracy. Detailed cycle element per drill per bench is included in appendix 9.3.

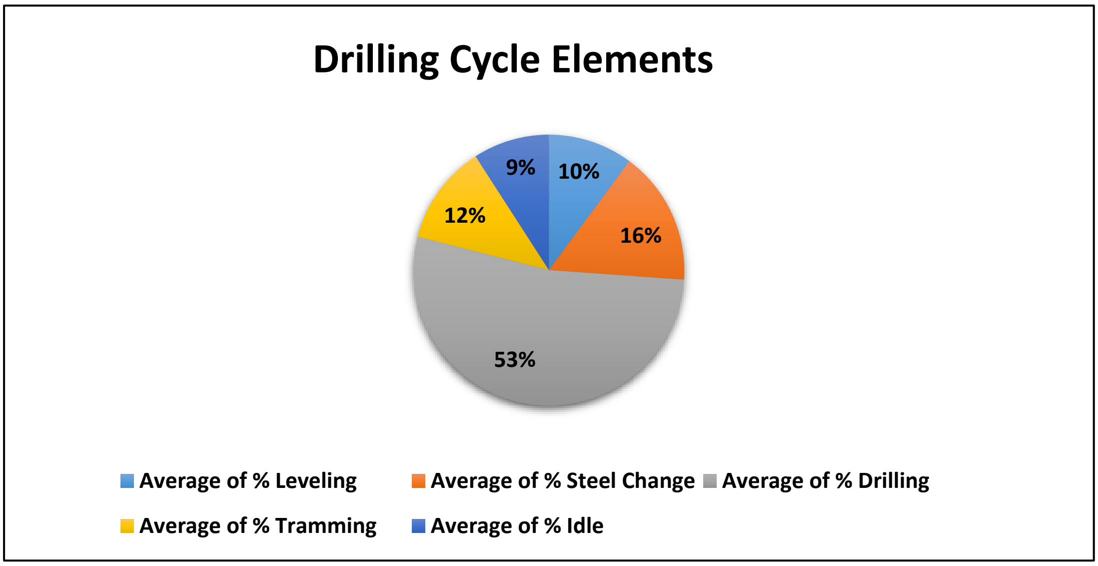


Figure 18: Drilling cycle elements

As shown in Figure 18, only 53% of the time was spent drilling and a significant 9% of the time was spent idling. Idling is a human component and with the introduction of technology, the idle time can be eliminated. Human components also result in longer tramming, steel change and levelling times which results in a longer overall cycle time.

4.4 Drill Rigs Monitoring System

The Modular system has been replaced by the Trimble DPS (Drilling Piling System) 900 system which is more user-friendly and has high drilling accuracy (within 300mm). Figure 19 below shows Trimble high precision drilling overview and how the information is sent to the drill rigs.

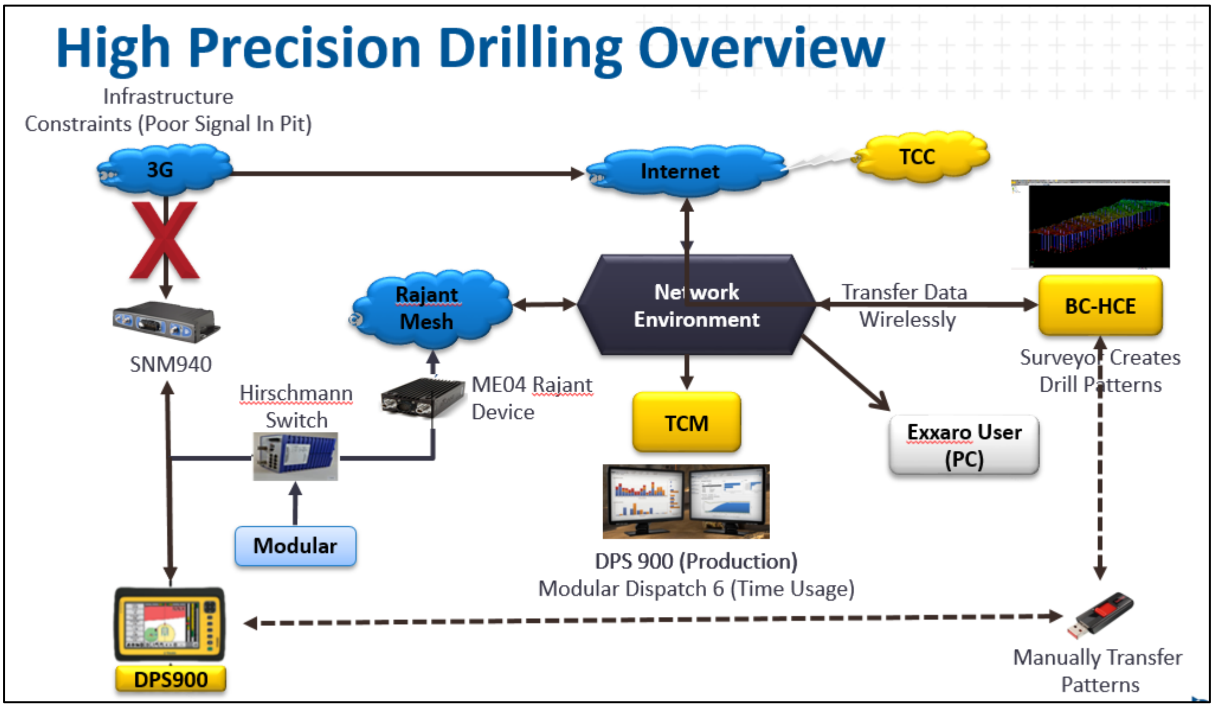


Figure 19: Network configurations (Trimble, 2016)

Production and reporting data is sent from the DPS900 device through the Rajant network to the Trimble connected mine (TCC) server and reporting platform. The SNM940 is Wi-Fi only and has no Ethernet, it connects to the ME4 via Wi-Fi. It collects important data required by the VisionLink in the Trimble cloud. Figure 20 shows the features that are installed in the drill rig and how the information is received and transferred in the field.

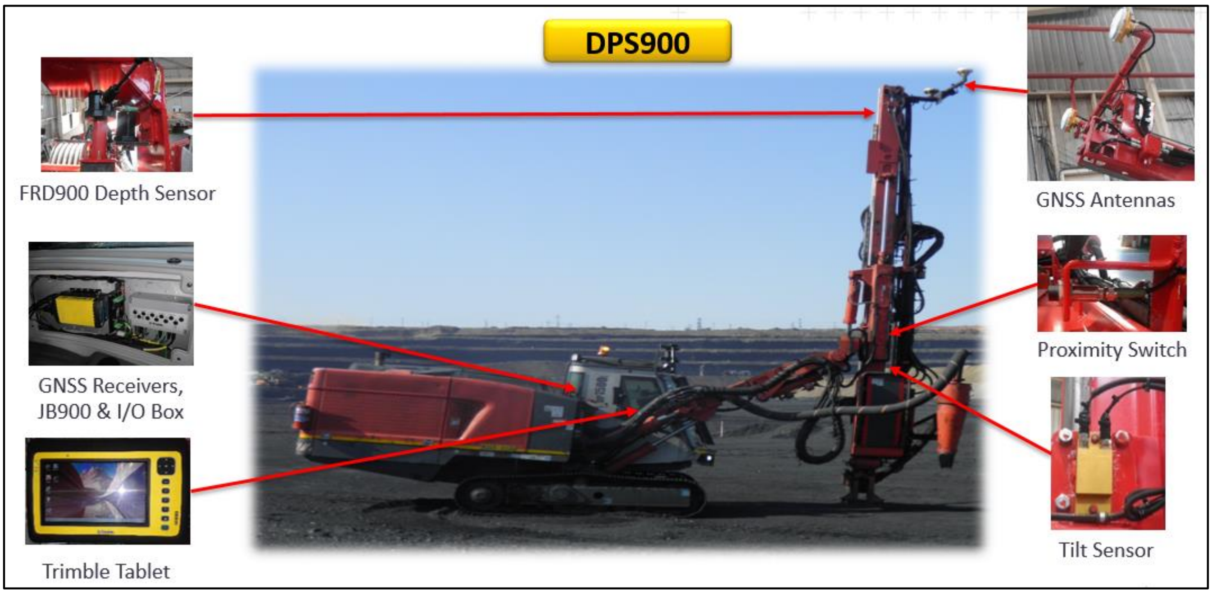


Figure 20: Installed features on the drill rig (Trimble, 2016)

DPS900 system is configured for use with the FRD900 depth sensor and tilt sensor for mast tilt and depth control, the sensors are both connected to the GNSS receivers and JB900 junction box through which they will receive clean power and Ethernet connectivity to each other, and to the site running the DPS900 software. GNSS receivers are connected to the GNSS antennas mounted on the dual-antenna mast mount, which in turn is mounted on the top of the mast of the drill rig. The DPS900 system is controlled by the Trimble tablet mounted on the cab-mount bracket in the cab, which provides the operator interface to the DPS900 system.

4.4.1 Data and Information

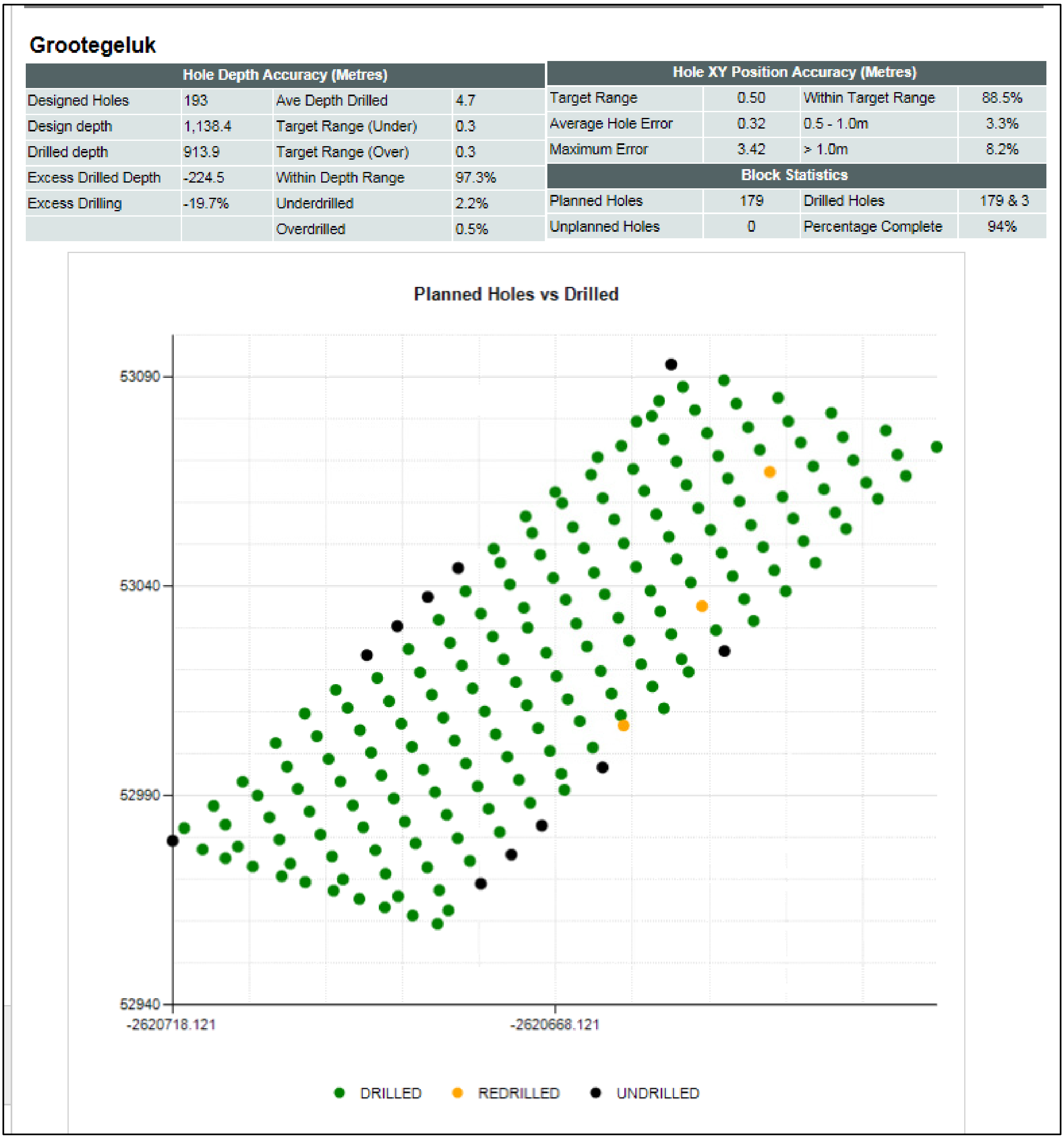
The system tracks and records all the necessary information to do a thorough analysis of the drill rigs. However, the mine still needs to purchase some of the system features like, measuring pressure change between different rock layers while drilling. This is to ensure that all the data required to do full drilling analysis is readily available. Information shown in Figure 13 was gathered manually and the data can be captured automatically in the future by the system.

To get some of the information on the performance of drill rigs, one has to conduct a time study which is time consuming, inaccurate and unsustainable. The following information is still not available but could be available once cycle time reports are completed.

- Drilling time per hole;
- Moving time per hole;

- No data available as to which drill bits perform better on which benches;
- No data available as to which drill rig perform better on which benches; and
- No proper data available to compile a thorough drilling schedule.

Figure 21 shows the block drilling report which gets automatically updated as drilling progresses.



Grootegeluk

Hole Depth Accuracy (Metres)			
Designed Holes	193	Ave Depth Drilled	4.7
Design depth	1,138.4	Target Range (Under)	0.3
Drilled depth	913.9	Target Range (Over)	0.3
Excess Drilled Depth	-224.5	Within Depth Range	97.3%
Excess Drilling	-19.7%	Underdrilled	2.2%
		Overdrilled	0.5%

Hole XY Position Accuracy (Metres)			
Target Range	0.50	Within Target Range	88.5%
Average Hole Error	0.32	0.5 - 1.0m	3.3%
Maximum Error	3.42	> 1.0m	8.2%
Block Statistics			
Planned Holes	179	Drilled Holes	179 & 3
Unplanned Holes	0	Percentage Complete	94%

Figure 21: DPS 900 drilling progress (Trimble, 2016)

The infill holes would be indicated as unplanned holes as they are not designed and require manual stacking. The system records all the drilled holes and the depth and automatically compares them against the planned or designed hole depth. The planned holes, re-drills and infill holes are also recorded and can be clearly identified on the drilling report. The Trimble DPS 900 system can also track the individual performances of the operator as well as the shift average as indicated in Figure 22.

Driller Self Management

Trimble

Operation	Start Date	End Date
Grootegeluk	12/05/2018	12/05/2018

I operated a 20701 for 7.7 Hours and drilled 442 Metres.

Your Performance					
How am I performing on the drill?	You	Your Crew Average	Site Average	Strongest Operator	Target
Hole Depth Accuracy					
On average, what proportion of holes that I drilled had a depth:					
- Within Depth Tolerance?	100.0%	91.9%	94.7%	100.0%	90.0%
- Underdrilled?	0.0%	8.1%	5.0%	0.0%	5.0%
- Overdrilled?	0.0%	0.0%	0.2%	0.0%	5.0%
Hole Location Accuracy					
On average, what was the proportion of holes that I drilled had a location:					
- Within Tolerance?	14.3%	77.4%	75.0%	100.0%	65.0%
- > tolerance < 2x tolerance?	0.0%	3.0%	10.1%	0.0%	35.0%
- > 2x tolerance?	85.7%	19.6%	14.9%	0.0%	0.0%
Drilling T (Minutes)					
Average Hole Drilling Time (Minutes)	17.2	12.0	8.1	0.0	25.0
Average drilling rate (Metres/Operating Hours)	57.2	55.0	59.5	68.2	40.0

Drill Operator: Bonex Jere Drill: 20701 Crew: C Depth Tolerance (Under) = 0.3m Depth Tolerance (Over) = 0.3m XY Tolerance = 0.5m

OMDR017 Generated on Friday, 18 May 2018 9:25:12 AM Page 1 of 8

Figure 22: Self driller management for individuals (Trimble, 2016)

Driller self-management is a report which supervisors can use to track individual performance of operators, how individual operator is performing as compared to the team.

The report shows the following:

- Operators name;
- Start date and end date;
- Hole depth and location accuracy;

- Drill time; and
- Meters drilled for the period

4.4.2 Inaccurate Target Parameter per Hole

Digital designs that are done by the surveyors or any other competent person are sent to the field and updated by the site solution. The data which is sent to the drill rigs indicated the bench number, block number and the depth of each drill hole. The drilling accuracy is within 0.3 m of the design hole depth. If the data cannot be synchronized through the cloud, a manual transfer can be done using a USB. The data which is sent to the production machine can be viewed from the office and the drilling of the block can be tracked. Figure 23 shows the display screen installed in the drill rig.

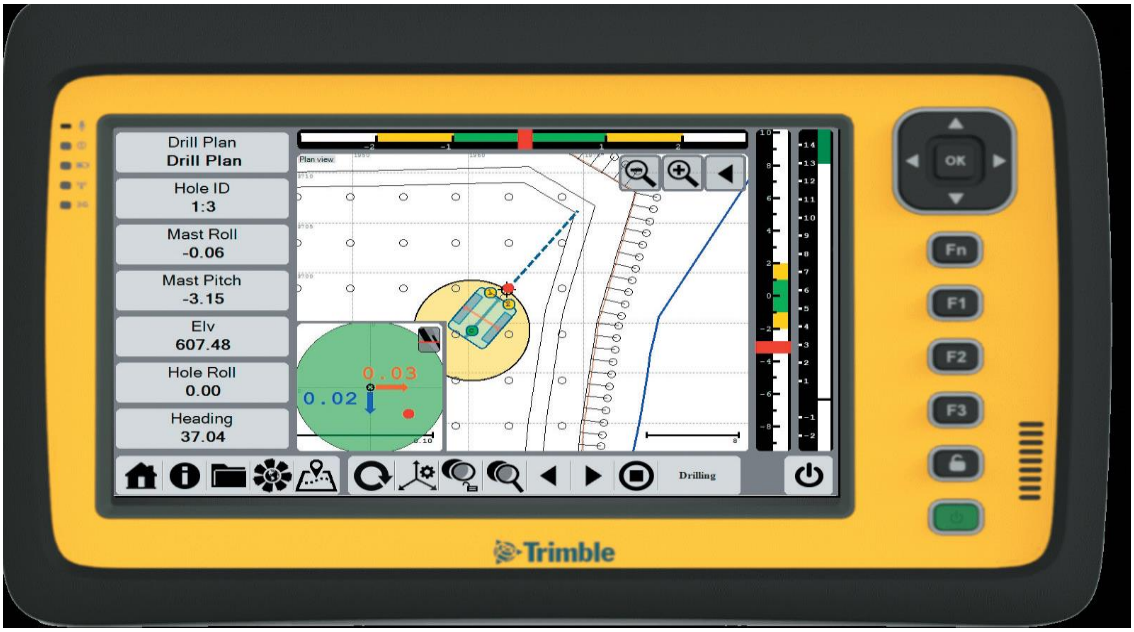


Figure 23: Trimble's operator visual screen installed on the drill rig (Trimble, 2016)

The display screen can be used to change the way the operator interacts with the DPS900 system. Site setup enables/disables access to the site setup screen where the current site, current design, and current drill plan can be selected. The operator can change the map display to use 1 to 4 views and show/hide the pitch and roll axis bars, depth bar and blow count bar.

4.4.3 Operator Error

The operator's margin for error on the upper benches (Bench 1B to 5) has been reduced as the drilling depth of the holes is no longer based on the operator's discretion. The DPS 900 auto stops when the design depth has been reached. However, there is still margin for error on the lower benches (Bench 6 to 11) because of manual operation.

The mine is currently conducting tests to measure while drilling (MWD) to ensure that the error is eliminated. MWD would automatically stop the drill rig when it picks up that there is a pressure change between different rock layers which could be related to a density change.

4.5 Mining Losses Because of Poor Drilling

Mining losses can mainly be attributed to four areas; namely:

- Geology;
- Drilling;
- Blasting; and
- Loading.

With the High Precision Drilling Technology installed on the drill rigs, the mining losses dropped quite significantly. The mining losses could, however, be decreased even more if human error is completely removed. It was observed during field visit that some of the operators does not drill a hole to the correct depth when drilling under pressure especially in areas where they need to add another drill rod to extend the hole depth by less than one metre. Table 6 shows the mining losses for all the benches. The measurements were taken over a period of five months.

Table 6: Mining losses

Bench	Loss-Roof	Loss-Floor	Contamination-Roof	Contamination-Floor	Net Roof	Net Floor	Total Loss	Total Contamination	Net%
2	-5,62%	-3,06%	6,02%	1,22%	0,40%	-1,83%	-8,68%	7,25%	-1,43%
3	-0,54%	-3,30%	2,01%	0,28%	1,47%	-3,02%	-3,84%	2,29%	-1,55%
4	-0,43%	-3,47%	3,03%	0,31%	2,59%	-3,17%	-3,84%	3,33%	-0,57%
5	-0,90%	-2,99%	1,58%	1,15%	0,68%	-1,84%	-3,89%	2,73%	-1,16%
6	-3,44%	-8,60%	9,20%	2,34%	5,77%	-6,26%	-12,03%	11,55%	-0,49%
7A	-0,99%	-5,76%	10,23%	3,89%	9,23%	-1,88%	-6,76%	14,12%	7,36%
7B&8	-2,91%	-3,37%	6,62%	5,92%	3,70%	2,56%	-6,28%	12,54%	6,26%
9	-6,69%	-5,33%	5,54%	1,45%	-1,15%	-3,89%	-12,02%	6,98%	-5,04%
10	-1,42%	-4,78%	16,24%	3,70%	14,82%	-1,08%	-6,19%	19,93%	13,74%
11	-8,14%	-11,46%	7,23%	1,81%	-0,90%	-9,65%	-19,60%	9,04%	-10,56%

The results show that there is a significant difference between the mining losses on the top benches (B2 to B5) and the lower benches to B11. The reason for this is that on the lower benches there are no planned mining elevation (PME) available. Subsequently, the operators are required to drill to the contact. For the high precision drilling system to function, a lower limit needs to be defined where the drill rig will automatically stop. Thus, the operators do not always reach the contact prior to stopping. Installing a pressure sensor on the drill rigs to gather MWD data could alleviate this challenge.

4.6 Autonomous Drilling

There are multiple inefficiencies in the drilling section which lead to the sub-optimal performance of the section. To fully optimize the drilling section's performance these inefficiencies, need to be minimized or eliminated as far as possible. It is necessary to consider technology such as autonomous drilling where the impact of human error will no longer influence the efficiency of the drill rig by decreasing utilisation or increasing fatigue or damages on system components.

4.6.1 Automation Technology Readiness

Since 2016 when the high precision drilling phase was implemented at Grootegeluk there have been significant advances in drilling technology and the level of technology that is available on the market. Three different OEMs, excluding third-party vendors, were consulted in the drilling automation technology investigation. Table 7 and Table 8 shows drilling technology availability comparison for 45-ton and 25-ton class.

Table 7: Comparison of the drilling technology produced by three OEM in the 45 ton class

	OEM A	OEM B	OEM C
Manual Operation	Available	Available	Available
Safety Systems	Full range	Not Available	Full range
Drilling to PME	Available	Not Available	Available
Accuracy	High	High	High
Auto drill (single and double)	Available (S)	Not Available	Available (S&D)
Auto tram	Available	Not Available	Available
Auto Level	Available	Testing	Available
Semi-Autonomous Operation	Not Available	Testing	Available
Tele-remote	Available	Testing	Available
Object detection	Testing	Not Available	Available
Auto bit changing	Not Available	Not Available	Testing
Autonomous Operation	Not Available	Not Available	Available

The findings showed that one of the OEMs currently have multiple sites internationally that are running 45-ton full autonomous drill rigs and both other OEMs indicated that their roadmaps to full automation are well underway. It also shows that the OEMs are already researching and testing automatic drill bit changing. This technology will only be available in a few years' time.

Table 8: Comparison of the drilling technology produced by three OEM in the 25 ton class

	OEM A	OEM B	OEM C
Manual Operation	OEM Discontinued Size Class	Available	Available
Safety Systems		Full range	Full range
Drilling to PME		Availiable	Available
Accuracy		High	High
Auto drill (single and double)		Available	Available
Auto tram		Not Available	Available
Auto Level		Not Applicable	Available
Semi-Autonomous Operation		Not Available	Testing
Tele-remote		Availible	Available
Object detection		Not Available	Testing
Auto bit changing		Not Available	Testing
Autonomous Operation		Not Available	Testing

The findings showed that OEMs are not ready to supply 25-ton fully autonomous drill rig. Indications are that the 25-ton class autonomous drill rig should be ready in 2020.

5 SOLUTIONS CONSIDERED IN RESOLVING GROOTEGELUK DRILLING INEFFICIENCY

Two solutions were considered in improving Grootegeluk drilling efficiency. The first solution is to increase manpower in operation and maintenance. The second solution is translating Grootegeluk drilling into autonomous drilling. Each solution will be discussed in detail and the benefit that can be realised with each solution. It is important to emphasize that the organisational structure first needs to be corrected before the technology can be implemented as a solution to improve the overall Base Case. Table 9 show various solutions considered for the study.

Table 9: Solution considered (Turner, 2017)

Definition	Manual drilling	Automatic drilling of block
Operator dependence and interference	High – operator on drill rig controlling all functions	Low – all drilling functions controlled by the Autonomous system
Operators	1 operator per drill rig	1 operator per one to three drill rigs
Improvement on machine life	0%	20% Longer*
Improvement of accessories life	0%	20-25% Longer due to auto drill (Achieved)
Improvement on fuel consumption	0%	20 to 30%* (Achieved)
Availability	82%*	90-91%* (Achieved)
Use of Availability	71%	90% (No human intervention, no shift change)
Infrastructure	No additional infrastructure is required	Control room with stable mine Wi-Fi network is required
Quality of XY offset	90% (Actual Trimble)	95%*
Quality of Z offset	95% (Actual Trimble)	95%*
Drilling cycle time (Hole-to-Hole m/h)	0% improvement	16% to 20% improvement
Cycle consistency	Cycle consistency is inconsistent	Since no operator is needed the rig will not stand and wait until the rig gets moved to the next hole.
Re-drill reduction	0%	20% reduction*

**Based on information from Epiroc*

From the background information, it was highlighted that there are numerous inefficiencies within the operation which needs to be resolved before considering any form of technology or automation. Hence, for the autonomous solution to be considered, additional manpower first needs to be realised. Although the additional manpower is evaluated as a standalone solution, the same organisational structure changes are incorporated into the evaluation of the autonomous solution.

5.1 Base Case, Additional Manpower and Autonomous Drilling

Base Case, additional manpower (Solution 1) and autonomous drilling (Solution 2) focus on maintaining blasted floor stock levels, drilling capacity as well as quality. The difference between Solution 1 and the Base Case is that additional manpower (operational and maintenance) are required which will increase the uptime on drill rigs. This will, however, not have any additional technological advantages.

The difference between the Base Case and Solution 2 is that the current drilling fleet will be replaced by a fully autonomous drill fleet. This will result in even more uptime which in-turn will result in fewer drill rigs required to sustain the floor stock levels. With Solution 1 and 2, there will be changes to both operational and maintenance structure.

5.2 Base Case

The Base Case is the current drilling strategy used at Grootegeluk mine together with current norms and standards. Grootegeluk drilling strategy indicates that the current drilling fleet will be replaced with the same standard of drill rigs and technology that is currently used on the mine and to keep manpower as it is for both mining operations and mining maintenance.

Drill rig replacements will occur at 30 000-hour intervals and 15 000-hour intervals for 45 ton and 25 ton class drill rigs respectively and 45 ton class drill rigs will be rebuilt at 15 000 hours. Drill rigs will be fitted with a Modular and Trimble DPS900 unit. The benefits and disadvantages of the Base Case are stipulated in Table 10.

Table 10: Base Case benefits and disadvantages

<table>
<tr><th>Benefits</th><th>Disadvantages</th></tr>
<tr><td>No change in operating philosophy</td><td rowspan="2">Not able to use technological advancements to improve drilling norms and standards, safety, etc.</td></tr>
<tr><td>No additional training required</td></tr>
<tr><td>Lower CAPEX per unit</td><td>Not sweating the assets / More drill rigs needed to reach targets</td></tr>
<tr><td>No spare parts management change</td><td>No improvement on GGC NPV Integrated Model</td></tr>
<tr><td>Same operational structure</td><td>Existing challenges remain the same.</td></tr>
</table>

5.2.1 Standards and Norms

The drilling capacity requirements for the Base Case was determined by using the physical standards and norms from Table 11 and Figure 24. In Figure 24, top benches refers to bench 1 to 5 and lower benches refers to bench 6 to 11.

Table 11: Physical standards and norms for Base Case

Norms	Base Case	Comment
Utilisation	49%	Actual 2017, Dispatch / Trimble
UoA	65%	Actual 2017, Dispatch / Trimble
Availability	76%	Actual 2017, Dispatch / Trimble
45 ton Drill Rigs Rebuild and Replace Hours	15 000/ 30 000 hours	OEM Recommendation
25 ton Replace Hours	15 000 hours	OEM Recommendation

Table 11 shows that the availability and use of availability need to be improved to get utilisation to above 74% as stated by Fourie (2016). This means that the rebuild and replacement must also happen as recommended by the OEMs.

Bench	Hole depth (m)	Burden (m)	Spacing (m)	m/hour	t/m	Ø (mm)
B1A	16.5	6.8	7.3	38.241	124	149
B1B	4	7.5	8.7	31.374	140	
B2	13.5	7.5	8.7	56.07	104	
B3	16.1	7.5	8.7	53.694	121	
B4	16.9	6.8	7.3	56.07	92	
B5	16.7	8	9	55.116	135	
B6	4	4	8	54.9	53	115
B7A	4.9	6.8	7.3	39.42	110	
B7B	5.8	6	6	37.512	79	
B8						
B9A	4	5	6	55.44	39	
B9B	4	5	6	54.9	46	
B10	6	4	4	27.99	40	
B11	4	5	6	54.9	46	

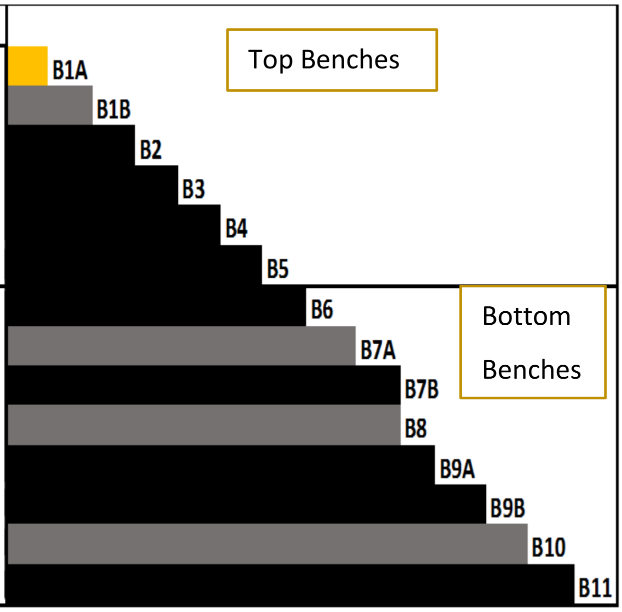


Figure 24: Base Case physical standards (Heerden, 2016)

Figure 24 indicates the physical standards of all benches for the Base Case. Drill hole diameter used for top benches is 149 mm and 115 mm for lower benches. Hole depth is critical for blast pattern design where each bench has its own burden and spacing. It is imperative to remember that the physical parameters for Base Case is the same as other alternatives.

Drill rate is calculated as the meters that are drilled divided by the operating hours of that specific drill rig, expressed in meters per hour. Operating hours include activities of normal operations (drilling, levelling, steel change, and moving from one drill hole to the next, within the same blast block). When operational delays occur, it is booked as a delay or as a standby. Operational delays are not included in operating hours used to calculate drilling rate and will thus reflect in the use of availability Figures. The drilling rate, therefore, can be used as a guideline to calculate how long it will take to drill an entire block.

5.2.2 Ex-Pit Tonnages

Ex-pit tonnages were obtained from the planning department and will form the basis of calculations used when calculating number of drill rigs required per year. Figure 25 shows focused ex-pit tonnages for the top and bottom benches for the period 2019 to 2047.

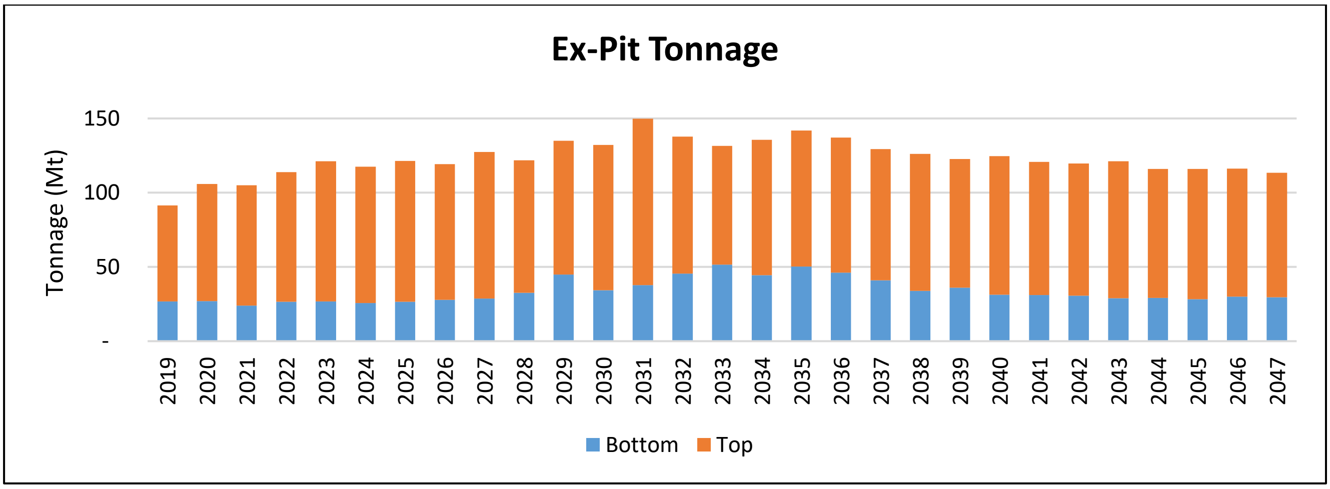


Figure 25: Ex-Pit tonnage requirements for top and bottom benches

Ex-pit tonnages are the sum of ROM and waste mined from the pit. Ex-pit schedule does not necessarily indicate the maximum mining and plant capacity. It is a function of the specific market demand in the various years. Figure 25 gives an indication of the longer term expected Ex-pit tonnages.

5.2.3 Drilling Meters Required

Drill metres required are calculated by using ex-pit tonnages from Figure 25, the ex-pit tonnages are converted to number of drill blocks per bench. Figure 26 shows that drill metres will increase from 2019 to 2035. The number of drill rigs must be aligned to drill metre requirements. Ex-pit tonnes peak in 2031 which is different to drill metres peak in 2033. The reason for the difference is that in 2031 the pit is turning towards the Northern side where more overburden is mined. The overburden on the northern side is weathered and does not need blasting (free digging with hydraulic Shovel).

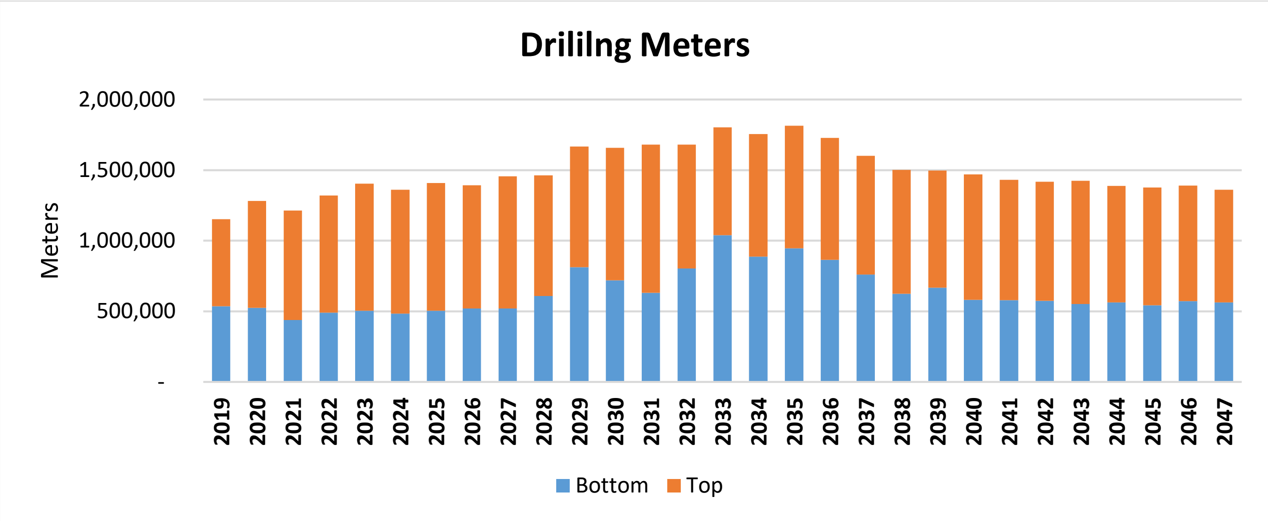


Figure 26: Drilling meters required

Utilizing the tonnes per metre, as calculated from the standard bench parameters as shown in Figure 24, and the Ex-pit tonnage requirements per annum and the drill meter requirements were determined for the top and bottom benches as shown in Figure 26.

5.2.4 Drilling Capacity Requirements

As can be seen from Figure 27 that the number of drill rigs required for the next four years will stay constant on seven drill rigs but will increase to ten drill rigs in 2029 which will also lead to a bigger operational and maintenance structure. Interburden spike can be addressed by moving 45 ton drill rig down to lower benches to mitigate the spike, Fragmentation will not be affected by this move. As can be seen in Figure 27 the Interburden spikes will happen in the year 2029, 2030, 2032, and 2033. When using the 45 ton drill rig on Interburden, blasting pattern/design and power factor will be adjusted accordingly to get the same fragmentation results as 25 ton drill rig.

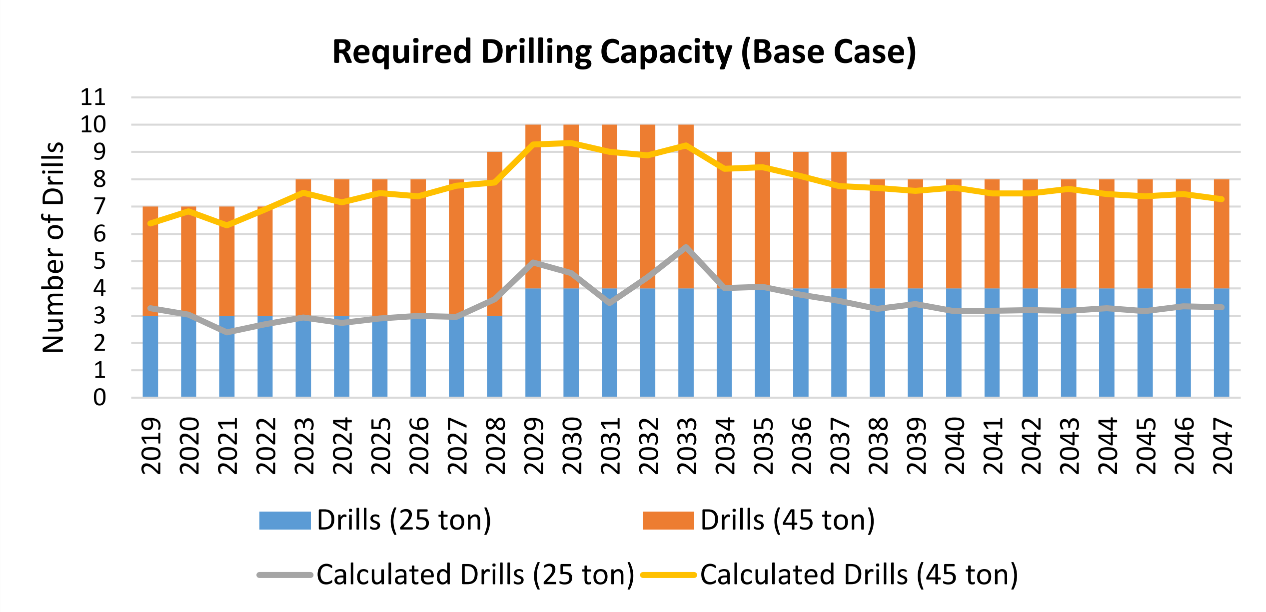


Figure 27: Base Case drilling capacity requirements

Utilizing the drilling meter requirements for the top and bottom benches together with the drilling rate the total drilling time in hours required per bench was calculated. The number of drill rigs required per bench was then calculated using the required hours per bench divided by the scheduled time multiplied by the utilisation as per the Equation 7.

$$\text{No} = \frac{\text{RHB}}{\text{ST}} \text{ x UoA x A x 100} \quad (7)$$

Where No is number of drill rigs required

RHB is required hours per bench

ST is scheduled time per drill rig

A is drilling operational availability.

UoA is use of operational availability

5.2.5 Rebuild and Replacement Schedule

Using the drilling requirements together with the current drill hours the replacement schedule as shown in Table 12 was drawn up showing the drill rig replacements and rebuilds for the next five years. CAT 1 was replaced by Pantera 3 in the begging of 2019, the reason why CAT was replaced with Pantera is to ensure that CAT drill rigs are used mainly on top benches and Pantera drill rigs used mainly on lower benches.

Table 12: Base Case rebuild and replacement schedule

Phases of strategy		Current operation					
	Number	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Caterpillar MD6290	CAT 1	Replace with Pantera 3					
	CAT 2		ME2			Rebuild	
	CAT 3	Rebuild			ME3		
	CAT 4	Rebuild			ME4		
	CAT 5		Rebuild			ME5	
Pantera DP1500i	Pantera 1			Small ME 1			Small ME 1
	Pantera 2		Small ME 2			Small ME 2	
	Pantera 3	Pantera 3			Small ME 3		

In Table 12, ME stand for mass equivalent, meaning 45-ton drill rig will be replaced with another 45-ton drill rig. Based on the current rebuild and replacement strategy as shown in Table 12, CAT 1 was replaced by Pantera 3 in quarter one of 2019, CAT 2 will be replaced by ME drill rig in 2020 and in 2022 CAT 3 and 4 will be replaced by ME drill rig. CAT 5 will be rebuilt in 2020, Pantera 1 will be replaced in 2021 with the same type of a drill rig and Pantera 2 will be replaced in 2020 with the same type of a drill rig.

5.3 Additional Manpower

Solution 1 is based on adding operational and maintenance manpower to the organisational structures. Figure 30 shows 3 additional position in operation organisational structure and Figure 31 shows 9 addition position in maintenance organisational structure for Solution 1. This should result in an increase in the availability as well as better use of availability. The subsequent result will be fewer drill rigs required to achieve the drilling meter target. Figure 29 shows required number of drill rigs for Solution 1 as compared to Base Case. For the year 2029 to 2033 Base Case require 10 drill rigs as compared to 8 drill rigs for Solution 1.

The drilling fleet will still be replaced by the same standard of drill rigs and technology that is currently implemented on the mine. Drill rig replacements will still occur at 30 000 hours intervals and 15 000 hours intervals for 45-ton and 25-ton class drill rigs respectively and 45-ton class drill rigs will still be rebuilt at 15 000 hours. Drill rigs will also still be fitted with a Modular and Trimble DPS900 unit. The advantages and disadvantages of Solution 1 are stipulated in Table 13.

Table 13: Solution 1 advantages and disadvantages

Advantages	Disadvantages
UoA increase due to additional Pit worker per shift	Increased operational costs due to three additional pit workers.
Availability increase due to the dedicated maintenance team	Not able to use technological advancements to improve drilling norms and standards, safety, etc. This is because the operator is still required to be in the drill rig cabin for operation.
Fewer drill rigs needed than Base Case to achieve drilling target	Still stop drill rigs during shift change and if the operators is absent the drill rig stops the entire shift.

5.3.1 Additional Pit Workers and Lowbed Benefit

A time study was conducted over fifteen shifts to calculate the number of drilling hours saved by having an additional Pit worker per shift. On average 87.6 drilling minutes per shift were gained over the drilling fleet as can be seen in Table 14.

Table 14 shows that 87.6 minutes on average can be saved by adding another pit worker to help with shift change and long walks. This means that the mine can save 4 hours 23 minutes per day over three shifts. By appointing an additional pit worker, the mine will save over 1 314 hours per annum. The number of long walk hours planned per month, based on services and moving to new blocks, can be seen in Table 15.

Table 14: Pit worker time study

	CAT1			CAT2			CAT3			CAT4			CAT5			P1			P2			Total
Shift	**2 Pitworkers**	**1 Pitworker**	**Time Lost**	**2 Pitworkers**	**1 Pitworker**	**Time Lost**	**2 Pitworkers**	**1 Pitworker**	**Time Lost**	**2 Pitworkers**	**1 Pitworker**	**Time Lost**	**2 Pitworkers**	**1 Pitworker**	**Time Lost**	**2 Pitworkers**	**1 Pitworker**	**Time Lost**	**2 Pitworkers**	**1 Pitworker**	**Time Lost**	**Time Lost**
1	54	70	16	54	70	16	36	58	22	36	58	22	54	54	0	36	36	0	36	36	0	**76**
2	52	70	18	52	70	18	33	58	25	33	58	25	52	52	0	33	33	0	33	33	0	**86**
3	44	72	28	44	72	28	37	60	23	27	50	23	44	44	0	27	27	0	27	27	0	**102**
4	49	80	31	49	80	31	44	68	24	31	55	24	49	49	0	30	30	0	31	31	0	**110**
5	60	89	29	54	83	29	49	71	22	38	60	22	54	54	0	32	32	0	38	38	0	**102**
6	54	82	28	49	77	28	44	65	21	34	55	21	49	49	0	26	26	0	34	34	0	**98**
7	62	95	33	55	88	33	55	76	21	40	61	21	55	55	0	40	40	0	40	40	0	**108**
8	61	79	18	49	67	18	35	55	20	35	55	20	49	49	0	35	35	0	35	35	0	**76**
9	58	76	18	58	76	18	41	64	23	41	64	23	58	58	0	41	41	0	41	41	0	**82**
10	46	64	18	46	64	18	29	52	23	29	52	23	46	46	0	29	29	0	29	29	0	**82**
11	45	63	18	45	63	18	30	51	21	30	51	21	45	45	0	25	25	0	30	30	0	**78**
12	51	69	18	51	69	18	39	57	18	39	57	18	51	51	0	31	31	0	39	39	0	**72**
13	59	77	18	59	77	18	40	65	25	40	65	25	59	59	0	32	32	0	40	40	0	**86**
14	48	66	18	48	66	18	35	54	19	35	54	19	48	48	0	27	27	0	35	35	0	**74**
15	48	66	18	48	66	18	31	54	23	31	54	23	48	48	0	31	31	0	31	31	0	**82**
Average:																						**87.6**

Table 15: Long walk hours per year

Longwalk to workshop for service					Longwalk to new block				
Drill	**Hours per year**	**Number of service (@ 250 hours)**	**Longwalk hours per service**	**Total**	**Number of blocks per year**	**Average drills per block**	**Number of longwalks**	**Duration of longwalks (hours)**	**Total longwalk hours**
CAT 1	3569	14	2	28					
CAT 2	3569	14	2	28					
CAT 3	3569	14	2	28					
CAT 4	3569	14	2	28	325	2.5	1560	0.67	1045
CAT 5	3569	14	2	28					
P 1	3569	14	2	28					
P 2	3569	14	2	28					
Total hours per criteria:				196					1045
Grand total per year (hours)	1241								
Grand Total per month (hours)	103								

Table 15 shows the total hours lost per year because of long walks. Drill rigs travel to the workshop for 250 hours service. Planned drill rig hours per year is divided by 250 to get the number of times a drill rig will travel to the workshop for the 250 hours service. Each drill rig is expected to run 3569 hours per year, therefore, each drill rig will travel 14 times to the workshop for the 250 service. From Table 15, the number of services at 250 hours is equal to the number of trips each drill rig will travel to the workshop. Each trip is expected to take 2 hours as per Table 15. Using the number of blocks planned to be drilled per year, the amount of time lost when travelling between drill blocks is calculated. Table 15 shows that total hours lost per month for the long walk for the 250 hours service and travelling between drill blocks is 103 hours. It is important to note that even though the distance between blocks and the workshop changes, average distance between drill blocks and the workshop will be used for the calculation. The data from Table 14 and Table 15 were then built into the actual data from Trimble for 2017/2018 which increased the UoA to 71.8% as can be seen in Table 16.

Table 16: Solution 1 UoA

Criteria	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18
Shift change	110	110	110	110	110	110	110	110	110	110
Long walks actual	230,2	184,9	221,7	210,2	256,8	197,9	224,6	271,3	118,7	204,3
Long walks planned	103	103	103	103	103	103	103	103	103	103
Long walks benefit (Due to new lowbed)	127,2	81,9	118,7	107,2	153,8	94,9	121,6	168,3	15,7	101,3
Total Benefit	**237,2**	**191,9**	**228,7**	**217,2**	**263,8**	**204,9**	**231,6**	**278,3**	**125,7**	**211,3**
Fleet scheduled production time	4 493	4 235	4 735	4 043	4 675	4 679	4 658	4 448	3 651	4 957
Fleet available time	3 543	3 184	3 242	3 169	3 324	3 353	3 446	3 534	2 315	3 074
Fleet uptime	2 283	2 043	2 054	2 155	2 258	2 257	2 305	2 399	1 251	2 048
Fleet uptime after benefit	**2 520**	**2 235**	**2 283**	**2 372**	**2 522**	**2 462**	**2 537**	**2 677**	**1 377**	**2 259**
UoMA	71,1%	70,2%	70,4%	74,9%	75,9%	73,4%	73,6%	75,8%	59,5%	73,5%
Average UoMA	**71,8%**									

In Table 16 average use of availability is calculated to be 71.8%. The UoA was calculated by reducing the shift change time to 110 minutes based on the time that was saved by adding a second pit worker. The benefit of new lowbed was calculated and the benefit indicated for each month. Fleet uptime was calculated by incorporating improved shift change time and reduced long walks time.

5.3.2 Maintenance Team Benefit

If maintenance team is increased to align to the number of drill rigs on the mine, the unplanned breakdowns can be decreased by 50% as per the Barloworld audit findings (detailed audit report in Appendix 9.4). Table 17 calculates the percentage improvement in drill rigs availability that can be achieved if the unplanned breakdowns are reduced by 50% by aligning maintenance team to the seven drill rigs on the mine.

Table 17: Reduction in unplanned downtime.

	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Average
Fleet scheduled production time	4,493	4,235	4,735	4,043	4,675	4,679	4,658	4,448	3,651	4,957	4,457
Fleet available time	3,543	3,184	3,242	3,169	3,324	3,353	3,446	3,534	2,315	3,074	3,218
Fleet availability %	79%	75%	68%	78%	71%	72%	74%	79%	63%	62%	72%
Fleet total downtime	950	1,051	1,493	874	1,351	1,326	1,212	914	1,336	1,883	1,239
Total fleet unplanned down	764	890	785	580	820	980	793	607	874	1,478	857
Total fleet planned down	186	161	708	294	531	346	419	307	462	405	382
Half of unplanned down	382	445	393	290	410	490	397	304	437	739	429
Half of unplanned down plus fleet available time	3,925	3,629	3,635	3,459	3,734	3,843	3,843	3,838	2,752	3,813	3,647
Availability after reduced unplanned downtime											82%

Using the period when the study was conducted, Aug 2017 to May 2018, Availability could be improved by 10% from 72% to 82% in the same period. Improved availability is calculated by reducing the unplanned breakdowns by 50% as per Barloworld audit report. The reduction unplanned breakdown by 50% is based on adjusting maintenance team to align to seven drill rigs currently on the mine.

5.3.3 Standard and Norms

From the Pit worker and maintenance team benefit as discussed, the equipment utilisation for Solution 1 was then calculated as can be seen in Table 18. The drilling capacity requirements for Solution 1 was determined by using the same physical standards as Base Case Figure 28 and norms for Solution 1 from Table 18.

Table 18: Norms for Solution 1

Norms	Base Case	Solution 1	Comment
Utilisation	49%	58%	Improvement of 18.4%
UoA	65%	71%	6% UoA gain as calculated in Table 16
Availability	76%	82%	Improved availability as calculated in Table 17
45 ton Drill rigs Rebuild and Replace Hours	15 000/30 000 hours	15 000/30 000 hours	OEM Recommendation
25 ton Replace Hours	15 000 hours	15 000 hours	OEM Recommendation

Table 18 shows that utilisation will improve by 18.4% from 49% Base Case to 58% Solution 1. The improvement in utilisation for Solution 1 is because of 6% gain in the use of availability and 6% gain on the availability after reducing unplanned breakdowns by 50%.

Bench	Hole depth (m)	Burden (m)	Spacing (m)	m/hour	t/m	Ø (mm)
B1A	16.5	6.8	7.3	38.241	124	149
B1B	4	7.5	8.7	31.374	140	
B2	13.5	7.5	8.7	56.07	104	
B3	16.1	7.5	8.7	53.694	121	
B4	16.9	6.8	7.3	56.07	92	
B5	16.7	8	9	55.116	135	
B6	4	4	8	54.9	53	115
B7A	4.9	6.8	7.3	39.42	110	
B7B	5.8	6	6	37.512	79	
B8						
B9A	4	5	6	55.44	39	
B9B	4	5	6	54.9	46	
B10	6	4	4	27.99	40	
B11	4	5	6	54.9	46	

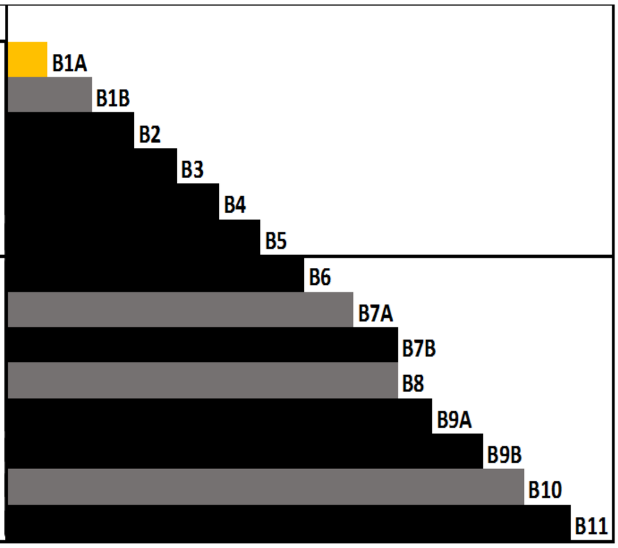


Figure 28: Solution 1 physical parameters (the same as the Base Case) (Heerden, 2016)

5.3.4 Drilling Capacity Requirements

The same process was followed as with the Base Case to determine the capacity requirements for Solution 1. However, since the equipment utilisation was higher it resulted in fewer drill rigs required. From Figure 29, the drilling capacity requirements for large and small drill rigs per annum can be seen for Solution 1 as compared to the Base Case. It can clearly be seen that with the additional manpower, the 45-ton drill rigs capacity required for Solution 1 is reduced by two drill rigs from the year 2029 to 2034. The capacity required for 25 ton drill rigs is reduced by one drill rig from the year 2037.

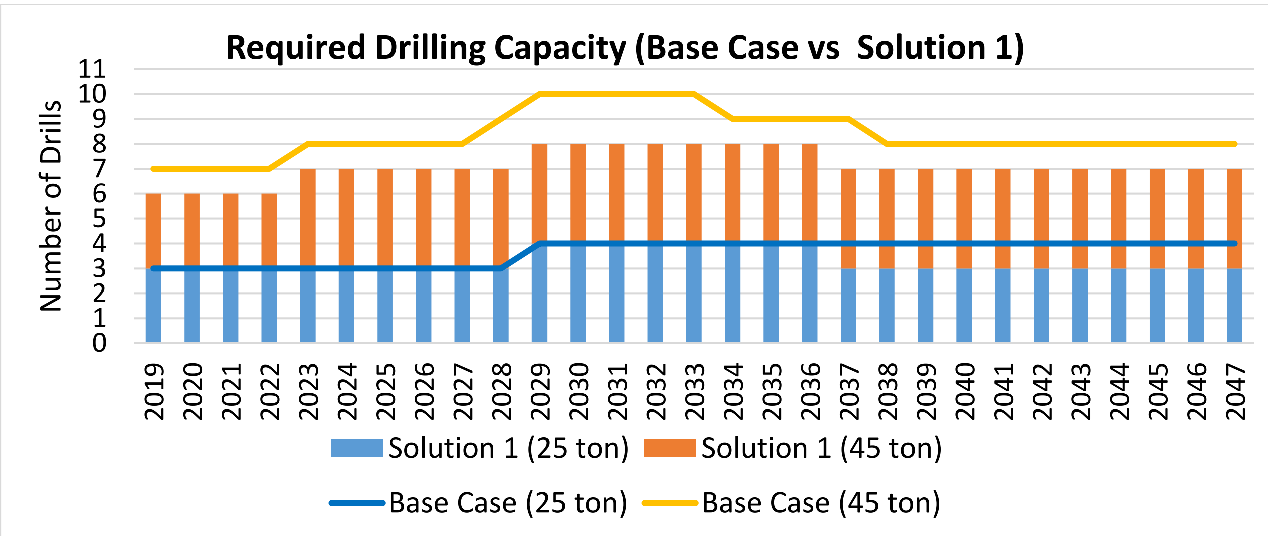


Figure 29: Solution 1 drilling capacity requirements

The graph follows the same approach as it was applied to the Base Case. Utilizing the drilling meter requirements for the top and bottom benches together with the drilling rate, the total drilling time in hours required per bench was calculated. The number of drill rigs required per bench is calculated using the required hours per bench divided by the scheduled time multiplied by the utilisation.

Figure 29 shows Solution 1 drilling capacity requirements for large and small drill rigs per annum and compare to the Base Case. The bar chart shows the smoothed out or rounded up drill rig requirements for Solution 1 where the line graph shows smoothed out or rounded up drill rig requirements for base the case.

5.3.5 Replacement Schedule

Using the drilling requirements together with the current drill hours, the rebuild and replacement schedule (Table 19) was drawn up showing the drill replacements and rebuilds for the next five years.

Table 19: Solution 1 rebuild and replacement schedule

Phases of strategy		Current operation					
	Number	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Caterpillar MD6290	CAT 1		Replace with Pantera 3				
	CAT 2		Remove				
	CAT 3	Rebuild			ME3		
	CAT 4	Rebuild			ME4		
	CAT 5		Rebuild			ME5	
Pantera DP1500i	Pantera 1			Small ME 1			Small ME 1
	Pantera 2		Small ME 2			Small ME 2	
	Pantera 3	Pantera 3			Small ME 3		

Solution 1 shows that only three of 45-ton drill rigs and three of 25-ton drill rigs will be required in the next five years. Based on Solution 1 drill rig requirements, CAT 2 will be stopped taking into consideration that drill hours, exceeded 30 000 hours and the drill rig shows a significant amount of structural deterioration as discussed in section 4.1.4. CAT 3 and 4 will be rebuilt in 2019 while CAT 5 will be rebuilt in 2020. CAT 3 and 4 will be replaced in 2022 while the CAT 5 will be replaced in 2023. Pantera drill rigs will be replaced as indicated in Table 19.

5.3.6 Operational Organisational Structure

Figure 30 illustrates the proposed mining operational organisational structure with additional positions for three pit workers (one per shift). The structure was run through the strategic workforce planning (SWP) model.

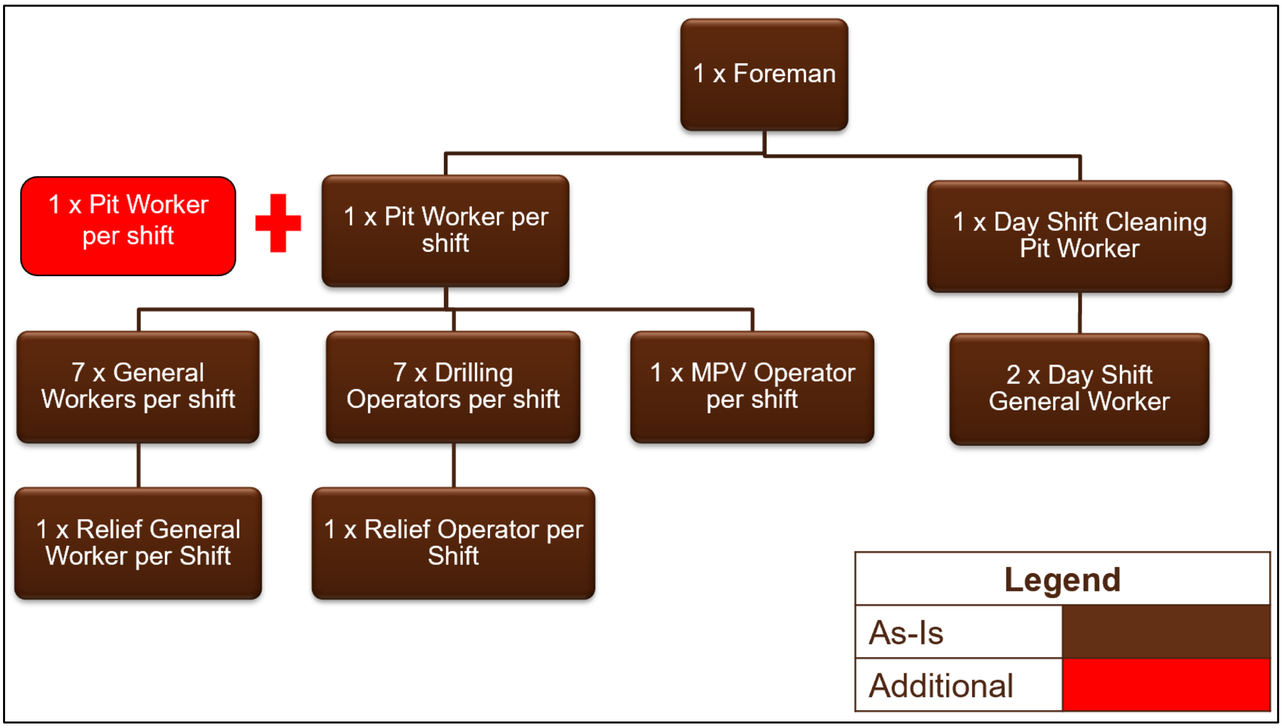


Figure 30: Solution 1 operational structure requirement

With Solution 1, the manpower will increase as the fleet size increases. Amongst others, the additional pit worker will help in improving; quality control, enforcing standards, decreasing shift change time, and decreasing accessory change out time. The addition of an additional pit worker will result in the UoA increasing to 71% compared to the current 65% as shown in Table 18.

5.3.7 Maintenance Organizational Structure

To ensure that the drill rigs are maintained to the required level (above the budget of 80%) a dedicated drill rig maintenance section, as shown in Figure 31 is required. The section should make provision for a dedicated Foreman, Master Artisan, additional Millwrights, Artisan Aids and Maintenance Helpers. The number of Millwrights, Artisan Aids and Maintenance Helpers will change with the number of drill rigs changing as dictated by the SWP model. The SWP suggested that a ratio of 2 employees be allocated per drill rig (one Artisan together with an Artisan Aid or

Maintenance Helper). The additional maintenance team will result in the availability increasing from the current 76% to 82%.

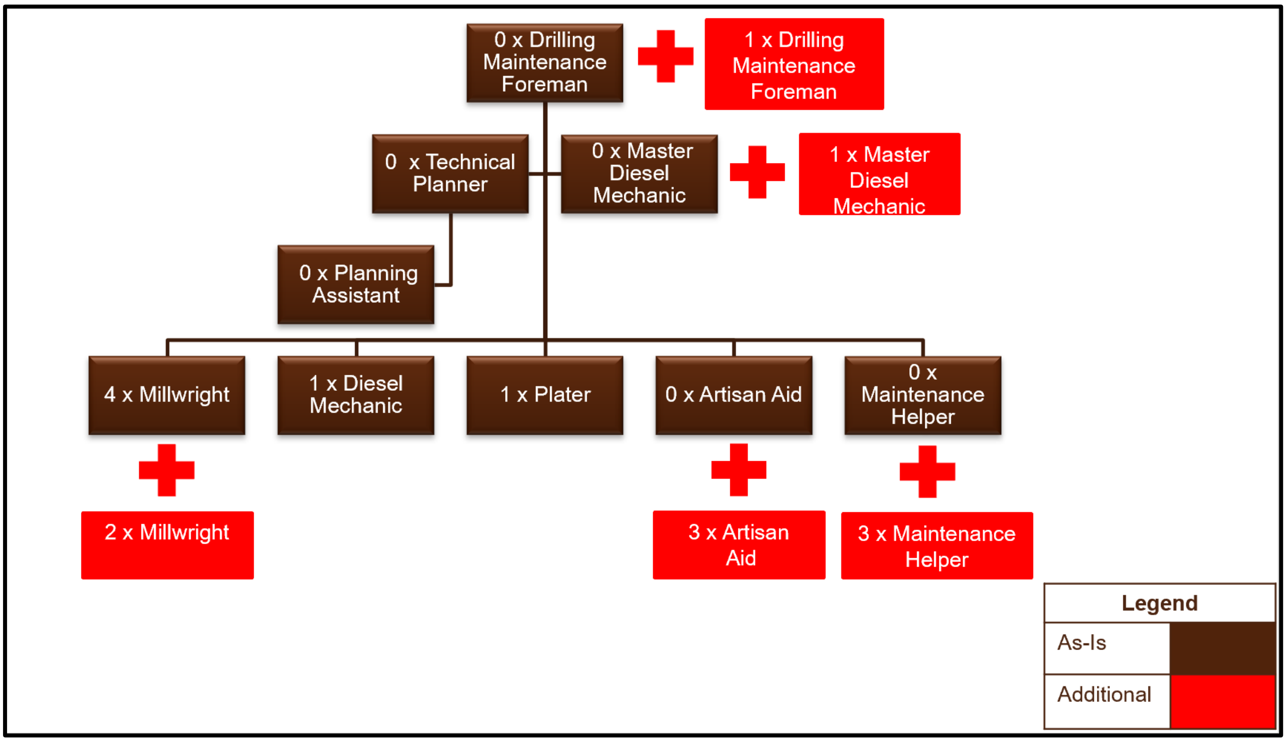


Figure 31: Solution 1 maintenance organizational structure requirement

Figure 31 shows the additional position that must be created as per Solution 1. A dedicated drill rig maintenance foreman must be appointed together with one master diesel mechanics, two millwrights, three artisan aids, and three maintenance helpers.

5.4 Autonomous Drilling

Solution 2 will replace the current drilling fleet with an autonomous fleet over a period of three years (2020 to 2022). Autonomous drilling is where the operator is removed from the drill rig and only monitors the drill rig from a remote location or control room. All the drilling cycle functions namely drilling, tramming between holes, levelling and rod changes are controlled by the machines artificial intelligence system. Functions such as filling water, changing drill bits and rods, filling diesel, tramming to next benches and blocks would still require human intervention.

5.4.1 Autonomous Drilling Overview

Figure 32 portrays an overview of an autonomous drilling system. The drill rig can be operated from either a control room or manually from the cab of the drill rig if inadvertent conditions ever prevail. With autonomous drilling one remote control station (RCS) can be used to monitor/control one to three drill rigs simultaneously. Average bench height for top benches is 13.95 metres and lower benches is 4.6 metres (Figure 34), to drill a hole on top benches it will take more than double the time it takes to drill a hole on lower benches, therefore, less time will be spent drilling a hole on lower benches as compared to top benches. This well results in a drill rig moving more frequent between holes on lower bench.

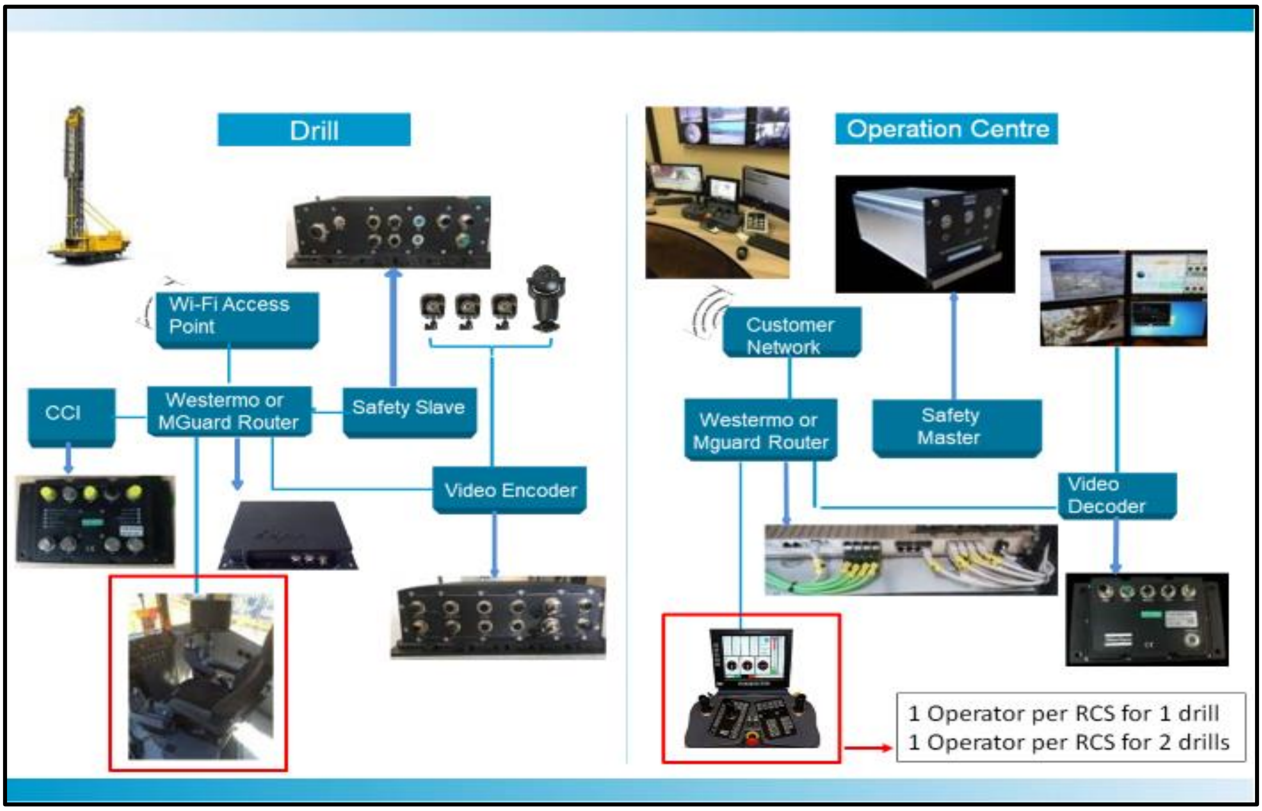


Figure 32: Autonomous drilling system overview (Mare, 2017)

Figure 32 shows an autonomous system overview where common communication interface allows the rig control system (RCS) screen to communicate with the surface manager, remote desktop and rig remote access (RRA). The machine server negotiates the assignment of autonomous drill rigs via the operator control station (OCS). The OCS start the safety heartbeat between safety master and their paired safety slaves. RRA client displays the status of connected rigs and monitors the transfer of files between rigs and RRA server. Desktop viewer remotely views the RCS screen as if they are on the drill rig.

Table 20 and Table 21 depicts the benefits and challenges of autonomous drilling as well as the operational improvements which could be realised, based on the information from OEM. Note that this information is not tested and rely on the OEM, this is because autonomous drill technology is still new and only a few sites in the world run fully autonomous drill rigs.

Table 20: Autonomous drilling operational improvements (OEM)

Description	Improvement on Base Case (Percentage point)
UoA	▲20%
Availability	▲9%
Utilisation	▲23%
Hole-to-Hole drilling rate (m/h)	▲16 to 20%
Diesel consumption	▼20%
Drilling accessories	▼10%
Additional hours run pa	▲1 936 hours

In Table 20 utilisation improve by 23% as compared to the Base Case. Availability improves by 9% and the use of availability improves by 20%. Diesel consumption is down 20% with autonomous drill rig because the drill rig has less idle time and moves quicker with precision between drill holes as compared to the Base Case. In Table 21 it is important to highlight that employees will not be retrenched but re-deployed to other section.

Table 21: Autonomous drilling benefits and challenges (Turner, 2017)

Benefits	Challenges
The consistency of performance and predictability	Increased CAPEX (Drill rig, infrastructure, IM)
Efficiency increase	Change management process
The decrease in machine damages	Possible human resource impact (re-deployment)
The decrease in bit damages and bent rods	Additional training
Drilling quality & accuracy (x,y,z) improvement	In time management complexities
The decrease in re-drilled holes	Control room setup
Safety improvement	Network stability
Real-time reporting and monitoring	Pit visibility
Improved geological information availability (MWD)	Employee relations management
Production time increase	

Autonomous drill rig will eliminate delays experienced when human operates the drill rig, this will result in improved performance, consistency and predictability. Human get bored when doing repetitive activities like drilling. Start of shift, human performance is high as the shift progress the performance drops (Caterpillar, 2018). Autonomous drill rig cannot be distracted, it does not have distressful problems at work and at home. Autonomous drill rig quality and accuracy is high, the drill rig will always drill a hole as planned to the correct depth, and this will eliminate re-drill holes. Human does have tendency to deviate from the planned when under pressure.

Change management will be crucial to ensure that the autonomous drill rig get the support from employees. Because of high unemployment in the country most employees might feel that the drill rig will take their jobs. Grootegeluk is in the expansion phase which will require more employees and the expansion is expected to continue for the next few years. Therefore, employees who are not able to operate the drill rig will be moved to other sections.

Network communication is key to a successful autonomous drilling, the drill rig will automatically stop if communication breaks between the control room and the drill rig. Additional safety measure for the autonomous drill rig are bench cameras, the drill rig will be stopped if visibility in the pit deteriorate to a point where employees in the control room cannot see the drill rig on bench cameras.

Figure 33 shows the improvement in the drilling cycle elements where it is shown that the average time spent drilling increased significantly due to the other elements taking less time. Due to autonomy, the idle time decreases to 0%.

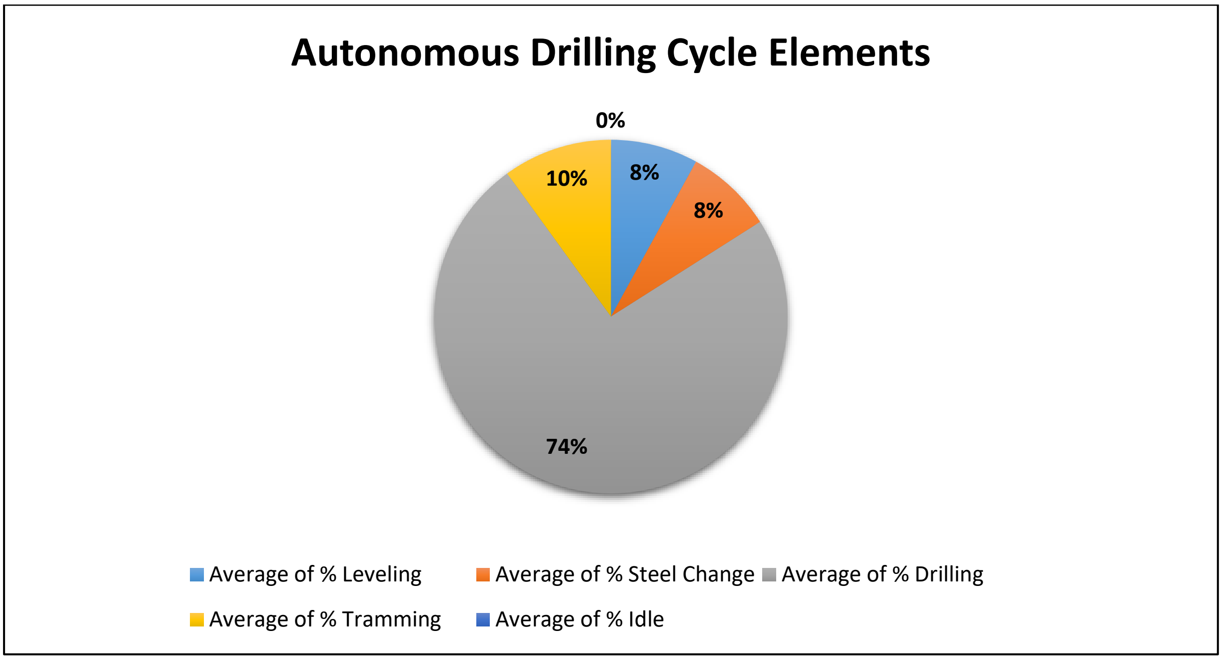


Figure 33: Autonomous drilling cycle time (Turner, 2017)

Information from Figure 33 was obtained from the OEM who supply the autonomous drill rigs. With autonomous drilling, the mining losses would also potentially decrease. The is because autonomous drill rig has high drill accuracy and minimal errors. Therefore, the drill rig will drill to the correct depth as planned and not damage the bench below.

5.4.2 Autonomous Benefit

In Table 22, various operational impacts that will be eliminated/minimised through autonomous mining can be seen, as well as the long-term benefit. With these benefits added to the Base Case, the potential UoA for the autonomous solution increased to 85.19%.

Table 22 shows the actual numbers obtained from the dispatch system. Every time a drill rig is booked standby the operator enters the code into the system which can be accessed at any given time. Table 22 shows the delays which will be eliminated by the autonomous drill rigs, such as shift change, standby no operator, lunch, accident, transport shortage, meeting, toilet, waiting for an operator, training and tired. Average use of availability was calculated to be 85.19% because of autonomous benefit.

Table 22: UoA full benefit

Criteria	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18
Shift change	349.4	315.7	394.3	304	286.9	227.7	314	291.5	332.6	286.5
No Operator	58.7	40.7	5.2	21.1	17.5	15.9	43.7	23.2	249.5	5.8
Lunch	31.6	46.1	19.8	63.2	32.8	89.5	60.4	39.4	14.8	41.3
Accident	24.6	0	0	0	0	0	0	0	0	0
LDV- Transport shortage	**23.5**	**25.7**	**28.7**	**11.9**	**9.4**	**4.2**	**2.3**	**8.5**	**1.8**	**0**
Meeting	8.2	13.4	24.5	0	11	7.8	15.8	9.4	8.1	18.9
Toilet	5.4	4.7	0	4.8	5.5	5.4	5	4.2	6	3.8
Waiting for operator	4.8	0	0	10.8	0	2.2	4	10.4	9.9	10.4
Operator report to supervisor	4.5	0	9.1	0	0.9	23.2	32.1	0	0	0
Operators fault	1.6	0	0	0	0	0	0	0	0	0
Blasting	56.6	83.9	85	100.2	81.8	107.9	98.6	79.5	49.3	74.8
Training	0	0	3.3	0	0	0	0	0	0	0
Tired	0	0	0	0	0	2.1	0	10.2	2.7	3.7
Long walk actual	230.2	184.9	221.7	210.2	256.8	197.9	224.6	271.3	118.7	204.3
Long walk planned	103	103	103	103	103	103	103	103	103	103
Long walk benefit (Due to new lowbed)	127.2	81.9	118.7	107.2	153.8	94.9	121.6	168.3	15.7	101.3
Total benefit	**696.1**	**612.1**	**688.6**	**623.2**	**599.6**	**580.8**	**697.5**	**644.6**	**690.4**	**546.5**
Fleet scheduled production time	4493	4235	4735	4043	4675	4679	4658	4448	3651	4957
Fleet available time	3543	3184	3242	3169	3324	3353	3446	3534	2315	3074
Fleet uptime	2283	2043	2054	2155	2258	2257	2305	2399	1251	2048
Fleet uptime after benefit	2979	2655	2743	2778	2858	2838	3003	3044	1941	2595
UoA	84.08%	83.39%	84.60%	87.67%	85.97%	84.63%	87.13%	86.12%	83.86%	84.40%
Average UoA	**85.19%**									

5.4.3 Standards and Norms

The drilling capacity requirements for Solution 2 were determined by using the norms from Table 23 and physical parameters from Figure 34.

Table 23: Norms for Solution 2

Norms	Base Case	Solution 1	Solution 2	Comment
Utilisation	49%	58%	72%	
UoA	65%	71%	85%	See Table 26
Availability	76%	82%	85%	OEM Recommendation
Drill Rig Hours	4 185	4 932	6 121	
45 ton Drill rigs Rebuild and Replace Hours	15 000/ 30 000 hours	15 000/ 30 000 hours	20 000/40 000 hours	OEM Recommendation
25 ton Replace Hours	15 000 hours	15 000 hours	15 000 hours	OEM Recommendation

Comparing the Base Case with Solution 2, Table 23 shows that utilisation will improve by 23% from 49% to 72%. The improvement in utilisation for Solution 2 is because of 12% improvement in the availability and 31% improvement in the use of availability.

Bench	Hole depth (m)	Burden (m)	Spacing (m)	m/hour	t/m	Ø (mm)
B1A	16.5	6.8	7.3	45.89	124	149
B1B	4	7.5	8.7	37.65	140	
B2	13.5	7.5	8.7	67.28	104	
B3	16.1	7.5	8.7	64.43	121	
B4	16.9	6.8	7.3	67.28	92	
B5	16.7	8	9	66.14	135	
B6	4	4	8	65.88	53	115
B7A	4.9	6.8	7.3	47.3	110	
B7B	5.8	6	6	45.01	79	
B8						
B9A	4	5	6	66.53	39	
B9B	4	5	6	65.88	46	
B10	6	4	4	33.59	40	
B11	4	5	6	65.88	46	

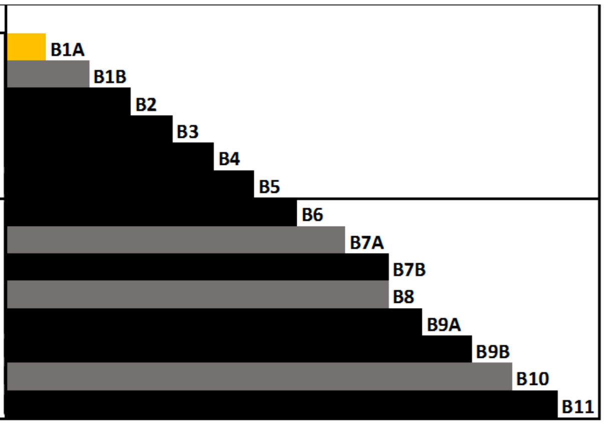


Figure 34: Autonomous drilling physical standards (Heerden, 2016)

5.4.4 Drilling Capacity Requirements

The same process was followed as with the Base Case to determine the capacity requirements for Solution 2. However, since the equipment utilisation, as well as the tempo (meters per hour), were higher, it resulted in fewer drill rigs required. From Figure 35, the drilling capacity requirements for large and small drill rigs per annum can be seen for Solution 2 compared to the Base Case. The difference between the bar graphs and the line graphs clearly show the difference in the number of required drill rigs compared to the Base Case. The capacity required for Solution 2 reduced with three drill rigs from 2023 to 2027, and peaks with five drill rigs less required from 2029 to 2033. This results in manpower reduction of 19 (Base Case has a total of 59 employees and Solution 2 when on steady state will require 37 employees as per Figure 37).

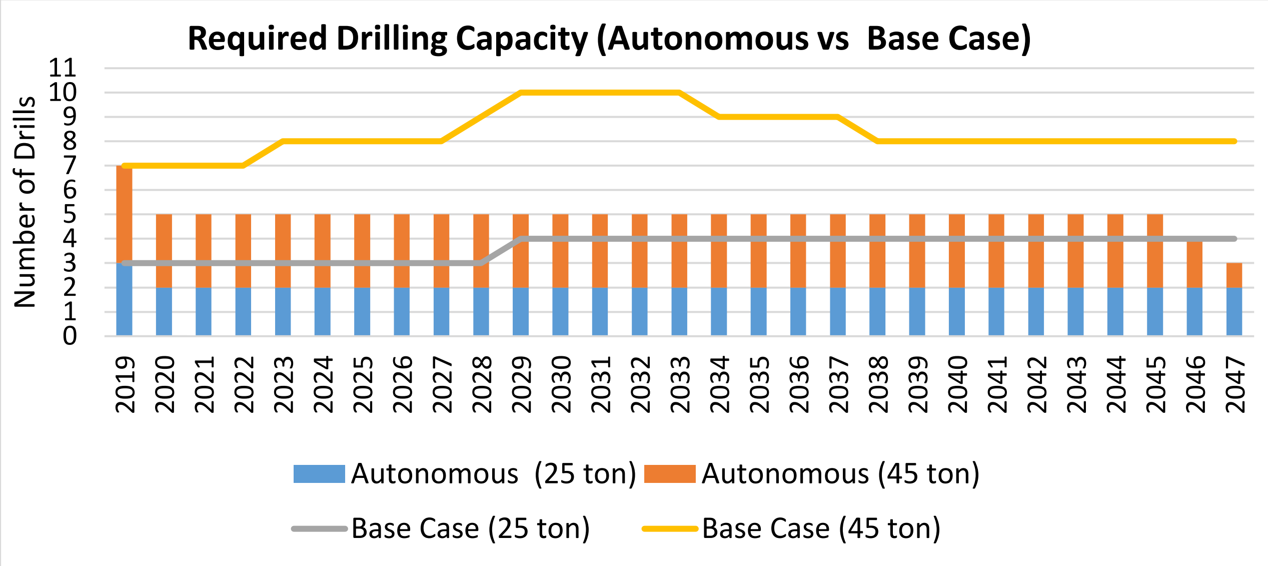


Figure 35: Solution 2 drilling capacity requirements

The graph follows the same approach as it was applied to Solution 1. Utilizing the drilling meter requirements for the top and bottom benches together with the drilling rate the total drilling time in hours required per bench was calculated. Figure 35 shows Solution 2 drilling capacity requirements for large and small drill rigs per annum and compare to the Base Case.

5.4.5 Rebuild and Replacement Schedule

The schedule (See Table 24) shows the replacement and rebuild schedule for the next five years to transition to autonomous drilling. Also shown is a two-years change-over period (2020 to 2022).

Table 24: Autonomous drilling replacement schedule

Phases of strategy		Current operation					
					Full Autonomous from 2022		
	Number	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Caterpillar MD6290	CAT 1	Replace with Pantera 3					
	CAT 2		Auto 1			Rebuild	
	CAT 3	No-Rebuild	Auto 1			Rebuild	
	CAT 4	No-Rebuild	Auto 1			Rebuild	
	CAT 5			Remove			
Pantera DP1500i	Pantera 1		Remove				
	Pantera 2		Small Auto 2		Small Auto 2		Small Auto 2
	Pantera 3	Pantera 3			Small Auto 3		Small Auto 3

In Table 24, Auto refer to 45 ton autonomous drill rig and Small Auto to 25 ton small autonomous drill rig. The current 45 ton drill rigs will not be rebuilt but will rather be extended until the new autonomous drill rig arrive in 2020. Pantera 1 will be stopped in 2020, while Pantera 2 will be replaced by small autonomous drill rig and Pantera 3 will be replaced in 2020 by the small autonomous drill rig. Indications from OEMs' are that they will be ready with small autonomous drill rig in 2020.

Bearing the transition and implementation period in mind the steady state autonomous drilling fleet capacity and benefits would only be fully realized from 2022 onwards as shown in Table 24. The 45 ton class drill rigs will be fully transitioned to autonomous drill rigs by 2020 and the 25 ton class drill rigs by 2022.

5.4.6 Operational Organisational Structure

For Solution 2 the operational organisational structure will change to accommodate the transition to autonomous drilling. The following categories will be affected as shown in Figure 36:

- One general worker per two drill rigs;
- One autonomous operator per two autonomous drill rigs; and
- One additional pit worker per shift.

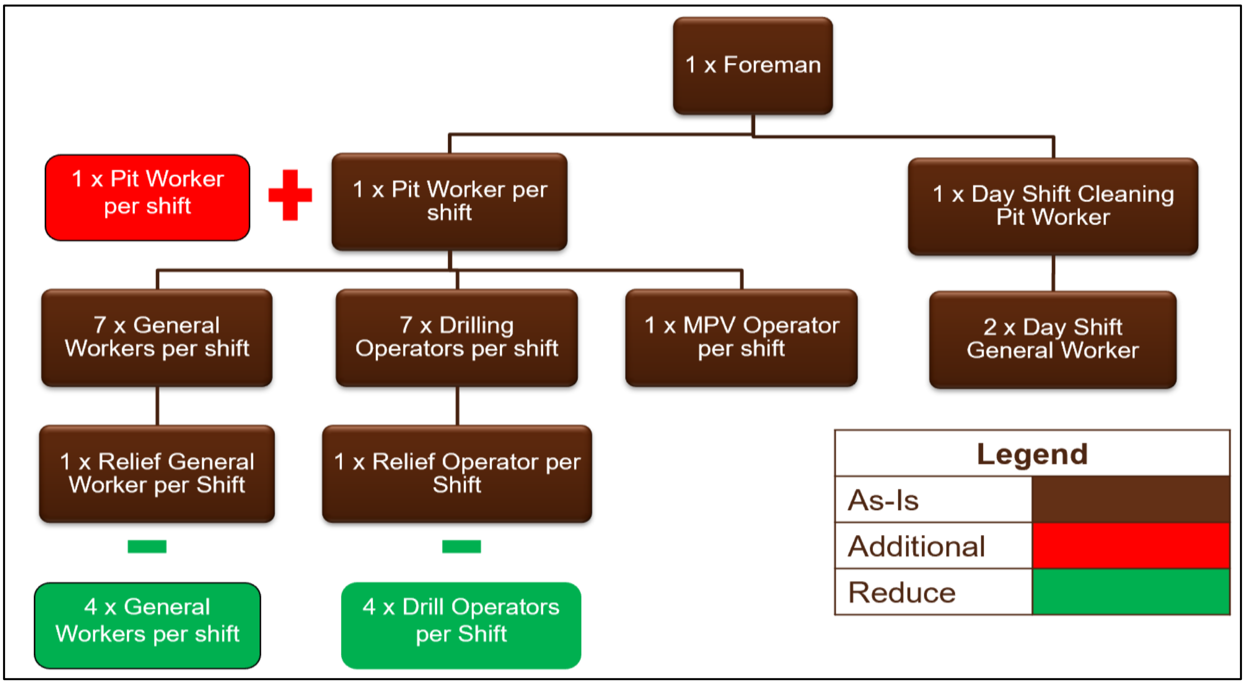


Figure 36: Solution 2 operational structure requirement

Figure 36 shows the position that will be added to the mining operational structure and positions that will be reduced because of fewer drill rigs required for Solution 2. One person will operate two drill rigs for Solution 2 from the rig control system. The final steady-state operational organizational structure is depicted in Figure 37. Number of drill rigs will be reduced with Solution 2 resulting in reduction in manpower, the following positions will be taken away from the mining operational organisational structure:

- 12 x General Workers and
- 12 x Drilling Operators.

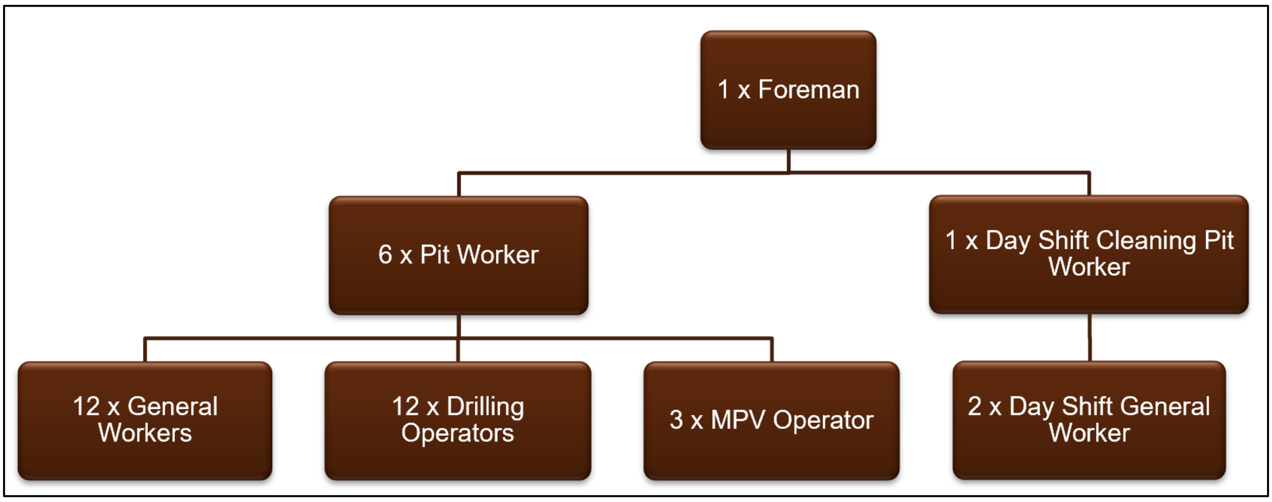


Figure 37: Solution 2 steady state

Steady state will require one foreman, 7 pit workers, 12 drill rig operators, 14 general workers and 3 MPV operators.

5.4.7 Maintenance Organizational Structure

The manpower for the drilling maintenance crew was modelled through the SWP on the same ratios as for Solution 1, except for an additional diagnostic technician as shown in Figure 38. The manpower for Solution 2 will, however, stay constant over time as the number of drill rigs stays constant over the modelled period.

The additional technician is motivated based on the level of technical expertise required to maintain the sensors and high precision GPS' as they exceed that of a millwright/artisan. With the significant increase in the number of sensors on an autonomous system, it is imperative that a diagnostic technician will be required to ensure that the availability targets are achieved.

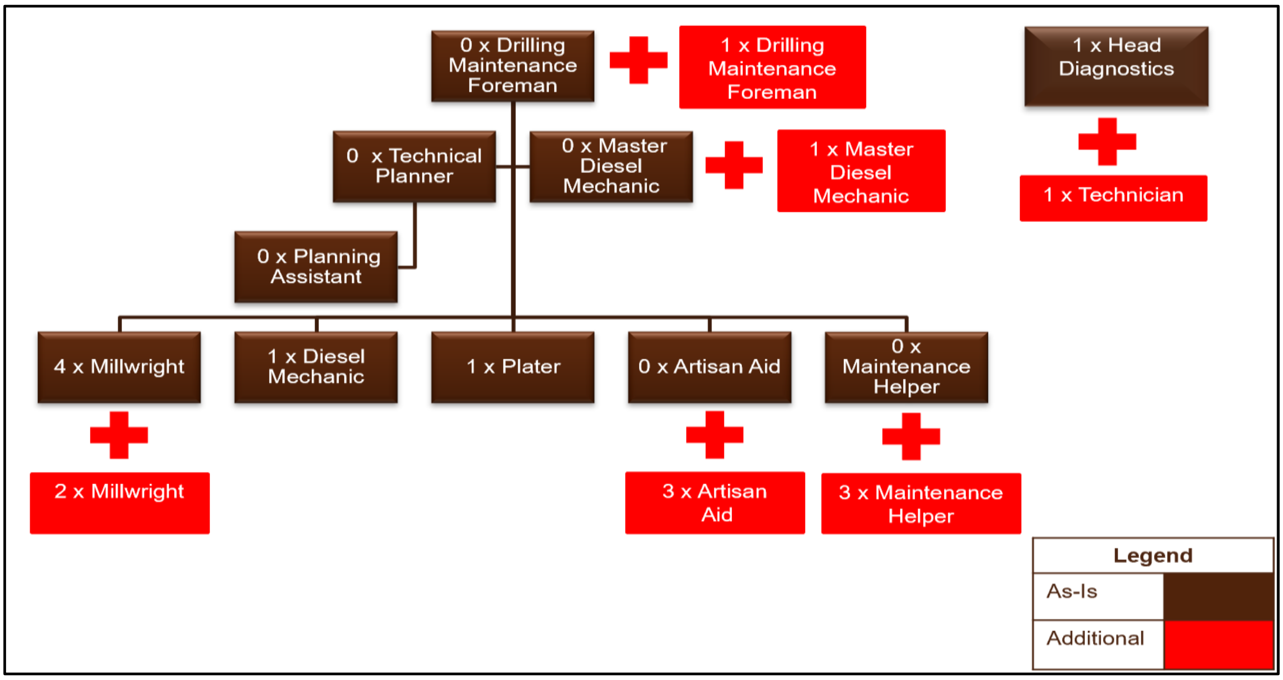


Figure 38: Solution 2 maintenance organizational structure requirement

5.4.8 Infrastructure Requirements

For the autonomous drilling solution, a control room will be required. The control room will be a container-based control room and positioned close to the current drilling green area and as close as possible to the nearest Rajant beacon. The control room would also be required to be equipped with computers, LCD TV screens and network connections.

5.4.9 Network and Bandwidth Requirements

The architectural design (AD) will have to be completed according to the Exxaro standards. The sections below highlight the imperative information from the AD. The bandwidth requirements are determined by the number of drill rigs being operated per remote control station, a number of drill rigs on the system as well as whether the drill rig is used in allocated or passive mode.

- Allocated mode refers to the drill rig that the operator is tracking in real time and requires data for a Heartbeat (2MBps) as well as data for video streaming (6MBps); and
- Passive mode refers to the drill rig that is not actively being tracked and only requires data for the Heartbeat (2MBps).

As a worst-case scenario, with one operator operating a drill rig in allocated mode all the time and the maximum required drill rigs over the LOM, a 40Mbps connection would be required (5 x allocated mode streaming). For the evaluation, it is assumed that one operator can operate two drill rigs which means that in steady state autonomous drilling operation, a total of 3 RCS stations will be required to operate the five autonomous drill rigs. Thus, a total of 40MBps will be required for the current evaluation.

The autonomous drilling system is fully dependent on a stable network and if the heartbeat (network connection) is lost for more than 6 seconds, the drill rig will not shut down but will stop the function. Once the network is restored the drill rig will proceed with the function it was busy with. Typical latencies required for autonomous drilling is 100-200 milliseconds. The Grootegeluk pit network is currently below 30 milliseconds which is within the required specifications. Grootegeluk information management team has confirmed that the network capacity and latency is sufficient and that the network will be available for the autonomous drilling strategy to be brought onto the network. As a contingency, the drill rigs can be connected directly to the network backbone (Point-to-Point).

5.4.10 Current Network Capacity and Status of AD

Currently, the Grootegeluk pit network has a 1Gbps capacity of which only 0.17% is utilized. The Mesh radios installed on the equipment are military specification radios and have a 99.99% uptime and speed of 300Mbps. Taking this into consideration the Grootegeluk network will be able to supply the required capacity for the autonomous drilling solution.

5.4.11 Bench Cameras

Bench cameras, with infrared/night vision, to view the drill rig from the control room and the office will be required as an additional safety precaution. A total separate network will be required to run the site cameras without burdening the production network.

6 CONCLUSION

Grootegeluk saw an increase in availability from 2013 to 2016 where 80% was achieved in 2016. The increase in availability was mainly due to new drill rigs arriving on the mine. Currently, the budgeted availability of 80% is not being realised even with the support from the other sections to help improve availability. There are also two additional artisans and one technical representative that is contracted in to assist with the drill maintenance.

The main contributor to low availability is the maintenance organisational structure which is not aligned with the number of drill rigs currently on the mine. When drill rigs were increased, the maintenance team remained the same resulting in insufficient manpower to service and maintain the drill rigs. Since 2014 the drilling fleet size increased (three additional drill rigs procured) without adjusting the maintenance structure resulting in the men to equipment ratio decreasing from 1.5 to 0.86. Currently, there is no dedicated drill rig maintenance team and the maintenance personnel for the drill rigs form part of the secondary equipment maintenance structure. The structure only caters for one foreman who is responsible for the drill rigs, rubber wheel dozers, track dozers and cable handlers.

Availability can be increased to 82% if the maintenance structure is changed to cater for the seven drill rigs. Availability can further be increased to 85% if autonomous drill rigs fleet replaces the current drilling fleet over a period.

The replacements of CAT 2 did not materialize as per the current strategy and the drill rig is still in operation. Despite the drilling hours that have exceeded 30 000 for CAT 2, the drill rig show a significant amount of structural deterioration, declining reliability and declining availability. Based on the structural deterioration and poor performance of the drill rigs, it must be replaced to prevent inadvertent critical failure.

CAT 3 and 4 were scheduled to be rebuilt in June 2017 and October 2017, respectively. However, the two drill rigs have far exceeded planned rebuild hours and CAT 5’s was scheduled to be rebuild in July 2018 and also exceeded planned rebuild hours. As a result, none of the three drill rigs are reaching their availability and reliability targets.

The availability and reliability of all three drill rigs are erratic and thus replacing any of the three drill rigs would have a significant improvement on the standards and norms. It is also important to highlight that CAT 3 and CAT 5 are both high pressure drill rigs and have C27 engines compared to CAT 4 which has a low-pressure compressor and C18 engine. This causes difficulties in standardizing spares for the drill rigs resulting in spares shortage.

UoA dropped between 2013 and 2014, this is primarily due to the increase in a number of drill rigs without the substantial increase in supervision (Foreman and pit worker). The current mining operational structure only caters for one drilling foreman for the section working only day shift and one pit worker per shift. This lack of supervision negatively affects the performance of the section. An average of 87.6 drilling minutes per shift can be saved over the drilling fleet if additional pit worker is appointed on each shift.

Shift change, standby no operator, blasting, lunch, toilet breaks, tired, transport, meeting, training, long walk, accident and waiting for the operator are the main operational breakdowns which have an impact on the use of availability. Shift change is the biggest single contributor to the operational breakdowns impacting UoA. This is mainly due to transport and the fact that one pit worker in the afternoon and night shift must take in seven drill rig operators and their assistants using a single double cab LDV which can carry four people at a time.

Grootegeluk procured a lowbed in 2018, however, the new lowbed was only put in operation early in 2019 due to the design problem where drill rigs couldn’t be taken onto the lowbed. As soon as the design challenges were resolved the mine saw a decrease in the number of long walk hours. Time study still need to be conducted to verify if the expected reduction in long walk hours per month (103 minutes per month) were realised. Adding extra pit worker per shift and utilizing the new lowbed fully present an opportunity to increase UoA from 65% to 71%. The UoA can further be increased to 85% if the autonomous drill rigs fleet replaces the current drilling fleet over a period.

Amongst other, the additional pit worker is motivated based on; quality control, enforcing standards, and shift change time decrease as well as accessory change outs. The addition of an additional pit worker will result in the UoA increasing to 71% compared to the current 65%.

Trimble DPS 900 (Drilling Piling System) tracks and records all the necessary information to do a thorough analysis of the drill rigs. However, the mine still needs to purchase some of the system features to ensure that all the data required to do full drilling analysis is readily available.

However, the following information is still not available but could be available once cycle time reports are completed.

- Drilling time per hole;
- Moving time per hole;
- No data available as to which drill bits perform better on which benches;
- No data available as to which drill rigs perform better on which benches; and
- No proper data available to compile a thorough drilling schedule.

The Trimble DPS 900 system can also track the individual performances of the operator as well as the shift average. The drilling accuracy is within 0.3 m of the design hole depth.

There is a big opportunity to replace the current drilling fleet with an autonomous fleet over a period of five years. Operators will be removed from the drill rig and only monitors the drill rig from a remote location or control room. The control room will be a container-based control room and positioned close to the current drilling green area and as close as possible to the nearest Rajant beacon. The control room will be equipped with computers, LCD TV screens and network connections.

One remote control station (RCS) will be used to monitor/control one to three drill rigs simultaneously. Due to fast penetration rates and shallow benches, a maximum of two drill rigs will be operated from one RCS.

All the drilling cycle functions namely drilling, tramming between holes, levelling and rod changes are controlled by the machines artificial intelligence system. Currently, drill rigs at Grootegeluk only spend 53% of the time drilling and a significant 9% of the time is spent idling. Idling is a human component and with the introduction of technology, the idle time can be eliminated. Human components also result in longer tramming, steel change and levelling times which results in a longer overall cycle time. Drilling cycle elements can be improved where the average time spent drilling increased significantly from 53% to 74% due to the other elements taking less time and idle time decreases from 9% to 0. Functions such as filling water, changing drill bits and rods, filling diesel, tramming to next benches and blocks would still require operators to be in the drill rig. Operators will be removed from drill rigs, and they will operate from the control room.

The autonomous drilling system is fully dependent on a stable network; therefore, it is important to ensure that Grootegeluk network has sufficient latency and adequate capacity. The network must be available for the autonomous drilling strategy to be brought onto the network. As a contingency, the drill rigs can be connected directly to the network backbone (Point-to-Point). To ensure that drilling is done safely, bench cameras with infrared/night vision must be installed.

Therefore, Grootegeluk network will be able to supply the required capacity for the autonomous drilling solution. The pit network has a 1Gbps capacity of which only 0.17% is utilized. The mesh radios installed on the equipment are military specification radios and have a 99.99% uptime and speed of 300Mbps.

7 RECOMMENDATION

- It is recommended that Grootegeluk take a phased approach in improving drill rig utilisation by correcting organisational structure first before the technology can be implemented as a solution to improve the overall utilisation.

  From the background information, it was highlighted that there are numerous inefficiencies in the operation which needs to be resolved before considering any form of technology or automation to improve the Base Case.

- It is also recommended that three pit workers be added to the operational manpower which will increase UoA. A dedicated drill rig maintenance foreman, one master diesel mechanics, two millwrights, three artisan aids, and three maintenance helpers be appointed in maintenance organisational structure to improve availability.

- Install a pressure sensor on the drill rigs to gather MWD data. The drill rig will automatically stop when it picks up that there is a pressure change between different rock layers. This will help increase drill accuracy.

- The mine has already installed Trimble DPS 900 system on the drill rigs, therefore, in order to optimise drilling process; it is recommended that the mine purchase some of the Trimble DPS 900 systems features to ensure that the following information is available:
  - Drilling time per hole;
  - Moving time per hole;
  - Drill bits performance per bench;
  - Drill rig performance per bench; and
  - Data to compile a thorough drilling schedule.

- For bench cameras, with infrared/night vision, to view the drill rig from the control room and the office, a totally separate network be utilized to avoid burdening the production network and causing instability.
- It is recommended that the current 45 ton drill rigs not be rebuilt but rather be replaced with 45 ton autonomous drill rigs.

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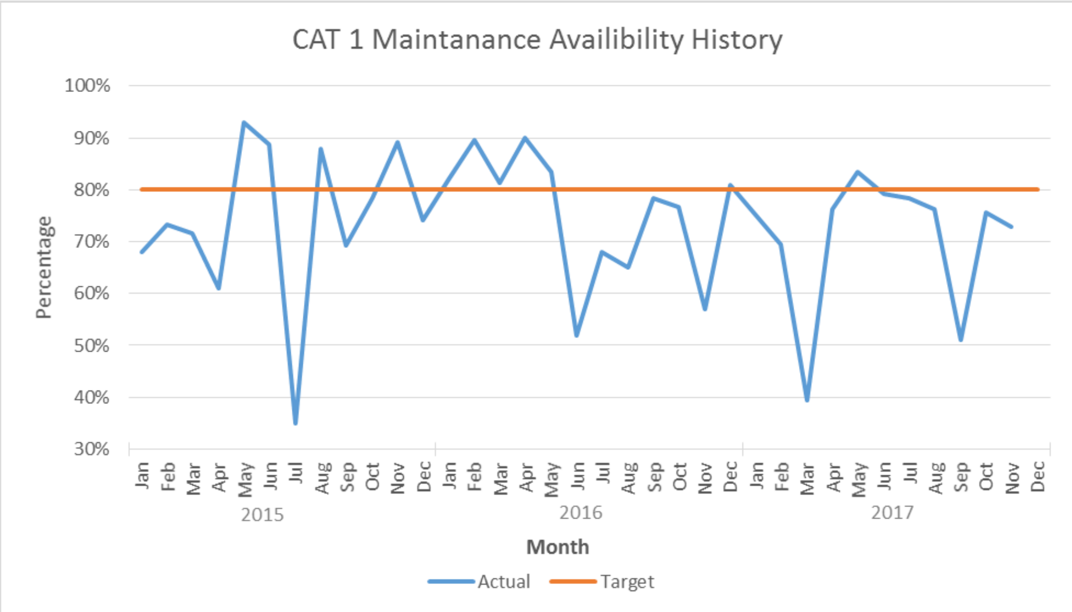
9 APPENDIX

9.1 Equipment under Engineering Secondary Foreman

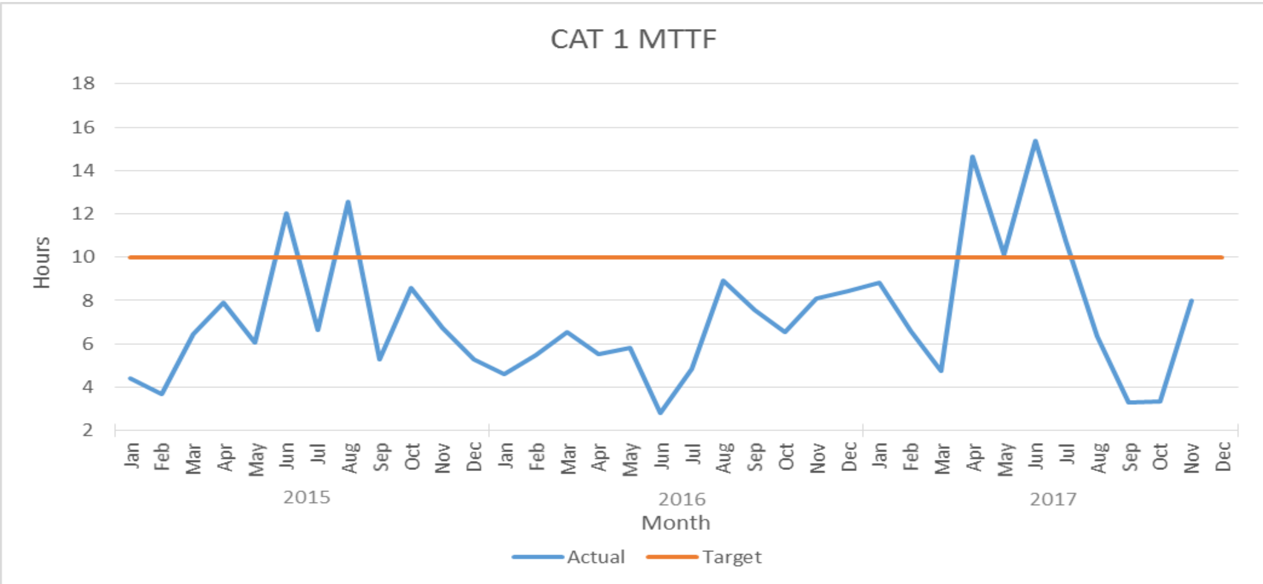
Rubberwheel Dozers		***Foreman***
GGEM16108	Cat 824C R/W Dozer 08	ERNEST
GGEM16109	Cat 824C R/W Dozer 09	ERNEST
GGEM16110	Cat 824H R/W Dozer 10	ERNEST
GGEM16111	Cat 824H R/W Dozer 11	ERNEST
GGEM16112	Cat 824H R/W Dozer 12	ERNEST
GGEM16113	Cat 824H R/W Dozer 13	ERNEST
GGEM16114	Cat 824H R/W Dozer 14	ERNEST
GGEM16115	Cat 824H R/W Dozer 15	ERNEST
GGEM16116	Cat 824H R/W Dozer 16	ERNEST
GGEM16117	Cat 824H R/W Dozer 17	ERNEST
GGEM16118	Cat 824H R/W Dozer 18	ERNEST
GGEM22003	CAT Cable Handler 824 03	ERNEST
GGEM22004	CAT Cable Handler 824 04	ERNEST
GGEM26003	854K RubberwheelDozer 03	ERNEST
GGEM26004	854K RubberwheelDozer 04	ERNEST
Trackdozers		
GGEM16001	CAT D9N Trackdozer	ERNEST
GGEM16501	CAT D9L Trackdozer Attachment	ERNEST
GGEM26604	CAT D10T Trackdozer 04	ERNEST
GGEM26605	CAT D10T Trackdozer 05	ERNEST
GGEM26606	CAT D10T Trackdozer 06	ERNEST
GGEM26607	CAT D10T Trackdozer 07	ERNEST
GGEM26608	CAT D10T Trackdozer 08	ERNEST
GGEM26609	CAT D10T Trackdozer 09	ERNEST
GGEM26610	CAT D10T Trackdozer 10	ERNEST
GGEM26611	CAT D10T Trackdozer 11	ERNEST
GGEM26612	CAT D10T Trackdozer 12 Attachment	ERNEST
GGEM26801	KOMATSU Trackdozer 01	ERNEST
Terex Drills		
GGEM20701	Terex Drill 01	ERNEST
GGEM20702	Terex Drill 02	ERNEST
GGEM20703	Terex Drill 03	ERNEST
GGEM20704	Terex Drill 04	ERNEST
GGEM20705	Terex Drill 05	ERNEST
GGEM20801	Pantera DP1500i Small Diameter Drill 01	ERNEST
GGEM20802	Pantera DP1500i Small Diameter Drill 02	ERNEST

9.2 CAT Maintenance Availability and MTTF

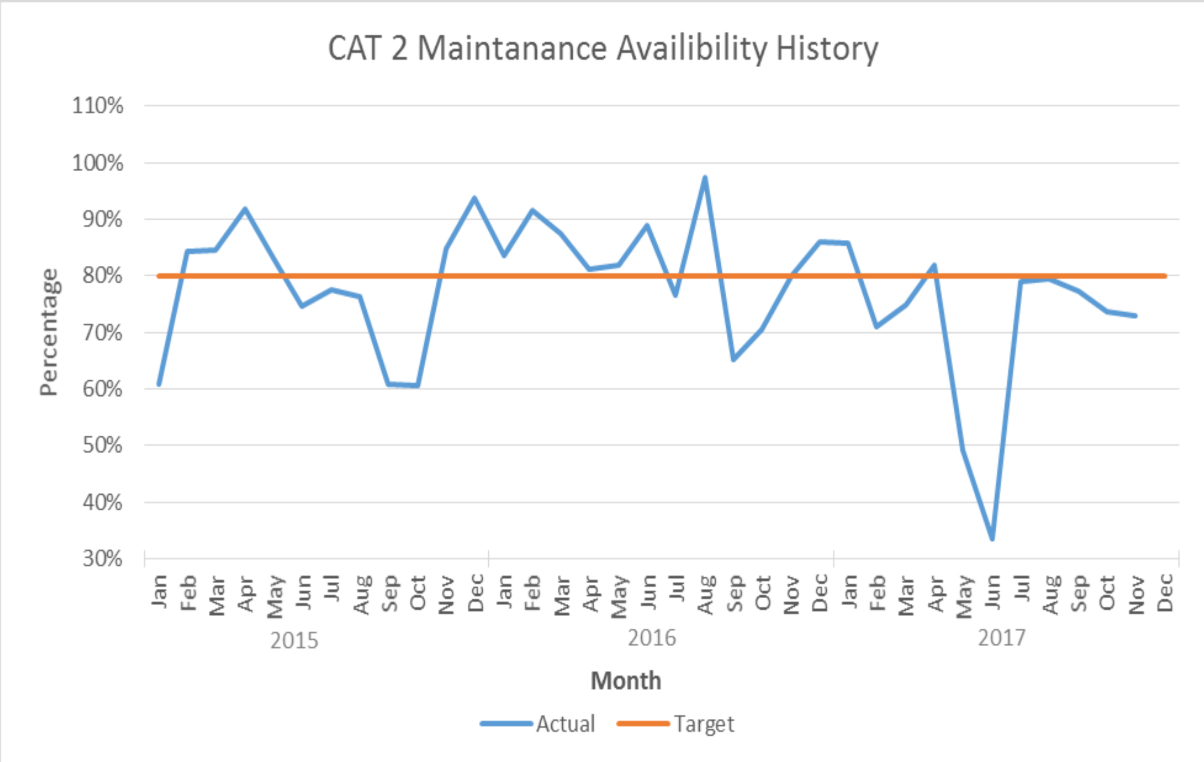
MTTF AND MAINTENANCE AVAILABILITY



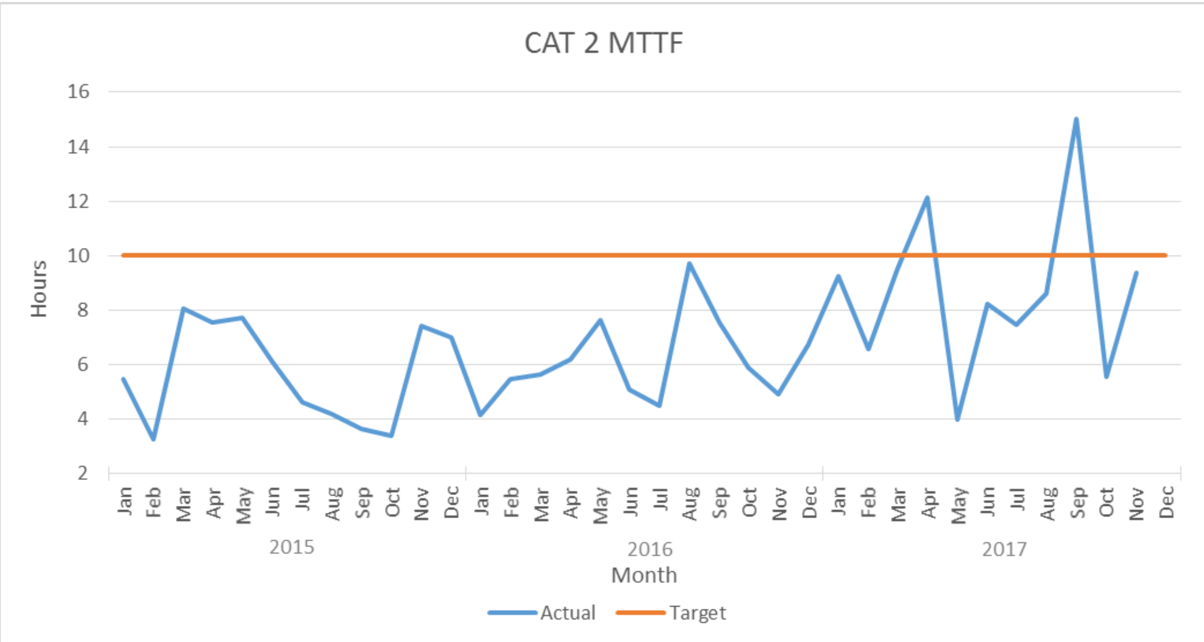
CAT 1 Availability Trend



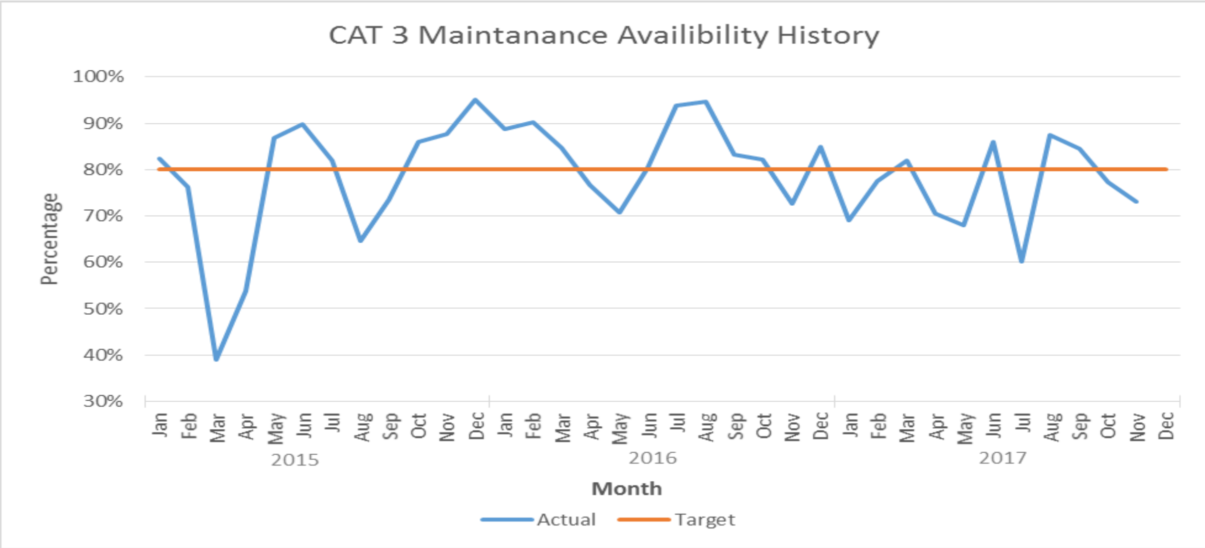
CAT 2 Availability Trend



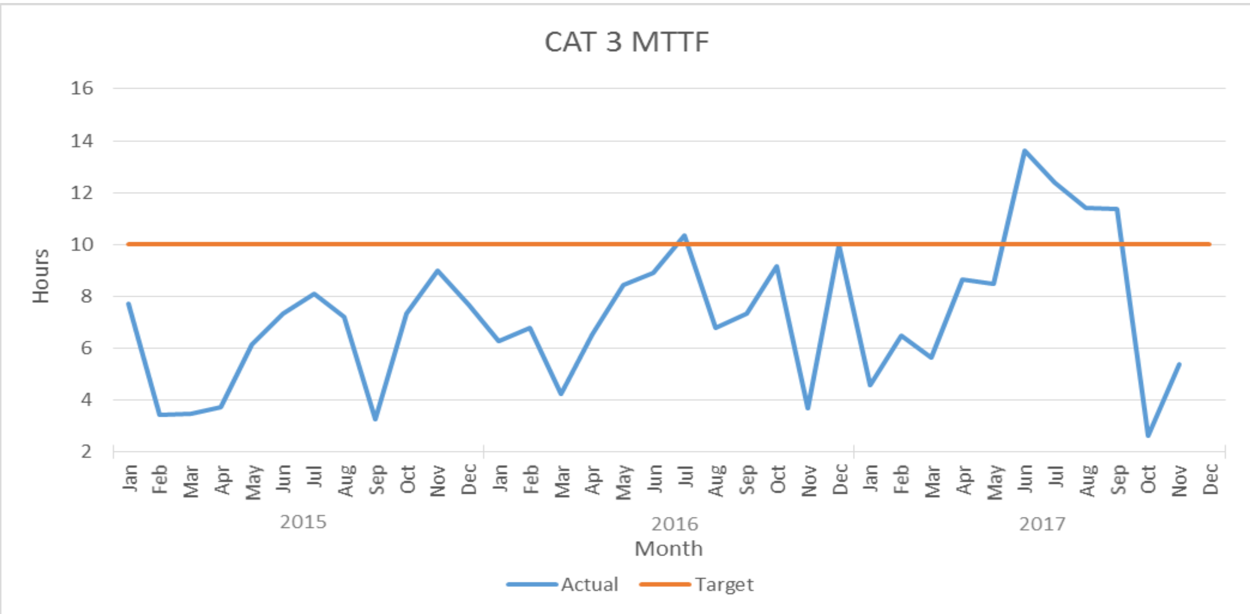
CAT 2 MTTF Trend



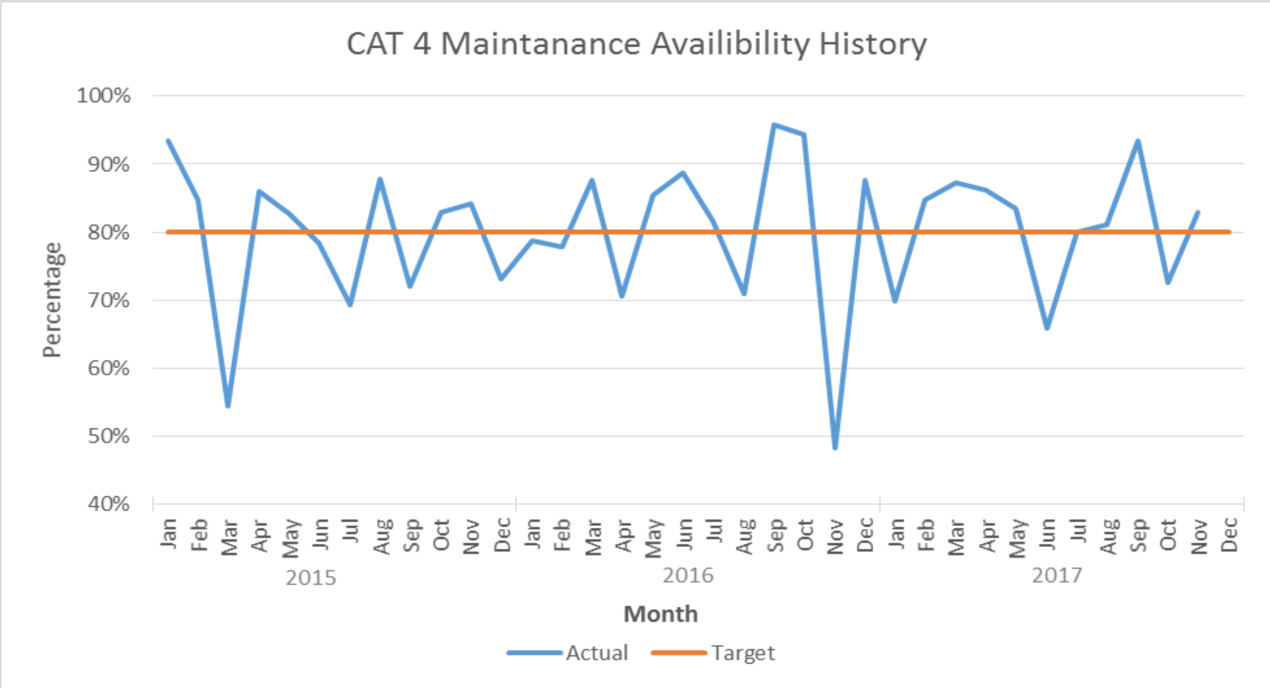
CAT 3 Availability Trend



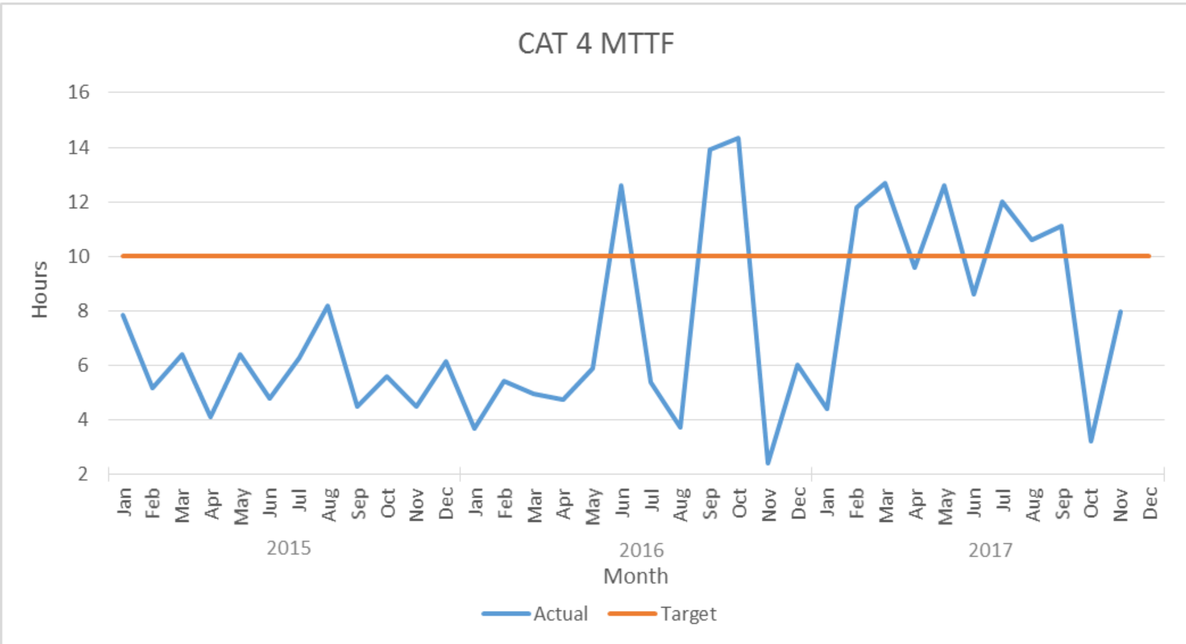
CAT 3 MTTF Trend



CAT 4 Availability Trend



CAT 4 MTTF Trend



9.3 Cycle Element per Drill per Bench

Row Labels	Average of m/h	Average of % Leveling	Average of % Steel Change	Average of % Drilling	Average of % Tramming	Average of % Idle
CAT1	**47,03**	**0,12**	**0,11**	**0,56**	**0,11**	**0,09**
3	54,42	0,04	0,23	0,59	0,05	0,09
9A	43,23	0,17	0,05	0,55	0,14	0,09
CAT2	**48,14**	**0,06**	**0,16**	**0,61**	**0,08**	**0,09**
2	78,69	0,09	0,24	0,49	0,08	0,09
3	39,87	0,07	0,19	0,60	0,06	0,09
1A	37,23	0,03	0,13	0,67	0,08	0,09
1B	24,50	0,06	0,07	0,69	0,09	0,09
CAT3	**47,38**	**0,06**	**0,21**	**0,53**	**0,10**	**0,09**
2	58,85	0,05	0,26	0,52	0,08	0,09
4	50,22	0,06	0,32	0,45	0,08	0,09
1B	26,71	0,10	0,09	0,57	0,16	0,09
CAT4	**51,83**	**0,04**	**0,20**	**0,61**	**0,06**	**0,09**
3	50,07	0,04	0,22	0,58	0,07	0,09
4	55,95	0,03	0,20	0,64	0,04	0,09
1A	35,42	0,04	0,00	0,66	0,21	0,09
CAT5	**53,60**	**0,04**	**0,21**	**0,61**	**0,05**	**0,09**
3	56,47	0,04	0,21	0,61	0,05	0,09
1A	44,66	0,04	0,21	0,63	0,03	0,09
Pantera 1	**45,29**	**0,15**	**0,15**	**0,43**	**0,18**	**0,09**
10	42,19	0,14	0,13	0,50	0,14	0,09
9A	49,93	0,16	0,19	0,32	0,24	0,09
Pantera 2	**37,02**	**0,16**	**0,17**	**0,38**	**0,20**	**0,09**
7A	29,76	0,09	0,29	0,41	0,12	0,09
9A	38,67	0,18	0,14	0,38	0,21	0,09
Sandvik5	**25,34**	**0,09**	**0,06**	**0,68**	**0,08**	**0,09**
10	25,34	0,09	0,06	0,68	0,08	0,09
Grand Total	**43,98**	**0,10**	**0,16**	**0,53**	**0,12**	**0,09**

9.4 Audit report by Barloworld on Cat 1

Dr001 Engine hours 9532.3

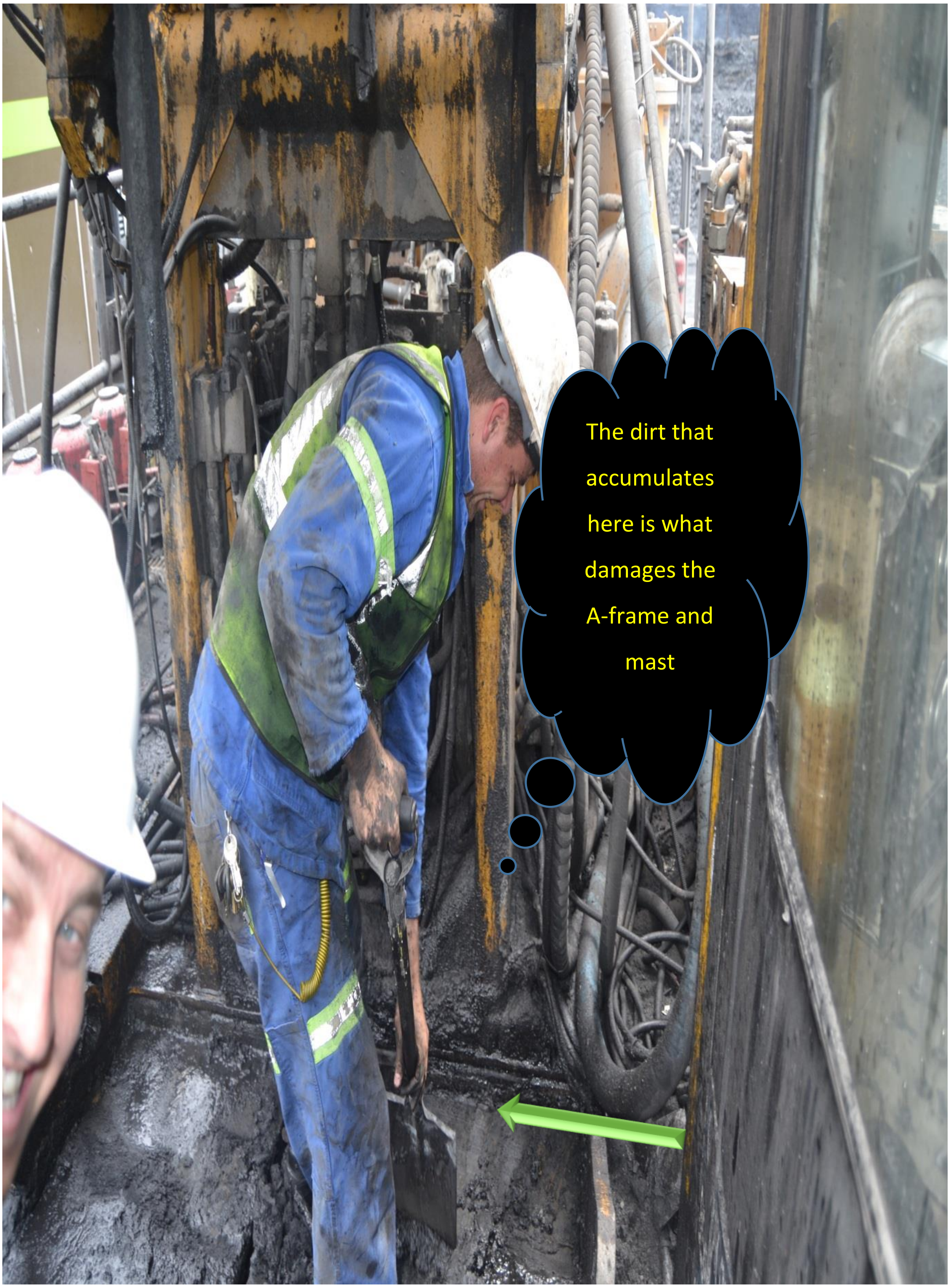
In the picture above, you can clearly see that neither the dry nor wet dust collector is working.

This is detrimental to the machine; air filters are permanently exposed to dust and the dust is also drawn through the cooler.

It is of utmost importance that the dust suppression is fixed on this machine.

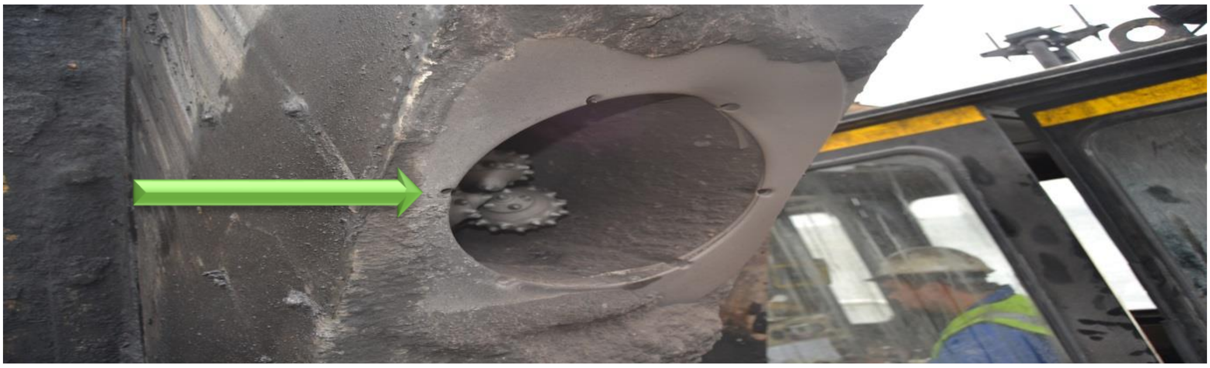
Drill deck

This is the number one cause of structural damages. There is no excuse for operators not cleaning their drill deck at end of every shift!!!!



Deck seals must be replaced; new deck bushing must be fitted.

Deck hood must be repaired.



Both bottom sheaves and bearings need to be replaced.

Sheave ropes must be inspected and replaced if necessary.

Both mast locking cylinders need to be replaced to the new style cylinder with the proximity's fitted in the cylinders.

Mast locking indicators are not functioning and play a role in the cracking of the mast and A-frame

Deck fork must be inspected for excessive wear.

There are numerous structural cracks visible on the foot-plate and around the A-frame of the machine!!!!

Please note: All these listed items above is a result of no dust suppression!!!

Breakout Wrench

H.O.B.O needs to be refurbished.

New pins, bushes, liners and die tongs must be fitted.

Cylinders must be removed and refurbished

Or the new CAT (NPI) breakout can be fitted.

N.B: CAB ELECTRICAL HAS TO BE REPLACED.

1. New toggle switches
2. Joysticks

3. Relays
4. Decals
5. Circuit breakers
6. Gauges
7. Pressure switches

Interior

New style Cat seat can be fitted, and buddy seat must be replaced.

Cab interior must be refurbished with new roof and side liners

Air-con

Windows and rubbers

All broken and sandblasted windows must be replaced and all window and door rubbers.

Cracks

Mainframe jack tubes are cracked at front of the machine.

A previous repair was done on the frame.

If the root cause is not eliminated the frame will keep cracking.

Consistent weld repair will also affect the integrity of the steel.

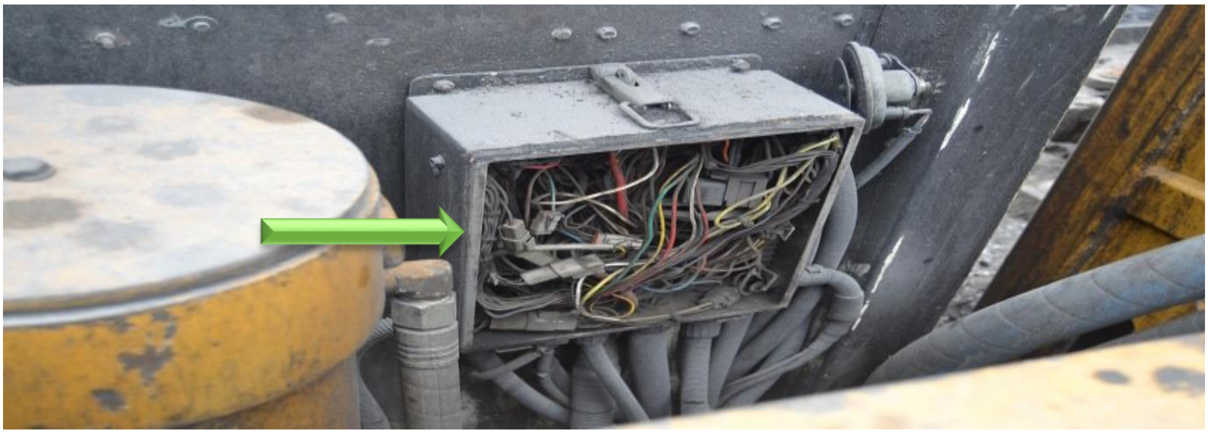
This is caused by jack cylinder-counter balance valves which are not correctly set and when the machine is lifted it twists the frame causing the frame to crack on these spots.

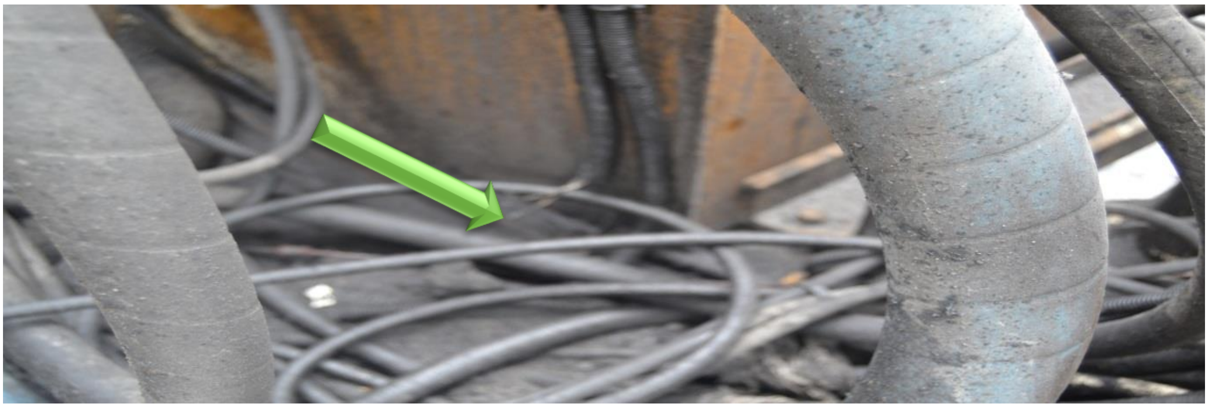
To do a quality repair the compressor, all pipes, as well as front water, the tank must be removed.

Correct weld repair procedure must be followed.

Cylinders must be removed resealed and counter-balance valves needed to set on a test bench.

Electrical





Machine’s electrical harnesses are in bad shape.

From what I could pick up most of the downtime is due to electrical faults.

This is caused by high acidity in the water causing the wires to corrode and rust.

New harnesses must be fitted and routed in a manner that they are easily excisable.

Wire numbering should also be used to simplify and make troubleshooting easier and less time consuming.

Bigger junction boxes must be used for better access

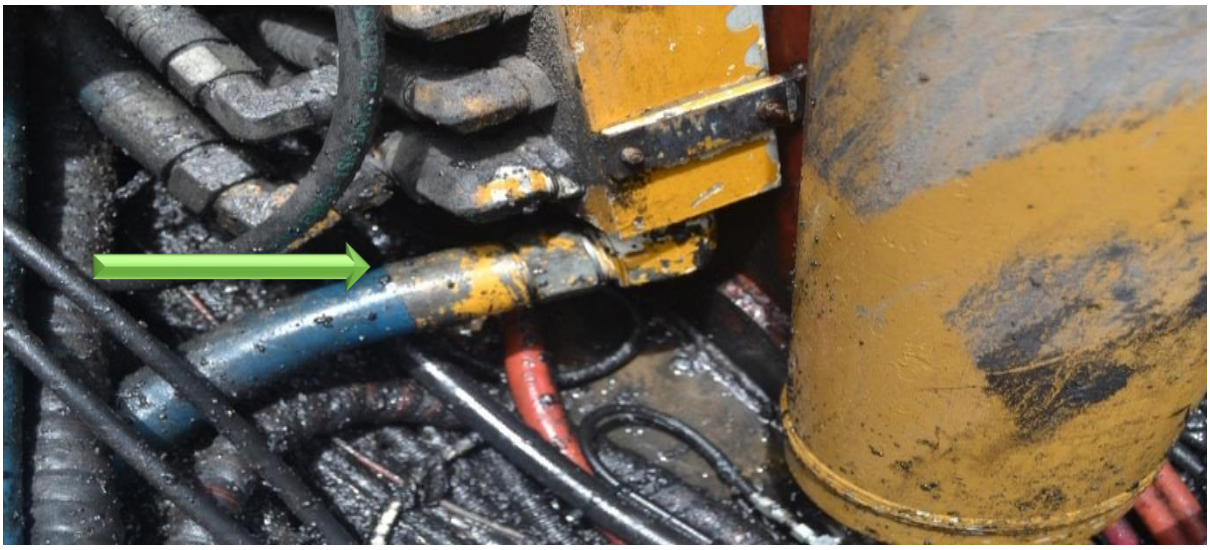
Compressor

Compressor butterfly cylinder should be changed to the poppet inlet style, this is maintenance free and the machine will have better-controlled regulation.

When the Cylinder and cylinder brackets start wearing, the compressor will start hinting causing the machine to consume more fuel.

This also adds torsional strain on the coupling and mounts and will affect the quality of holes.

Manifolds



Both case drain and return manifolds should be removed and resealed with new O-rings.

Cab mounts.

All cab and engine mounts must be replaced.

Undercarriage

Undercarriage should be upgraded to new Cat undercarriage to standardize fleet.

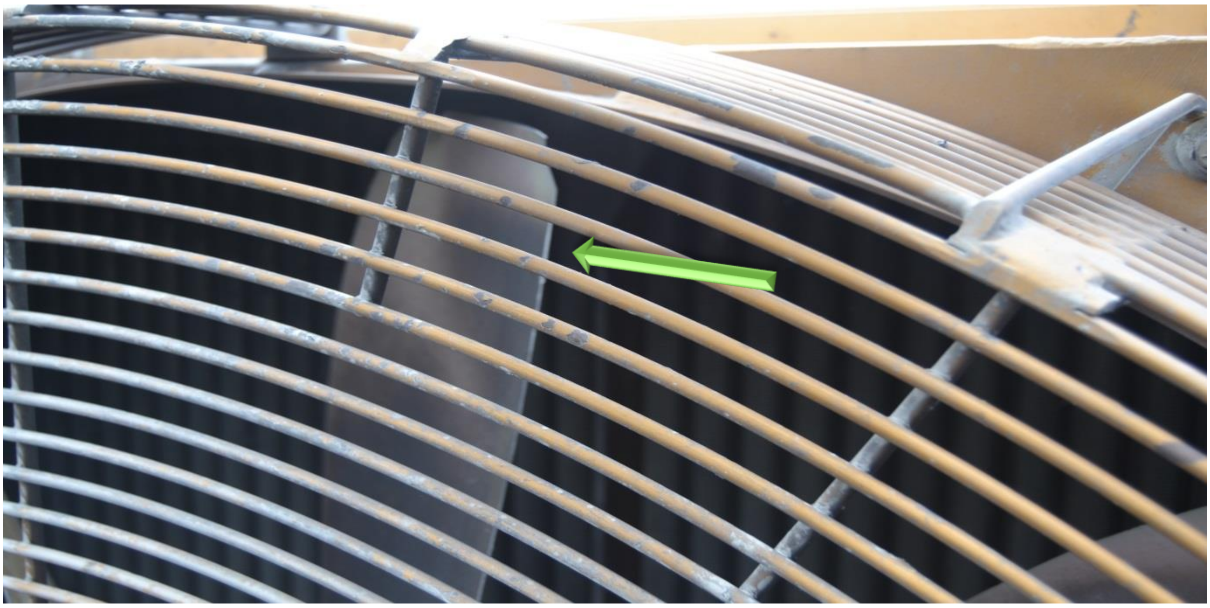
Auto Thread Greaser

Thread greaser is not working.

New regulator pump and activating valve must be fitted.

This circuit is very important for operators to grease their thread every time they do rod changes

Fan



Fan blades are damaged and sandblasted.

This will affect the cooling capability of the fans

Both fan blades must be replaced, and dust suppression must be fixed to prevent the fans from sucking dust through them.

Rotary head

Rotary head is leaking oil from the Duo-con seal.

Preload must be checked.

New water box housing seals must be fitted.

New wear pads must be fitted

Rod support

Rod support is completely removed.

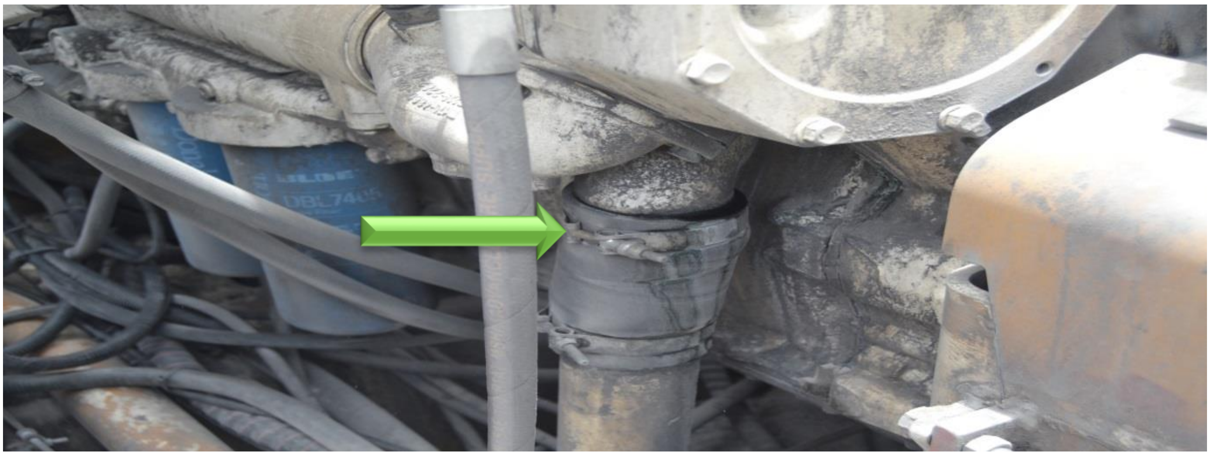
Repair and refit pipe support

Operators will struggle to load pipe and to join rods

Guards

Guards are loose, and bolts are missing

Intake and Coolant Hoses



New intake and coolant hoses must be fitted.

Fit all new clamps.

Recommendation

- The machine needs to be properly cleaned to do a proper structural inspection.
- Current cracks must be properly repaired; an OEM repair procedure must be followed.
- The machine will have to be rewired completely.
- Interlocks and safety circuits must be repaired
- Major component intervention needs to be followed.
- Cab must be refurbished
- All damaged hoses must be repaired.
- Undercarriage should be upgraded
- All tanks must be cleaned out.
- DUST SUPPRESSION MUST BE FIXED NB!!!!!!!