IMPLEMENTATION OF A GHH ROOF BOLTER MACHINE AT MERENSKY SHAFT (BOOYSENDAL PLATINUM MINE) – A CASE STUDY

Wonderboy Orchard Kekana

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

Johannesburg 2018

DECLARATION

I declare that this research project is my own unaided work. It is being submitted in partial fulfilment of the requirements for the Degree of Masters of Science in Engineering (Mining) at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

....

Wonderboy Orchard Kekana

Signed on this …03… day of …May……,… 2018.
(day) (month) (year)

ABSTRACT

Mining Merensky reef successfully at Booysendal Mine will require a machine which enhances team efficiencies delivering results on specified operational and quality parameters. The operational objective of the Booysendal Mine trial of the 3108 ADE Roof bolter was to prove that this machine can mine at 1900 mm stoping width and to set a base for KPIs. The purpose of the upgraded 3108 ADE machine was to achieve to drill and install a bolt in 8 minutes translating in 3 bords supported per shift. This machine had to deliver 235m, 1900 m² per month at stoping width of 1900mm translating to 2.55g/ton in terms of head grade.

The objective of this study is to assess the use of industrial engineering techniques to expedite the implementation of a roofbolter in the challenging environment at Booysendal Mine. The process of creating a learning environment is one of the important goals in many business improvement frameworks, and underlies the work done here.

To deliver on the above mentioned objectives, this research presents a case study in the use of several industrial engineering techniques:

- Lean Manufacturing tools were used to draw up effective communication channels for Operators engagement, visible performance data gathering and performance monitoring.

- Observational research methods were used to assess and evaluate the impact of 3108a modifications in achieving the set KPIs per shift in a real underground situation.

- The A3 report process was used as the framework to communicate the process of the 3108a machine Roll-out to people on the team.

Theory suggests that the method of implementation presented here will create a learning environment, which will in turn meet production targets.

The implementation team had set itself a number of production targets, primarily a demand for 42 bolts per shift to be installed and stoping width to be controlled to 1900mm. The targets were based both on benchmarks elsewhere and on economic demands at the mine.

The study shows that through a step-to-step improvement approach the Operators improved from installing less than 19 bolts per shift to move to 19 – 34 bolts per shift. The 1900mm stoping width target was not consistently achieved. In this study, the author played the role of Project Champion, actioning the knowledge acquired when attending the CMMS courses and applied tools/tactics learned from Trackless Mining and Operations Management courses and tools such as Lean Manufacturing, A3 reports and physical observations.

The main thrust of this study was to answer this central question: How well will a set of industrial engineering tools work to improve the modified GHH bolter performance to enable the Merensky shaft to efficiently mine at a stoping width of 1900mm consistently? The research shows that detailed improvement approach delivered more bolts drilled and installed per shift. The report goes further and gives practical on-site implementation team actions taken to ensure a machine delivers 3 bords per shift. Where the implementation team identified challenges outside the scope of this study for addressing the stoping width, the team gave recommendations to relevant technical team on-mine.

The tools performed well:

- The most successful tool was the use of visual indicators and other elements of communication from Lean to engage Operators and encourage the use of gathering data for process improvement because key feature of Lean is its ability to manage a large number and variety of issues simultaneously using visual prompts to assist in communication of issues.

- Lean promotes “going to the Gemba” – managers need to see exactly how things really work. The observational tools used in this implementation showed the value of physical observations because even if 8 minutes per installed bolts was not achieved the implementation team knew exactly where the constraints were and how to tackle it.

- The A3 methodology was an effective way of structuring and managing the improvement process in the implementation of the Roof bolter. Through the stepped approach in this case study we managed to deliver exceptional production results six months ahead of planned timeframe.

ACKNOWLEDGEMENTS

The author would like to extend his thanks and gratitude to various people for their inputs, support and discussions on the mine technology absorption capacity affecting this study. He fully acknowledges the contribution of the following organisations and its employees:

- Dr Declan Vogt (Project Supervisor) for direct and frank technical criticism and guidance.
- Northam Platinum Limited and Willie Theron for providing funding support and allowing the author to carry out this study during his official working hours.
- Cules Kolbe (Mining Consultant with 30 years' experience of Mining & Industrial Engineering application on Mines) for invaluable technical guidance in technology Roll-out.
- Robin Pearce (GHH Business Development Manager) for his swift response to design changes that were brought about by the implementation.
- Thys Marais, Mark Cronje and Dennis Malepe (All Booysendal Technical employees) for provision of data and validation of field information.
- Daniel Mogapi and Nigel Reeder (Booysendal Operational Management) for the enthusiastic support and even criticism of some of the author's unorthodox tactics.
- Jean-Pierre (JP) Potgieter for meticulous eye in editing the initial layout of the report.
- Willie Swartz, Meshack Mqadi and Luto Mbombo (All Booysendal Mine Technical Services experts) for discussions of geological planned cuts and even verification of results obtained.
- Andy Duncan (Mine Chief Surveyor) for provision of audited stoping width and shaft head grade data.
- Elaine Dodge Content Creation for editing the final report.

Table of Contents

Contents **Page**

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

LIST OF SYMBOLS

°	degrees
%	percent
4E	platinum, palladium, rhodium and gold
cm	centimetres
Cu	copper
dBA	decibels – A scale of acoustics to measure sound pressure level
g/t	grams per ton
hrs	hours
km	kilometres
kozpa	kilo ounces per annum
kt	kilo ton
ktpm	kilo tons per month
m	metres
m^2	square metres
mins	minutes
mm	millimetres
Moz	million ounces
Ni	nickel
oz	ounces
Pt	platinum
Rand	South African Rand
Rm	million Rands
t	tons

LIST OF ABBREVIATIONS

ADE	Model Type of the Roof Bolter from GHH
ASD	Advance Strike Drive
CEO	Chief Executive Officer
CMMS	Centre for Mechanised Mining Systems (Wits University)
DMS	Dense Medium Separation
FY	Financial Year
GHH	Roof Bolter Equipment Manufacturer
KPI	Key Performance Indicator/s
LHD	Load-haul-dump Machine
LP	Low Profile
OEM	Original Equipment Manufacturer
PGMs	Platinum Group Metals
ROM	Run-of-Mine
SLP	Super-Low Profile
SOP	Standard Operating Procedure
TARP	Trigger Action Response Plan
UG2	Upper Group 2 Reef
ULP	Ultra-Low Profile
XLP	Extra-Low Profile

1. INTRODUCTION

1.1 Mining Background and Rationale

The Booysendal mining right is located within the southern compartment of the Eastern Limb of the Bushveld Complex. It is approximately 35km from the town of Mashishing (formerly Lydenburg), and straddles the border of Limpopo and Mpumalanga provinces in South Africa. (Northam Platinum Limited, 2017).

The property hosts the PGM-bearing UG2 and Merensky orebodies, both outcropping along an extensive strike length. The characteristics of these orebodies allow a mechanised mining approach, with relatively shallow underground mining operations, developed in a modular fashion. (Northam Platinum Limited, 2017).

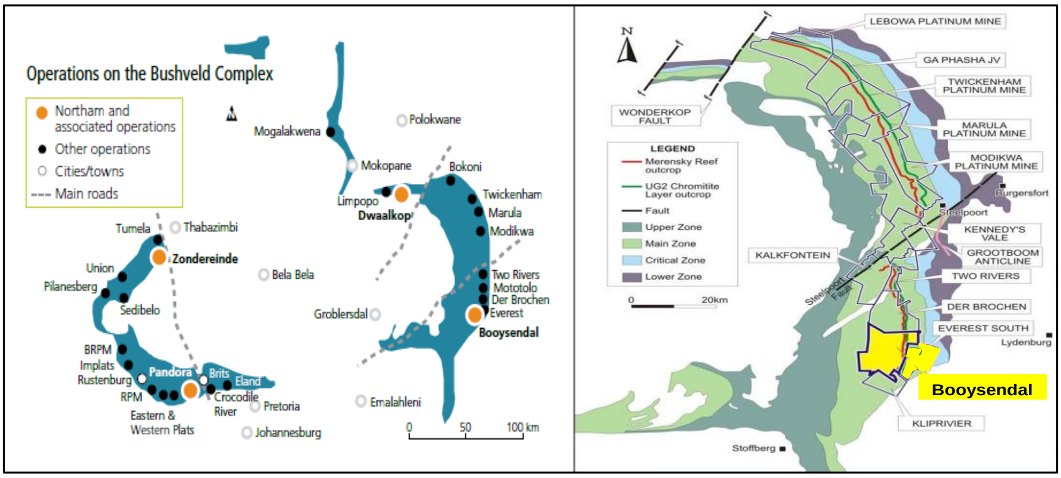


Figure 1a: Whole Bushveld Complex and the magnified Eastern Limb (Source: Northam Platinum Limited)

Both the UG2 and Merensky reefs dips at 11° from East to West. The Booysendal Mine lease area extends over 14.5km on strike and 10km on dip (refer to Figure 1a). In this research project, I focus only on the Merensky North Mine area. The area extends over 3.8km on strike and 2.1km on dip, the approach being to mine 25 000 tons per month over 4 years and in the next phase to increase production to 75 000 tons per month full capacity (refer to Figure 1b for Booysendal Mine. The Merensky Shaft is the area in light orange.)

It is against the above shortened description of the Booysendal Mine operations that the author needs to bring in extracts of talks given by the Northam Platinum

Mine executives to the markets and the significance of mining the Merensky reef in the Eastern Limb.

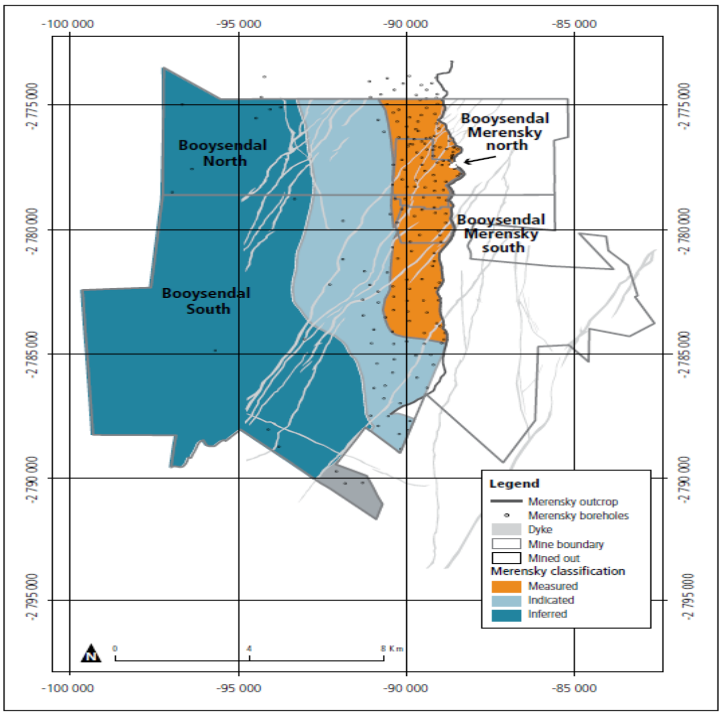


Figure 1b: Localised plan specific to Booysendal Lease Area (Source: Northam Platinum Limited)

Booysendal Mine has both the UG2 and the Merensky reefs in its lease area. For the last 6 years the UG2 orebody has been mined with an exceptional degree of success. In February 2015, a decision was taken to do a Merensky Shaft bulk sample. It proved to be a viable mining proposition, provided the stoping height could consistently be maintained at maximum 1900mm (see Figure 1b for Merensky North Shaft Area).

Booysendal Mine has 48Moz reserves of UG2 reef in its lease area. The reserves have a significant economic value for Northam Platinum when they are mined successfully.

The company strategy has always been to start up projects on either UG2 or Merensky in modular phases. Other mines in the Eastern Limb mine UG2 therefore it also made practical sense for Northam Platinum to start with UG2 mining.

The UG2 North Mine has been successful for 6 years, however its concentrate has high moisture content. This poses recovery challenges at the company smelter in Thabazimbi.

Booysendal Mine has also 36Moz of Merensky reef in its lease area. It has a high content of nickel and copper as compared to UG2 reef. Besides the significant economic value of the Merensky reef, when it is blended with UG2 concentrate the result is better PGMs recovery at the smelter. Despite the fact that no company has ever mined the Merensky reef's thin stratigraphic width successfully for a long period, NPL, aware of the challenges involved, took a decision to do so.

The NPL CEO, Paul Dunne, addressed the markets and specifically JPMorgan mining analysts on 30 June 2016. Here are extracts from that speech.

- "The Management outlined three expansion phases for the Booysendal Mine that will grow production to 475kozpa 4E (FY15: 122koz) by FY22.
- The first expansion phase (ongoing) will add 25kozpa 4E by mining the Merensky reef at the existing Booysendal North Mine, with a capital cost of R300m spent over two years. The Management sees the Merensky reef output as "swing" production with the option to increase mining as and when required. It sees an option to increase Booysendal North Merensky output to 75kozpa (from 25kozpa currently planned), market conditions permitting.
- The second expansion phase (deepening UG2) involves adding two additional levels to the Booysendal North UG2 Mine at a capital cost of R270m over three years. This will add 30kozpa 4E to the mine's capacity (for a total of 260kozpa) and will, in our view, likely require commissioning the installed DMS plant to ensure sufficient concentrating capacity.
- The third phase of expansion envisages exploiting the Booysendal Central and South Mines through the development of a new portal system near the middle of the greater Booysendal property. This portal system is to be used to establish at least two declines that will tap into the BS1 and BS2 portion of the orebody. The ore mined will be transported via a Ropecon (or rope conveyor) to the Everest processing site.

- This expansion is planned to deliver 230ktpm of ore (or 215kozpa 4E) at steady state and requires a capital spend of R4.2bn over six years. These three expansions will grow Booysendal Mine production from its current throughput of 160kozpa to 475kozpa."

Not one mine in the Eastern Limb of the Bushveld complex is currently mining the Merensky reef using the trackless mechanized method. The achieved mill head grade at the normal 2.2m Low Profile (LP) stoping height and increased dilution means it is not a financially viable business.

The obvious opportunity then lies in a mechanised application where the reef is mined at a reduced stoping height. Booysendal Mine gave GHH Mining an opportunity to do a trial at the Merensky Shaft to prove the 3108 ADE bolter's capability in a 1.9m mining environment.

This project aimed to optimise the operation of the modified 3108 ADE bolter.

First, the project ensured that the Operator was safe from harm through the addition of certain features in the new bolter. As a close out for the trial stage, a formalised Change Management process ensures all Operators are now informed of the new features and their applications.

Second, the project actioned a number of operations Management processes to set the baseline productivity and then applied a step approach to increase productivity to target levels.

Lastly, the project benchmarked its achievement with other mines productivity levels gathered through literature review.

1.2 Objectives

The objective of this study is to assess the use of industrial engineering techniques to expedite the implementation of a Roof bolter in the challenging environment at Booysendal Mine. The process of creating a learning environment is one of the important goals in many business improvement frameworks, and underlies the work done here in order to achieve the following output KPIs:

To produce 1 900m² with a 235m system face advance per month in a stoping to yield 11 500 tons per rig section at a defined stoping width of 1 900mm. To achieve that desired output, the 3108a ADE bolter must perform as per the following KPIs:

(i) Drill and install a 1.75m resin applied rock bolt in 8 mins.

(ii) Bolt installation times, including movement between bords, should be in the region of 2 hrs allowing for the flexibility of supporting 3 bords in the available 7 hrs face time.

(iii) For 3 bords to be completely supported, the Roof bolter must install 42 bolts per shift.

(iv) The bolter must be able to install bolts in stoping widths ranging from 1700 to 2000 mm to achieve the defined stoping width of 1900 mm.

In trials (Booysendal Mine June 2016 – Dec 2016), the bolter was not consistently achieving its KPIs. The objective of this research work was to optimise operation of the Roof bolter so that it could achieve Roof bolt drilling and installation in 8 minutes.

It needs to be stated that at 90% availability of the drill rig machine and 90% availability of the Roof bolter machine, if the stoping section manages to blast only 4 bords in 24 hours, it will only achieve 214m which equates to 1 710m² - not the expected production output.

With the same availability scenario of 90% for each machine, if the blast achieved is 5 bords in 24 hours, even if the blast rate is 90% per month, the section will achieve 235m and 1 900m² per month. If we take this a step further and achieve 6 bords in 24 hours with 90% availabilities on both pieces of equipment, even if the blast rate is 95% per month, the section will achieve 300m and 2 400m² per month. Clearly, a lesser number of bords supported per month will not only affect the mining cycle, but will result in less than expected production output per month.

The mining cycle differs completely from the manufacturing sector in that there are set blasting times and scientifically determined post blast re-entry periods. Missing a blast cannot be made up by working overtime in 24 hours.

After fully explaining the main objectives of this research, it needs to be stated that there’s a well-entrenched belief that Roof bolting is the main constraint in the mining cycle among the most experienced mechanised mine Operators in South Africa. According to them, two main areas need to be looked at if this technology is to be successfully implemented; namely the process and the people.

- Technological change will increase the Total Factor Productivity Index (TFPI) by increasing the efficiency of output per unit input (Green, cited in Neingo, 2014). This is proven in coal mining, which is highly mechanised compared to hard rock underground mining. The use of continuous miners (CM) in coal mining, which is currently coupled with continuous haulage, minimises the effect of human factors on productivity. In other words, productivity is more reliant in coal mining on the availability and utilisation of CM.

  Felske, cited by Wojciechowski, described new product development as the only direction in which Canada has a real technological advantage and is the only direction for significant economic gains for the industry (Neingo, 2014).

- An improvement in human capital will increase economic efficiency. A skilled and experienced workforce can obviously improve the quantity of output per unit of input (Green, cited in Neingo, 2014). Poor labour skills and negative attitudes can be significant sources of productivity problems, although Management is responsible for correcting these attitudes (Wojciechowski, cited in Neingo, 2014).

While the author is fully aware of the above two areas of concern raised by other researchers, it means the objectives of this new machine Roll-out must take into account the non-physical aspects of machine adoption.

1.3 Statement of the problem

The success of a properly implemented machine Roll-out in a typical mechanised trackless mine, such as Booysendal Mine, is the fleet suite’s ability to complete the mining cycle within a specified shift period.

A mining cycle comprises four main activities:

- Loading and hauling
- Supporting
- Drilling

- Charging and blasting.

It is defined by blasting at the end of shift at times specifically set by the mine. If any steps in the mining cycle take too long then the blast will not happen.

In a trackless bord and pillar method once a mining section is out of cycle during the 24 working days a month it becomes difficult and complex to get back into the cycle again. As a result, the mining section won't achieve its planned monthly production. The ripple effect of this will result in a failed mechanised mining system Roll-out.

It is against this context that the author intended to fully understand the successes and the failures of the GHH bolter implementation approach; the physical modifications done from trial stage to final adapted machine. He also needed to understand how this new machine was introduced to Roof bolter Operators, maintenance crew and the miner of the section.

The challenge that this Project had is there are no previous trackless Merensky mines in the Eastern Limb against which to benchmark the performance. The author used Roof bolter performance information available for UG2 and chrome trackless mines for comparison and benchmarking instead.

1.4 Scope

Although this project looks at the implementation of a GHH bolter in a 1 700 – 1 900mm stoping width environment, it must be stated the main aim is not to promote a certain OEM machine. It is, however, to critically examine why other successful mechanised mines in South Africa in similar environments are still using hand-held machines for bolting and what was their technology transfer approach.

For a critical investigation and examination of mines at 1 700 – 1 900mm stoping widths, four mines were looked at through literature review and some on-site underground observations were done as well as the application of the author's own extensive practical experience of trackless mine operations.

It was while examining mine operations in this context that the author extended his scope to examine the successes of the XLP suite application at Anglo American's Bathopele Mine. Various technical reports and research projects have fully unpacked the bolting successes of Bathopele Mine as well as stating the bolting challenges which still need to be fully researched.

The Roll-out of the GHH bolter machine at the Merensky Shaft focused on the following:

- Trial stage implementation and findings
- Change Management with the new modified machine
- Observational research methods to improve machine efficiency
- Analysis of operational results achieved and residual challenges identified

The research had to answer this main question: How well will a set of industrial engineering tools work to improve the modified GHH bolter performance to enable the Merensky shaft to efficiently mine at a stoping width of 1900mm consistently?

1.5 Importance of the study

Early successes of the Merensky Shaft outputs in the Eastern Limb have already sparked interest in other mining houses operating in this area. They are starting to have critical conversations about the value of supplementing UG2 production by adding Merensky reef mining. The author intends to unpack the impact and meaning of the GHH bolter Roll-out in four different mining areas.

Before unpacking the impact, the following two figures will contextualise what the author intends to assert (Figure 1c and Appendix 5 Figure 5(i)).

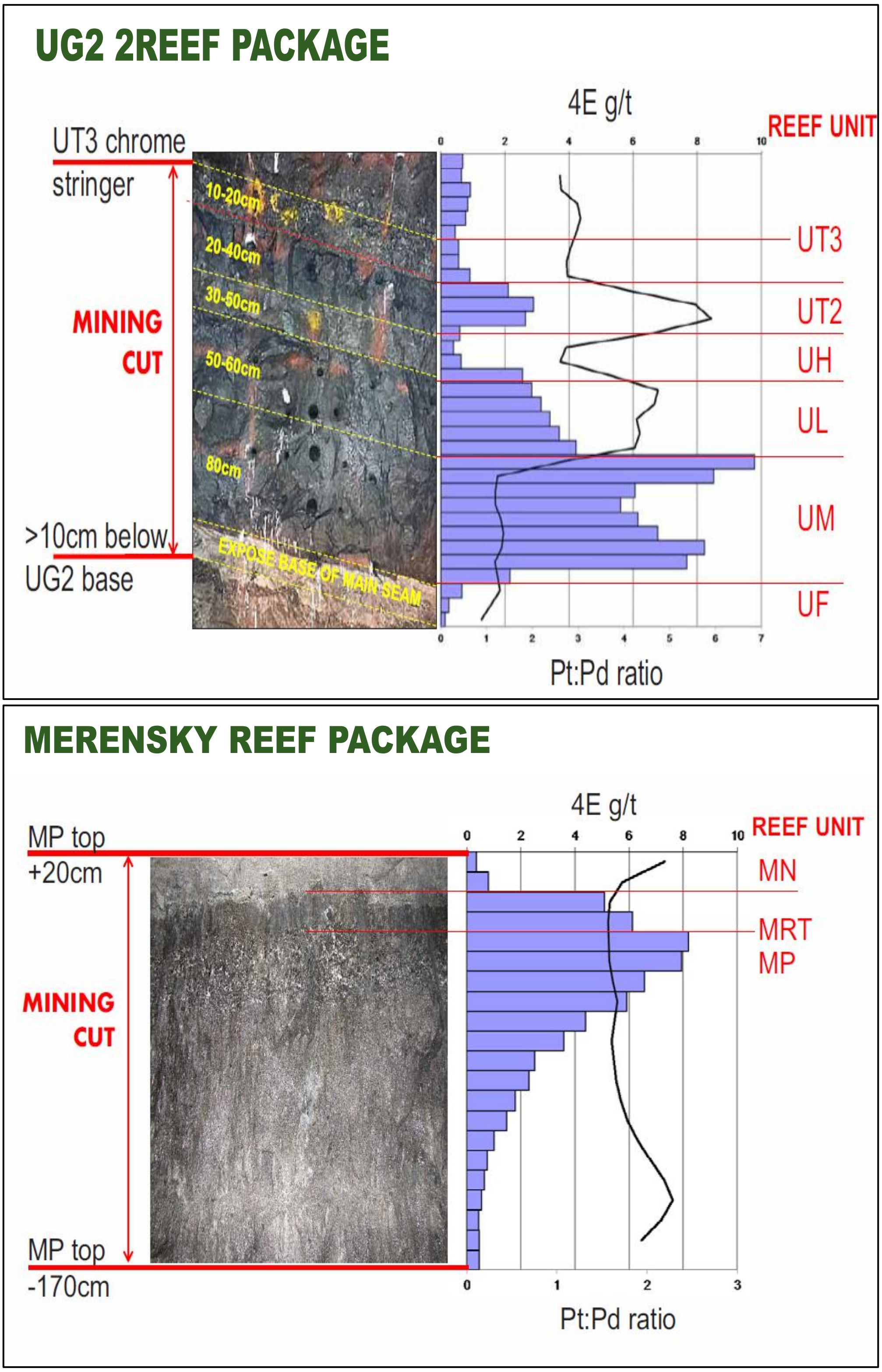


Figure 1c: Difference between UG2 and Merensky reefs in the Eastern Limb Area
(Source: Northam Platinum Limited)

As per the best cut diagrams shown in **Figure 1c**, it is important to understand that the stoping width has to be below 1 900mm. If the stoping width is maintained at levels higher than 1 900mm there will profound negative financial implications due to:

- Increased dilution means the concentrator recoveries will be lower than expected.
- Increased costs in both mining and concentrator will be incurred – mining will have to move additional unpayable tons at a cost and the concentrator ore flow will take longer due to the excess tons delivered.
- The mining sections will have to mine additional areas than initially planned to compensate for the lower-than-planned shaft head grade. This has additional cost implications to the mine.

If the project execution is successful and we are able to mine between 1 700mm to 1 900mm, what does that mean to the Booysendal Platinum Mine, Northam Platinum Mine, Eastern Limb Mines and Metallurgy fraternity?

- To Booysendal Mine, as per the strategic plan to increase the total output to 475kozpa by FY2022; Any experienced mine Operator will acknowledge this steep production ramp-up will have to be backed by rigorous project implementation processes. Even if the processes are solid and sound, the successful execution of the Merensky Module 1 Project will provide leverage should there be a delay in the Central Mine coming on stream as per the project schedule.

  At NPL's top Management level, there are already strategic conversations happening about initiating scoping and pre-feasibility studies of either one or two similar Merensky modular type shafts at the Central Mine. The capital expenditure at the Merensky Shaft will yield positive financial results for the mine especially when the basket price increases and the mine reaps the full benefits of the price upswing.

- The UG2 concentrate from Booysendal Mine has high moisture content; this ranges in the lower 20%. This poses a significant smelter recovery challenge at the Zondereinde Smelter in Thabazimbi.

To ensure that smelter recoveries are optimised, NPL purchases the Merensky run-of-mine ore (ROM) from the Plianesberg Mines. This ROM is put through the concentrator and then the UG2 concentrate from Booysendal Mine is blended with Merensky concentrate at ratios specified by metallurgists running the smelter to optimally recover the 4E PGMs.

Over and above the benefit of increasing the UG2 recoveries, the Merensky Shaft ore has a significant content of nickel and copper. These by-products are also further processed to yield significant financial returns to the company. Due to the financial sensitivities in the competitive mining environment, the author would rather not specify the percentages of Ni and Cu. Its profit contribution percentages will not be mentioned either.

Although NPL still incurs transport costs when moving Merensky Shaft concentrate from Booysendal Mine to Zondereinde Smelter, it does benefit by replacing the cost of ROM used to pay to other mines.

- As mentioned in the introduction, there is no single mine in the Eastern Limb which mines the Merensky reef due to the thin stratigraphic reef width. This width dilemma will be further unpacked in the project's main central chapters. It's in this context that the mines mining above the Steelpoort fault towards north right up until Lebowa Platinum Mine are finding it economically unviable to mine this reef in their own 'proven and entrenched' conventional hand held drilling and blasting method (Steelpoort fault is shown clearly in **Figure 1a**).

  A similar situation exists with the mines located in the south of the Steelpoort fault from Two Rivers Platinum Mine right through to Booysendal Mine lease area, even though these mines use the LP mechanised mining methods.

  So, where does the answer lie for these mines to unleash the Merensky reef's dormant economic potential?
  Surely, if there's a mine that can exploit this reef and have sound control on its dilution effect then all mines in the Eastern Limb will start looking at mining the Merensky reef. Currently, the mines in the Eastern Limb are using the 'wait and see' approach. They are waiting to see tangible results from the Booysendal Merensky Project - most probably for two to three financial years' performance.

Some mines have previously attempted the Merensky reef and failed, which explains the industry's cautious approach when planning strategic capital projects, especially in this low basket price environment.

- Metallurgists, both operational and research-based, are now faced with a dilemma; designing extraction processes which will blend both UG2 and Merensky ROM in the currently existing concentrators and still maintain recoveries above minimum of 85%.

  With all four concern and opportunity areas mentioned above, there's one main opportunity aspect that has not been mentioned. Between the UG2 reef plane and Merensky reef plane in the Eastern Limb, the middling is 170 – 180m and this allows both reefs to be mined concurrently.

  This is not the case in the Western Limb mines where the middling ranges between 36 – 40m, making co-extraction of both reefs impossible due to rock engineering challenges posed by stressed and destressed mining zones.

1.6 Trial stage findings

The Booysendal Mine trial for the GHH Roof bolter (model type 3108 ADE) started in June 2016 and was closed out six months later in December 2016.

The trial's main purpose was to test and prove the 3108 ADE's capability to support a bord in a Super-Low Profile environment – a stoping width between 1 700 – 1 900mm. The trial looked at three different types of bolts: 18mm rock bolts, 18mm 'spin to stall' bolts and 25mm rock bolts. The method of drilling during the trial was the rotary drilling mode, as compared to rotary-percussive mode used in other machines.

Sections **3.1** and **3.2** of this report will further unpack the trial stage results and the physical modifications that were done on the 3108 ADE bolter to modify it to 3108a ADE.

In the application of a SLP type bolter, coupled with the rotary drilling mechanisms, it would be unwise not to challenge the norms of rock bolt combinations as far as adhesive application and bolt support characteristics are concerned, so different rock bolt combinations were tested in this project. It is difficult to quantify the non-tangible benefits derived from the use of smaller diameter drilling consumables and associated equipment, but the outcome and cost effectiveness of the measurable items are listed below.

The following operational criteria installing 1,75m rock bolts was achieved during the trial period:

(Note: Bolt yield stress and support resistance in all cases are within acceptable limits)

a) 35mm hole diameters with 25mm rock bolt and related resin combination:

- Best bolt installation times – 7.4 mins/bolt
- Average bolt installation times – 9.2 mins/bolt
- Number of bolts per bord – 14 bolts
- Number of replacement bolts per bord, replacement bolts are due to either damaged bolts or incorrectly installed bolts – 3 bolts
- Indicated number of bords per 7 hr shift cycle – 2 bords

b) 25mm hole diameters with 18mm bolt and related resin combination:

- Best bolt installation times – 6.3 mins/bolt
- Average bolt installation times – 8.0 mins/bolt
- Number of bolts per bord – 14 bolts
- Number of replacement bolts per bord, replacement bolts are due to either damaged bolts or incorrectly installed bolts – 3 bolts
- Indicated number of bords per 7 hr shift cycle – 2 bords

c) 18 mm bolting with “spin to stall” resin application:

- Reduction in bolt installation times – 1.08 mins
- Average bolt installation times – 6.4 mins/bolt
- Indicated number of bords per 7 hr shift cycle – 3 bords

The conclusion from the trial was to take the 25mm hole 18mm diameter Roof bolt to implementation stage. Although the 18mm “spin to stall” bolts achieved 6 bords supported per 24 hours with ease, it did not pass certain rock engineering specifications that were required. The challenge with the 25mm hole 18mm rock bolt is that it consistently delivered only 4 bords in 24 hours. In sub-section **1.2** of this report the author mentioned that 4 bords will yield only 214m per month and it still be 21m below the expected production output. The results of this trial sets a base for the case study and the base is as follows: We have an operational problem, we want to mechanise roof bolting, but performance is inadequate.

To achieve 235m per month per mining section the GHH bolter has to install a minimum of 5 bords in 24 hours at 90% blasting rate to deliver the 1 900m² per month. To achieve that target, 42 bolts need to be installed in a 7.5 hour shift, translating to minimum of 6 bolts/hour.

1.7 Methodology

This case study will seek to entrench the performance achieved in the 3108 ADE bolter trial first, and then focus on its operational effectiveness to achieve 235m on monthly basis.

For this to be done, the following industrial engineering techniques will be used:

- Lean Manufacturing tools were used to draw up effective communication channels for Operators engagement, visible performance data gathering and performance monitoring.
- Observational research methods were used to assess and evaluate the impact of 3108a modifications in achieving the set KPIs per shift in a real underground situation.
- Experienced mechanised mining personnel were used to conduct time-and-motion time studies whilst the machines were physically operating at the faces underground.
- The A3 report process was used as the framework to communicate the process of the 3108a machine Roll-out to people on the team.

The following implementation Champions assisted in doing observations and sharing practical experience so that appropriate adaptations can be made:

(i) Project Champion: the author of this report (Wonderboy Kekana) – has 17 years' operational experience on gold, platinum and diamond mines. I have experience in conventional, hybrid and mechanised mining methods.

(ii) Operational Technology Champion: Nigel Reeder (Merensky Mine M/O with 30 years' operational mine experience, of which 20 years was at middle Management level).

(iii) Technical Champion: Robin Pearce (GHH Mechanical Engineer with over 25 years' industrial machinery experience).

(iv) Technical Champion: Cules Kolbe (Ex Mine Manager and Industrial Engineer with over 30 years' mining experience. He was the Project Leader implementing mechanisation in one of the Platinum companies in South Africa).

The main modus operandi was to observe, collect data, record results, engage Operators and do modifications.

Being the Mine Manager at Booysendal Mine, and carrying Management authority and power to give instructions and make decisions relating to this project, the author did this project as part of his work.

Macfarlane (2001) explains the following concept regarding a project leader, as was identified by Kotter, "It is essential to identify a project champion. The project champion must have a multi-disciplinary team around him who will assist in the successful transfer of the technology. Ideally, the champion should be a senior line manager. It is unlikely that any other person will have sufficient power to see the project through, or be able to seriously influence the change to the new method or technology. Many change initiatives have failed where senior or line Management are perceived to be sitting on the fence, not fully supportive, or waiting to see what happens before making a firm commitment of support." This must be avoided at all costs.

The GHH bolter implementation at the Merensky Shaft was a mini-project that enhanced the strategic growth of Merensky greenfield project. As the Mine Manager, the author was tasked by the Mine General Manager to lead this Roll-out. The implementation team's main members were the author, Nigel, Robin and Cules.

The team conducted briefing sessions with Operators and mining teams using flipcharts and posters on a biweekly basis. At the end of each briefing session the team followed up by doing physical on-site observations, noting these in their field books and taking photographs of the critical Roof bolting sub activities they observed. (Refer to **Appendix 1** and **3** for Roll-out posters used to communicate and get teams understanding, evidence of full team participation and the observations done).

The implementation team planned to do the on-site underground physical inspections on Tuesdays and have debrief sessions with Operators and maintenance team after each inspection over a period of 24 weeks. Instead of the 24 planned inspections, the team managed to do 20 inspections and 20 debriefs.

Time study data was conducted by the GHH technical team during the trial stage, and this was validated by an independent mining consultant. The other data for the full implementation was collected by the experienced trackless mining instructors employed by the mine. (See the results of the implementation time study in sub-section **4.5** of this report).

*What is observation***?**

According to the Department of Health and Human Sciences, (CDC), (2008) observation is a way of gathering data by watching behaviour, events, or noting physical characteristics in their natural setting.

Observations can either be direct or indirect. Direct observations are when you watch interactions, processes, or behaviours as they occur. (Department of Health and Human Sciences, (CDC), (2008)).

The Booysendal Mine implementation team only interacted with Operators at the waiting place during the start of shift briefing sessions. When it came to observations, because the team wanted to identify critical steps leading to either failure or success of the bolting activity, the modus operandi was to observe and take notes, not interact with the Operator.

The critical observations were discussed with all the Operators in the follow up sessions and a group solution was adopted for chronic recurring operational challenges.

When should you use observation for evaluation?

First, when you are trying to understand an on-going process or situation. Through observation you can monitor or watch a process or situation which you are evaluating as it occurs.

Second, when you need to know about a physical setting. Seeing the place or environment where something takes place can help increase your understanding of the event, activity or the situation being evaluated. The Department of Health and Human Sciences, (CDC), 2008). Brief 16 of the Evaluation team (2008) states that the advantages of direct observations are that field notes can be taken while the activity happens, capturing the real uninterrupted acts without relying on people's ability to respond.

In the case of the Booysendal Mine team, the advantage is that these observations are done by experienced team members. In fact, one of the team members had two cases of total mechanisation failure in one mine, so he could warn the team when identifying issues similar to his failed Roll-outs.

Is observation the only way to gather information?

Research by Leicht, Hunter, Saluja and Messner (2010) asserts that while quantitative research methods can be very important for answering certain research questions, there are important reasons for adopting qualitative or mixed methodology studies to gain a better understanding of complex phenomena.

Observational studies can provide answers to 'what' phenomena occurred, particularly when people are involved in the process, along with insights into 'why' it occurred. As the implementation team did not have any previous experience of the bolter performance in a Merensky environment it would have been inappropriate to do a structured observation with pre-set questions since the application of this unit is unknown in our current context.

It is difficult to determine when observational research methods were first used (Wax; Bauer et al., cited in Leicht et al., 2010). These techniques are, in many ways, natural steps in the research process.

Simply stated, if we are curious about why something occurs we are likely to seek observations of that phenomenon to more fully understand it.

What are the two main data gathering methods?

The use of observational methods within the qualitative data gathering context is divided into two main categorisations, usually identified as structured and unstructured observation (Yin, cited in Leicht et al., 2010).

Structured observations rely on frameworks of predefined actions, discussion content, or even body language to fit the activity within the variables and scope of the research question. By using the existing framework or developing a specific framework to track observed activities, the researcher has chosen the architecture around which they are fitting the hypothesis and they utilise the data from the observations to create correlations between the pieces (Leicht, 2010).

In contrast to structured observations, an unstructured observation utilises no pre-set framework. The concept driving unstructured observation is to have the researcher enter into the observations with no preconceptions regarding the expected outcomes. The researcher simply records and notes the behaviours in question and the trends in the behaviours will emerge with time.

Along with these, non-frequency techniques and contingency analysis, coding whether or not something is used rather than how often, or the absence or presence of an attribute may be more significant than the relative frequency of other characteristics (Leicht, 2010).

Was the implementation team biased?

Although the requirement for a sound unstructured observation is a ‘no preconceptions’ requirement, the implementation team members did have some biases. Cules and Robin have the experience of the 3108 ADE ‘dry-drilling’ at Mimosa Mine. As a result, the initial dry-collaring challenges experienced were a non-issue to them, while it was a concern to the on-mine team. Wonderboy and

Nigel regarded roto-percussive drilling to be faster than rotary drilling, although they had no proven record of their conviction.

Where do observations start and then stop?

Although the observations done by the Booysendal Merensky implementation team was done by a highly experienced team comprising both OEMs and mine operational persons, one may pose the question when do you start and when do you end the observations?

We were guided by the following principle, Merriam (1998) suggests that the most important factor determining what a researcher should observe is the researcher's purpose for conducting the study in the first place. "Where to begin looking depends on the research question, but where to focus or stop cannot be determined ahead of time" (Merriam 1998, cited in Kawulich, 2005).

1.8 Subsequent Chapters

This report is divided into six chapters.

Chapter 1 explains the underlying reasons why this case study was undertaken, the impact it will have on Booysendal Mine and the research methodology followed.

Chapter 2 unpacks what the main challenges mechanised mines face with regard to Roof bolting and what are the learnings from XLP projects implementation.

Chapter 3 thoroughly details the GHH bolter trial carried out and the outcomes.

Chapter 4 unpacks the application of Operations Management or industrial engineering tools in implementing the modified GHH bolter and what preliminary results have been achieved to date.

Chapter 5 analyses the results achieved while unpacking the challenges experienced and the residual challenges after remedial actions have been effected.

Chapter 6 summarises the observations, conclusions, recommendations and further research opportunities arising from residual challenges.

2. ROOF BOLTING CHALLENGES ON MECHANISED MINES

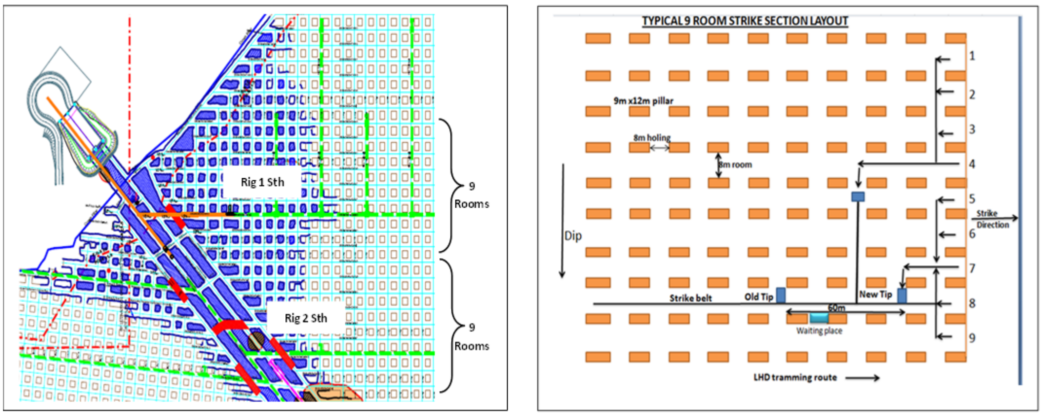
2.1 Background of four trackless mechanised mines

This chapter will review work written by other researchers on the technology used in four Low Profile (LP) mechanised mines (Three mines from Nong's research report and the fourth mine from Pickering's mechanised mines workshop). It looks at both chrome and platinum mines and the author summarises what has been documented about the technology Roll-out on these mines.

However, attention needs also to be drawn to other underlying issues about which other technical papers and dissertations are silent and the reasons why.

Before scrutinising the work done by Nong and Pickering, the author will explain basic mechanised and hybrid mine design specifications.

A mechanised Low Profile (LP) mine has the basic mine design parameters typical to the one shown in **Figure 2a** below. Design specifications vary, some mines will prefer 12 bords instead of 9. Access may be via four on-reef barrels whilst the fifth is in the footwall to ensure ore surge capacity creation though short ore passes (typically 18 – 25m).



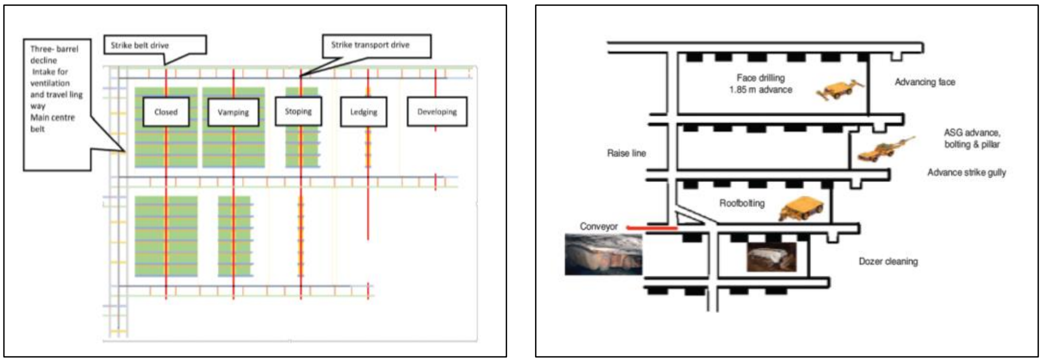
Stope width	2.0m	to	3.0m
Bord length	6m	to	12m

Figure 2a: Typical layout of Low Profile (LP) mechanised bord and pillar mine showing both macro and micro plans
(Source: Northam Platinum Limited)

Super Low Profile (SLP) design parameters are exactly the same as LP, the only difference is the stoping width varies between 1.7 to 1.9m.

The design parameters of an XLP mine

A mechanised XLP mine has design parameters typical to the one shown in **Figure 2b** below. This method is actually a combination of two mechanised processes; the ASDs are developed using LP equipment and the stope panel is mined with extra-low profile equipment, specifically built and customised, which fits in a 1.2 to 1.7m environment. The ULP operates in the same way manner as the XLP the only difference is that the stoping width varies between 0.7 to 1.2 m.



ASD width	4.0m	to	6.5m	Stoping width	1.2m	to	1.7m
ASD height	2.1m	to	3.0m	Panel length	25m	to	28m

Figure 2b: Typical mining layout of Extra Low Profile (XLP) mechanised mine showing both macro and micro plans
(Source: Pickering (2007) and Fourie (2014))

(See **Figure 2c** for high wall and low wall sides of the bords with their accompanying dimensions.) The high wall side of the bord is normally the up-dip side and is mined a few centimetres higher than the down-dip side. Low wall is on the down-dip side of the bord and is mined at height less that the high wall.

Exceptions are planned for in the mine design to cover occasions when bords mine through complex Geology (potholes, slumps, dykes etc.) then the high wall and the low wall are mined at the same height.

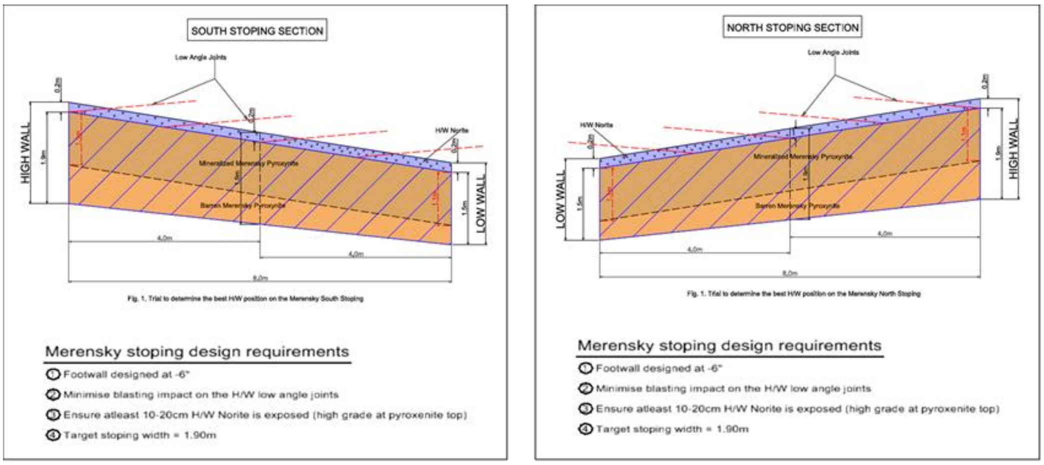
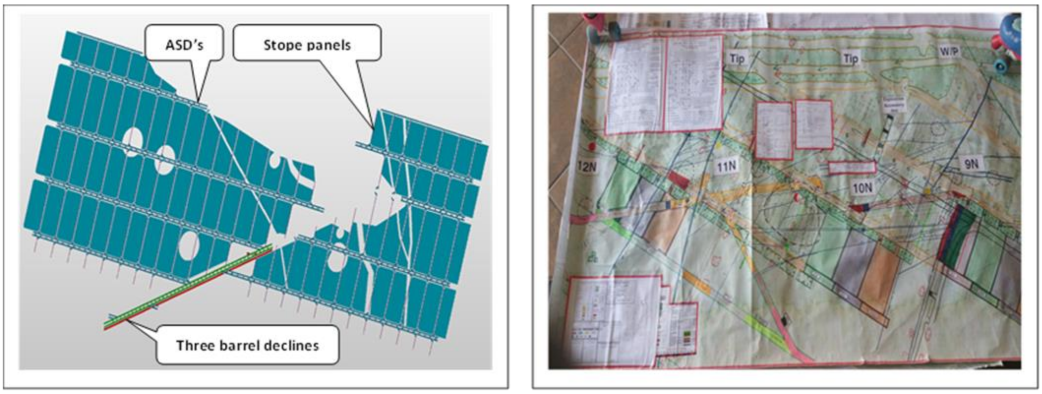


Figure 2c: Typical Booysendal Merensky bord high wall 1.9m and low wall 1.7m
(Source: Northam Platinum Limited)

The design parameters of a hybrid mine

Hybrid Mine Designs are not fully understood by a significant number of mining industry participants. While 'hybrid' simply means a combination of two mining methods, the predominant understanding must be a combination of conventional stoping mixed together with mechanised LP stope access development. (See **Figure 2d** below for typical hybrid mine design specifications.)



ASD width	4.0m	to	6.5m	Stoping width	0.9m	to	1.6m
ASD height	2.1m	to	3.0m	Panel length	24m	to	35m

Figure 2d: Typical mining layout of Hybrid mine showing both macro and micro plans
(Source: Northam Platinum Limited and Union Mine Monthly stoping plans)

Put simply, mechanised mine design is where the planning and execution of actual mining is done using a trackless mining fleet operated by trained, qualified and competent Operators. Hybrid mine design is where planning and execution of actual mining is done using a combination of hand-held mining equipment and a trackless mining fleet.

Here are extracts from Nong's (2010) research report on three different mines:

- Saffy and Hossy are Lonmin shafts situated in the Marikana area. These shafts mine only UG2. Both shafts implemented a fully mechanised mining method using XLP equipment. Saffy shaft's implementation failed – the reason given was the difficulties experienced with the implementation of the mining method and poor production performance. Saffy was changed to a hybrid mining method while Hossy remained as a fully mechanised mine.

  Both shafts had a reef dip within 12° which is well within the operating gradient for a mechanised mine. The reef width on both shafts goes up to 1.6m. The Geology has the normal challenges of a typical UG2 reef that makes it ideal for a mechanised mining method (as per **Figure 2b** specifications).

  A mechanised mining layout is used to facilitate a working system of in-stope and development equipment. The back length varied according to the panel sizes which are varied from 26m to up to 32m at Hossy shaft with the stoping width at 1.2m. The in-stope development is cut between 3.5 to 4m in width. (As per **Figure 2b** specifications). These dimensions were cut to accommodate the equipment and conveyor belt.

  In-stope drilling is done with XLP rigs and support holes are done with the bolters in the stopes. In-stope cleaning is done by dozers. The LHDs load broken rock from the strike and dip drives and tip it on the conveyor belt.

  The mining philosophy is planned to follow mining cycle of drilling and blasting, cleaning and support to ensure the tasks follow each other. This proved to be difficult where equipment failure was experienced. The bolter was identified as a constraint in the mining cycle. At Hossy hand-held drilling crews were introduced to assist the bolters.

The report then focuses on operational readiness:

- The workshop infrastructure
- The maintenance program
- Trained Artisans
- Good communication infrastructure.

These are really important factors to consider when a mechanised method is to be used. However, a weakness in this report is the failure to examine the selection of equipment especially the bolters.

Both Saffy and Hossy shafts failed to realise the complexity of matching XLP equipment and LP equipment to ensure a 1.2m stoping width in-stope, and less than 2.0m height in the development. An incomplete mining cycle, due to unmanaged bolter complexity, led to failure of the production teams to meet its expected targets.

This case study need to identify and use industrial engineering techniques so as to mitigate the above mentioned operational problem and also answer this question: How do we rectify this in other mining projects? Success will only be achieved if appropriately matched in-stope and strike drives equipment is selected at the beginning.

- Although mining operations have common challenges, the most prevalent challenge that Impala 12 shaft had was high dilution due to the location of the triplets above the main seam. The dilution has been recorded going over 40% in some areas resulting in low grade with an average head grade of 3.5 g/t.

  Due to the triplets, the minimum best cut was recommended to be 1.4m which included other geological parting planes. However, the decision was taken to mine at 1.9m to acquire large volumes of ore at an average grade of 3.5g/t.

  The Geology has normal UG2 reef challenges, i.e. fall of grounds due to hanging wall triplets, reef rolls and potholes, making this area ideal for a mechanised mining method (See **Figure 2a** for a typical LP layout). The reef dips between 6° and 10° which is ideal for mechanised, trackless fleet/equipment.

If the mine planners fully understood the complexity of mixing both the LP and XLP systems they wouldn't plan for only 8 bords per section. If they do, it's an indication that no face length redundancy has been planned for.

The room and pillar mining method used by Impala 12 Shaft has a section consisting of 8 rooms with a conveyor belt located in the middle. The crush pillars are designed to be 12m x 4m (length and width) and stability pillars 12m x 36m (length and width) along the conveyor belt. The stoping width is 1.9m with rooms of 12m bord length.

The mining layout uses LP mechanised equipment. The section consists of LP development drill rig, LHDs and utility vehicles. The swing or spare LHD is shared amongst the three sections to ensure that production is not hampered during breakdowns and scheduled maintenance of LHDs in the sections. Installation of support Roof bolts is done by hand-held equipment. This conventional equipment does not support the complete mechanised system. Mine mechanisation must be a complete system where human physical effort is minimised in all areas of operation.

The report then unpacks the challenges experienced by the mine caused by:

- Failure to maintain roadways
- Out of sequence mining leading to ventilation complications
- Location of workshop and critical spares availability

These are really important issues to plan for, if the mechanised method is to be successful.

The report stops short from unpacking the mining cycle complications of mixing a conventional support system with mechanised drilling loading.

***How do we ensure proper Equipment selection to enable an ideal mining cycle for the section*?** : It would be ideal if the OEMs had an off-the-shelf Roof bolting machine available as purchasing it would mean having an ideal suite of equipment. But there is no off-the-shelf Roof bolter that matches the 1.9m stoping width, which is why this mine currently uses hand-held equipment.

Millsell Mine

- Millsell Mine forms part of Samancor's western chrome mines. It exploits LG6 and LG6A chromite ores using a room and pillar mining method. The ore body dips at average of 9° and 11° at most. The total reef width package is 1.74m including internal waste making the environment ideal for mechanisation. Sections consist of 10 rooms (See **Figure 2a** for typical design specifications). The rooms are 14m in length with the stoping height varying between 1.74 and 1.8 m depending on local conditions. This is done to ensure that the mineable face length is adequate for equipment utilisation and to ensure that in the case of geological complications, production and productivity are maintained.

  The mining equipment includes the LP equipment for drilling and LHDs for loading ore, conveyor belts and utility vehicles. Handheld bolting is used to complement the mechanised fleet. No explanation was given as to why a mechanical bolter was not used. It might have been a matter of lack of capital outlay at the beginning of the project. The use of the existing equipment is effective, but the use of hand-held bolting was a concern.

  The majority of mechanised mining systems are motivated on the basis of improved safety, minimum human effort, improved production and higher efficiency. However, in most mines the author visited, hand-held bolters are used because the mechanical bolter was identified as a constraint. Hand-held crews were introduced as a measure to avoid production delays.

In this case, the report started looking at underlying issues that may have led to use of hand-held Roof bolting machines.

Was it capital availability, by design or removing the mechanical bolter as a constraint in the mining cycle? : According to the report, Millsell Mine had originally planned to use conventional hand-held bolting. Which mechanical bolter had high inefficiencies that led the mine's Management to the conclusion a mechanical bolter would be a constraint?

Is there a bolter currently available from the OEMs with capability of mining at 1.9m or support in a 1.74 to 1.8m environment? : No, there isn't. Because there is no off-the-shelf mechanised machine, and the fact that the mine's conventional supporting was done as a parallel system which delivered the expected production per rig section, Management saw no need to partner with an OEM to develop a machine with that capability.

Pickering's 2010 workshop

- At the 2010 workshop on Bord and Pillar best practice, Pickering explained that for a typical platinum hardrock room and pillar mine roof support is usually 1.5 to 1.6 metre resin grouted bolts with 4 to 6-metre-long cable anchors used at tips. With all the mines that presented at the workshop, four of the operations used low profile mechanised bolters for support installation. Three used auto rock drill units, to employ a combination of hand drilling and auto rock units, and one used hand-held drilling only.

  The paper carries on to unpack the fact that there is a certain Mine A in the Eastern Limb which mines platinum. The average production from a single drill rig section is 16 993 tons/month and with a maximum of production of 23 700 tons/month. The mining cycle is three shifts per day for five days per week and one blast per day. What Pickering et al. (2010) does not state is why this highly efficient and successful mechanised mine, which uses auto rock units for roof support in its bords, uses a conventional support system? The author was privileged to be able to have an underground visit at Mine A.

  The details of the mine will be kept discreet as permission has not been granted to write technical facts on their behalf. What was observed at the mine during the visits are the following facts:

  - A rig section has 12 bords of 8m bord length.
  - Each drill rig section has two strike conveyor belts - one in the middle and the other at the last bottom bord of the section.
  - Bolting is done in parallel during the day shift; that is three bords are supported simultaneously.

- The triplets are left in the hanging wall and therefore the average stoping height is less than 2.1m.

Pickering et al. (2010) further explains the bolting complexity facing the mines: the factors that need to be considered to determine the optimal Roof bolting strategy were initially thought to be a simple choice between mechanical bolters and the auto rock type of bolting. However, a complicating factor was the ever increasing need to install bolts that are longer than the stoping width. The individual issues identified were:

- Operator exposure
- The variability of the mining height
- Support length and anchorage mechanism
- Required bolting rate to match other activities
- Bolting density and bolts required per face advance

Operator safety was the overall dominating factor and it was concluded that the optimal solution was a mechanical cable bolter. It was decided that such a solution did not currently exist and that equipment manufacturers should be approached to develop a more efficient mechanised bolter installing longer bolts in narrower stoping width.

This paper assertions, combined with my tacit knowledge, highlighted the following; provided that optimal numbers of bords are planned per drill rig section, the mine using Auto rock support units can still be highly productive, even surpass fully mechanised mines in terms of overall efficiencies.

However, two main questions remain unanswered.

First: *If the stoping width varies below 2.1m is there a mechanical bolter with the capability to mine at this low end of the LP variable heights?*

Second: *Do we have a machine capable of combining both the Roof bolting and installation of long cable anchors into a single activity?*

Although one of my implementation members is currently dealing with a trial project to prove the second question, this will not be dealt with in this report as it not in the scope.

2.2 The common challenge of Roof bolting and the reason for that

In all four mine cases reviewed in sub-section **2.1**, fundamental questions are looked at for a successful mechanised mining system implementation. I will further unpack these questions as they later lead to a more structured research theme/direction for the GHH bolter implementation at Merensky Shaft.

- *How do we address the questions arising from the four projects reviewed in sub-section **2.1**?*

  Proper planning for mechanised mine sections will have to take into account the impact of mining cycle planning per shift if it is to mix two different kinds of fleets. In the case of Saffy and Hossy shafts, both LP and XLP fleets were used to supplement each other. However, the LP bolting in the strike drives proved to be a constraint.

  At the Merensky Shaft, the GHH bolter and its accompanying fleet units will be used in the stoping section. In the development section, different OEMs machines will be used because of their capability at higher mining heights.

- *Has the planning taken into account the interacting variables from these two fleets?*

  Remember, this led to the demise of the fully mechanised system at Saffy Shaft and eventually the whole of Lonmin. The challenge cannot be underestimated.

- *How do we ensure proper Equipment selection to enable an ideal mining cycle for the section?*

  We need to plan for the optimal number of bords that match the selected machine capability. In addition, the bord length must fit within a certain number of bords which need to be supported per shift. The bolting rate and length of bolts have to be considered adequately if we are to meet the planned mining cycle per shift.

- *Is there a bolter currently available from the OEMs with capability of mining at 1.9m*?

  No, but if there was could the Millsell Mine benefit from the OEMs trialling a bolter with 1.9m capability even though it is one of the most highly efficient mines in the hardrock category?

- *If the stoping width varies below 2.1m is there a mechanical bolter that has the capability to mine at this low end of the LP variable heights?*

  Could Mine A, which is the second-best platinum producing mine, improve its production even more if it could have a mechanical bolter capable of supporting in a LP environment of stoping height less than 1,9m? Besides having a positive impact on mill head grade, such a machine could improve the mine’s ability to install cable anchors in areas where geological complications are encountered.

To tackle the support complexity presented in Pickering et al. (2010), Mine A is also currently conducting trials using a cable anchor which combines both the functions of primary and secondary support. These trials are, however, still conducted using the auto rock unit to prove this new anchor innovation.

Once this trial is completed perhaps Booysendal Mine will be in position to share the method of using a machine capable of combining these two functions. This is a potential area where full research can be done; to first look at the machine being trialled at Booysendal Mine and combine that research with the results of the new cable anchor at Mine A.

2.3 Effect of stoping width on dilution

Jordaan (2002) explains that dilution is a detrimental factor that can make any mining operation an unprofitable venture. Cost and revenue in any operation is determined per unit produced, and South African mining operations are costed in Rand per ton. When dilution increases, the mineral content per ton mined is reduced. Revenue is generated per fine ounce of mineral. The result is a reduction in revenue can reach a point where the mining costs and revenue created per ton are the same.

Dilution is a complicated issue. It is a function of the orebody's dimensions and the machine operational dimensions; dip, and stoping width. If the dip is greater than that which the selected machines can handle efficiently, the orebody's dip forces dilution to be designed into the layout. Flattening the footwall to the desired gradient does this. The minimum machine operating heights determines the minimum stoping width.

Research by Nong (2010) seems to confirm the dilution challenges of mechanised mining. However, the research asserts the solution lies with the application of XLP machines. The next section of this research, **2.4,** will examine the XLP progress to date.

Nong (2010) states that in most cases waste is mined together with the mineralised zone, in the process diluting the in-situ grades. Dilution can take place as a result of mining activities, mine design process and poor waste management/control. It can be defined as ingress of waste material into the reef or mineralised rock during the mining operation. It impacts negatively on the mill head grade.

Using mechanised equipment requires large excavations due to a number of factors. These include the sizes and movement on the reef planes. Nong (2010) further put forward XLP equipment as a solution, the extra-low profile machines are designed to operate in stoping widths less than 1.2m to minimise waste mining. As Nong states, the solution lies in XLP, so the question as to why mining operations are reluctant to adopt this technology can arise.

Booysendal Merensky reef dips at 11° and varies in thickness mainly between 75cm to 100cm. From the stratigraphic reef cut width information gathered and analysed by the Booysendal Mine Geology department, a larger proportion of the orebody lies between 75cm to 100cm. However, there's still a significant part that averages around 150cm. **Figures 2a** and **2b** clearly show that any mine design process stating the stoping height should be less than 1.2m will be fundamentally flawed as it would leave behind mineral reserves.

The Booysendal Merensky Project team ran different scenarios and decided that the optimal stoping height for this shaft would be 1.9m as it still maximises value even though there's an element of tolerable dilution planned into it (see **Figure 1c** for the final Mining Cut that was agreed for the Merensky Shaft).

Now, the main challenge for a 1.9m stoping width is that there's no off-the-shelf Roof bolting machine. The author fully unpacks the challenge of a fit-for-purpose machine for a stoping of 1.7 m to 1.9 m when reviewing the mine cases stated in section **2.1** of this research report.

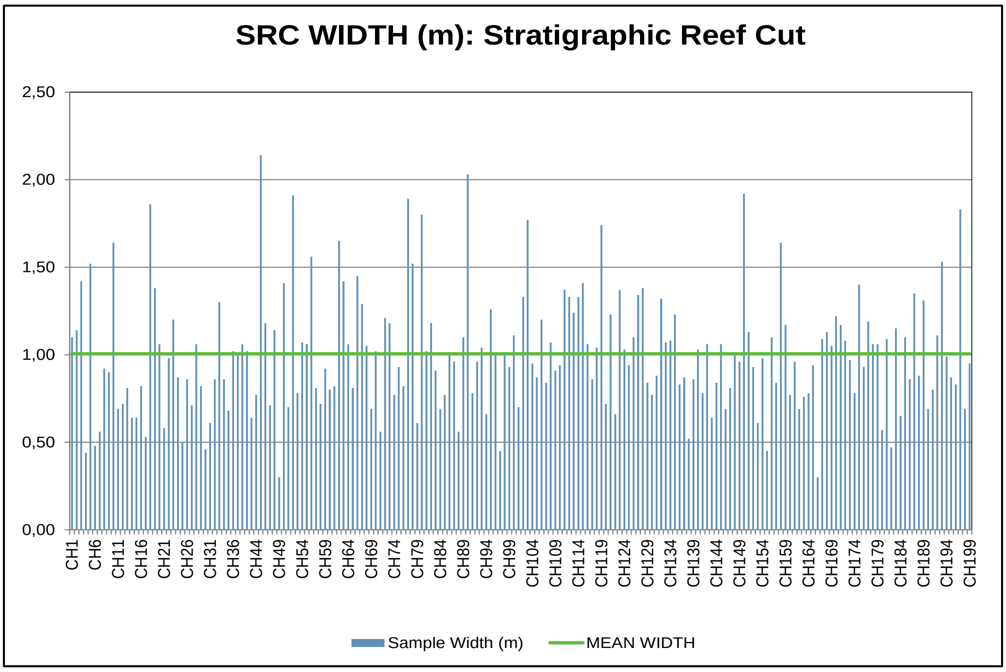


Figure 2e: Current SRC analysed from the surface boreholes (Source: Northam Platinum Limited)

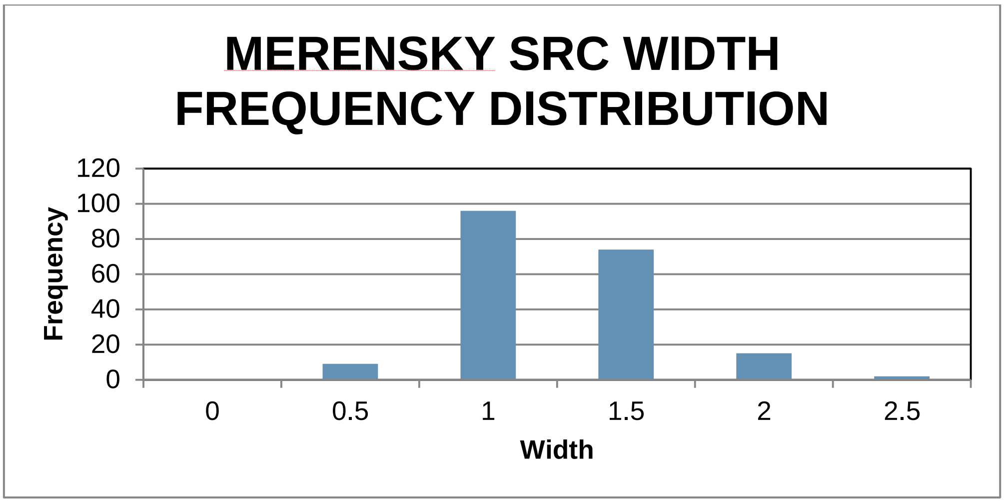


Figure 2f: Frequency of width distribution at the Merensky Shaft (Source: Northam Platinum Limited)

The challenge of mining at 1.7 to 1.9 m is threefold:

(i) There will be a steep learning curve for the platinum mines as we will be using a bolter machine with which we have limited or shallow experience.

(ii) If the machine is not ideal for the 1.9m environment we will have to work with OEMs to modify the machine to have the required capabilities.

(iii) As stated in Pickering et al. (2010) we will have to partner with the OEMs to develop a machine that can combine two functions – that is, install resin bolts which are primary support and be capable of installing long cable anchors if the ground conditions warrant secondary support.

See **Figure 2g** below for an ideal stoping width targeted at Booysendal Mine (the dilution factor in this design is within tolerable ranges accepted for the mine).

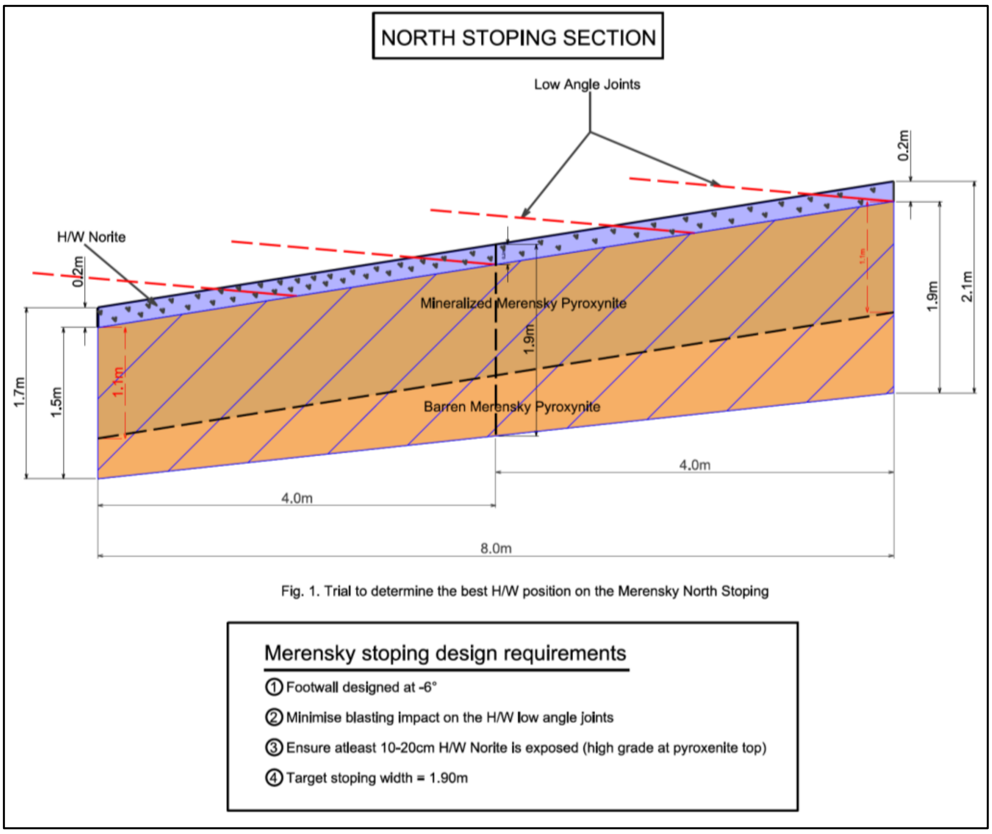


Figure 2g: Planned Best Cut at the Merensky Shaft (Source: Northam Platinum Limited)

2.4 Mechanising XLP bolting and lessons learned

Comprehensive modelling work done by Fourie, Valicek, Krafft and Sevenoaks (2014) gives the fundamental parameters to be considered for mechanised mine design and planning. Although the work presented in Fourie et al. (2014) lays firm parameters, models and different scenarios to be considered for mechanised mining section, there are some design and operational flaws that need to be dealt with.

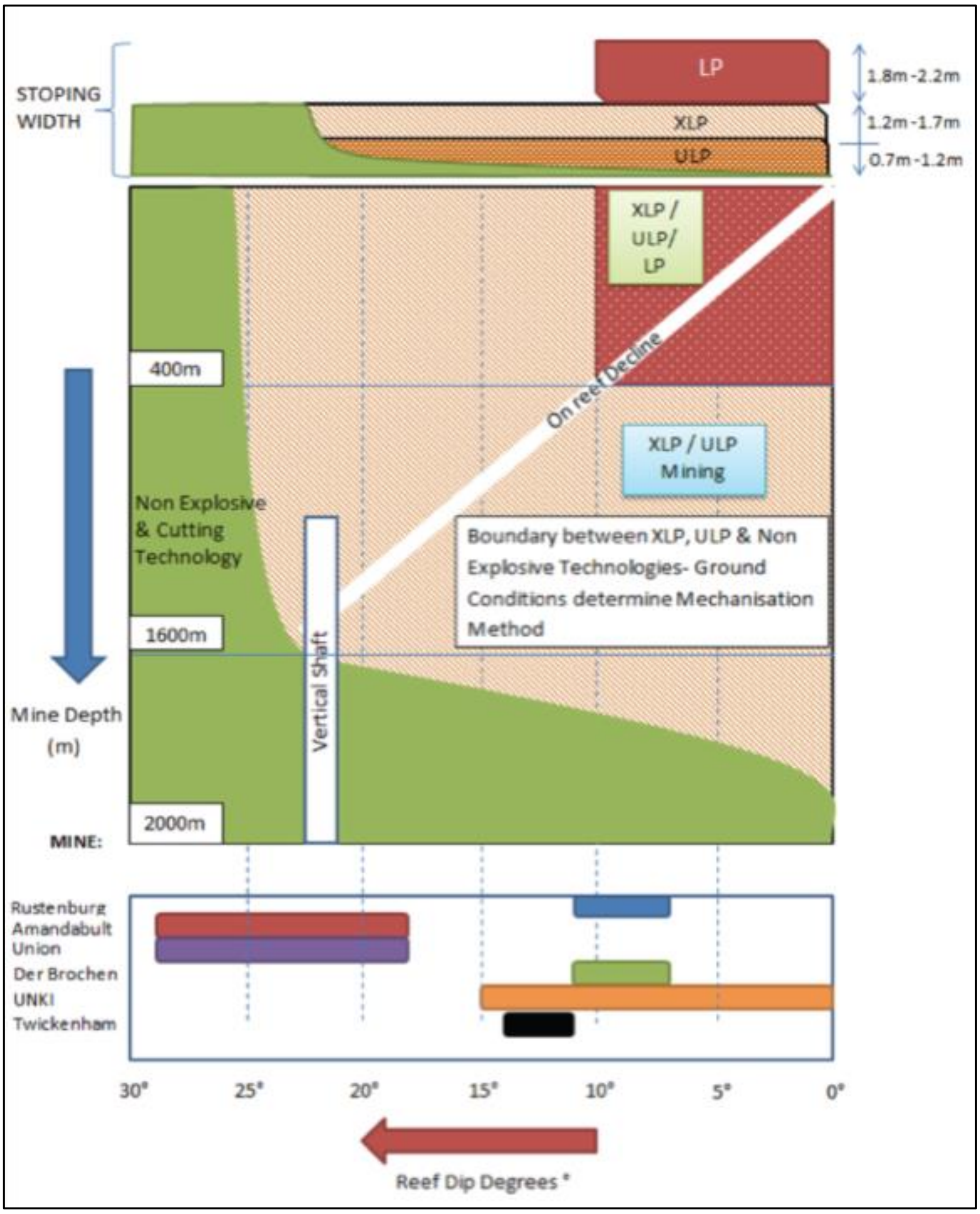


Figure 2h: Physical mine design parameters considered and classification of mechanised mining methods
(Source: Fourie et al. (2014))

Table 1: Mechanised mining method's physical specifications

Table I Summary of stoping methods			
	LP	**XLP**	**ULP**
Depth+	0-400m	350-1800m	350-1800m
Stoping Width	1.8-2m	1.3-1.7m	0.9-1.2m
Mining Method	Bord and pillar	Breast mining	Breast mining
Dip	±10°	0°-22°	0°-22°
Production	2100-3000m^2	2100-3000m^2	2000-4000m^2
Orebody	Consistent ore deposits without major faults	Consistent orebody, high extraction ratio	Fairly consistent orebody, high extraction ratio
Advantages	Low Level operating complexity	Less dilution when compared to LP Low wastage introduced into plant	High-grade ore Able to deal with orebody complexities
Disadvantages	High volume tonnages Low Grade High operating cost Complex infrastructure	Robust equipment Labour-intensive Highly skilled workforce Complex infrastructure	Advanced technology Highly skilled workforce Technology in POC phase

(Source: Fourie et al. (2014))

The technical paper seems to vary the stoping width interchangeably between different methods as if this variation is insignificant. On **Figure 2b,** the ULP method is said to operate between 0.7 to 1.2m and on **Table 1** there's 0.2m difference. In the context of the Merensky Shaft planned at Booysendal Mine, even a 0.15m variation on the planned stoping height will have a significant impact on the mill head grade, so we have to be absolutely clear on what the planned ranges are.

Due to the use of 0.2m variation in between the methods, I will take the results derived from ULP-LP combination to apply equally to the XLP-LP combination. These results will be used to extract the learnings to be considered for Booysendal Merensky section.

Table 2: Simulated output of mixed mining layouts (XLP and LP fleet combined)

Table III
Stoping production tables

Mining equipment	Stope element	Ht m	Effective face length m	Advance per blast m	m2 per blast m^2	Mining rate m^2/ month	Panel face advance m	Stoping system advance before geoloss m	Total m^2
ASD development with LP equipment	ASD	2.0	5.0	2.8	14.0	50.7	10.1	20.27	709
	Siding	1.0	1.5	2.8	4.2	15.2	10.1	20.27	182
	Total LP*	**1.8**	**6.3**	**2.8**	**17.6**	**63.7**	**10.1**	**20.27**	**892**
Panel stoping with ULP equipment	Panel	1.1	20.0	1.8	36.0	202.7	10.1	20.27	2 838
	Vent holing	1.1	2.2	1.8	4.0	22.5	10.1	20.27	270
	Total ULP*	**1.1**	**21.9**	**1.8**	**39.4**	**222.0**	**10.1**	**20.27**	**3 108**
Total stope and gully (excl. RSE)*		**1.3**	**28.2**	**2.0**	**57.0**	**285.7**	**10.1**	**20.27**	**4 000**

***Weighted averages have been applied to this table in order to accommodate the two top panels not requiring any sidings or vent holings.**

Description	**Units**	**ULP equipment**	**LP equipment**	**Total/average**
Effective face length	m	21.9*	6.3*	28.2
m^2 per month	m^2	3 108	892	4 000
Tons per month	t	20 886	5 994	26 880
Face advance	m	1.80	2.80	2.02
No. of blasts		79	51	70
Tons per blast	t	265	118	383
Days per month		23	23	23
Blasts per day		3.4	2.2	3.0
Tons per day	t	908	261	1 169
m^2 per day	m^2	135	39	174
No.of faces		14	14	14
Face advance	m	10.1	10.1	10.1
Blasts per face / month		5.6	3.6	5.0

(Source: Fourie et al. (2014))

It's clear from the planning that for a mechanised mining section to achieve its planned target the following must be specified:

- Total number of Roof bolts to be drilled and installed per shift must be specified. In Fourie et al. (2014) it was specified that the total cycle time to drill 30 bolts (1.6m extension drilling) shall not exceed two hours.
- The number of bords supported per shift must also be specified. In Fourie et al. (2014) it was specifically stated that two 20m panels shall be drilled in one shift.

- Range for stoping width must be clear so that all mining participants are aware. In Fourie et al. (2014) it was stated that for a ULP section, the range will be 0.9 to 1.2m.

Fourie et al. (2014) modelling results in **Table 2** applies a 0.833 confidence factor and states that the achievable production from the ULP-LP combined suites of equipment is 4 000m². The author was an Operational Manager for years at Union Mine Declines (Anglo American Platinum) where a hybrid mining method was used, so his view is that the above model, if put in practice, won't yield the expected results (tacit, experiential knowledge). The constraint in a combination of the two processes as above won't be the in-stope activities, but the strike drives development always tend to lag behind. The case above in **Table 2** plans exactly the same advance in the panel and in the advance strike drive. From experience, the strike drive must always lead the panel by a minimum of at least 9.0m for the system to work.

In the above combination, the modelling does not take into account the interaction between the vehicles in the ASDs in case of breakdowns or when the machine needs to go in for a scheduled maintenance.

Even though Fourie et al. (2014) did not take into account the full impact of the operational complexity of mixing the two processes, the mine design parameters and operational KPIs set out in this work will yield significant positive results if they are adhered to at Booysendal Merensky Shaft.

2.5 Why is bolting a bottleneck?

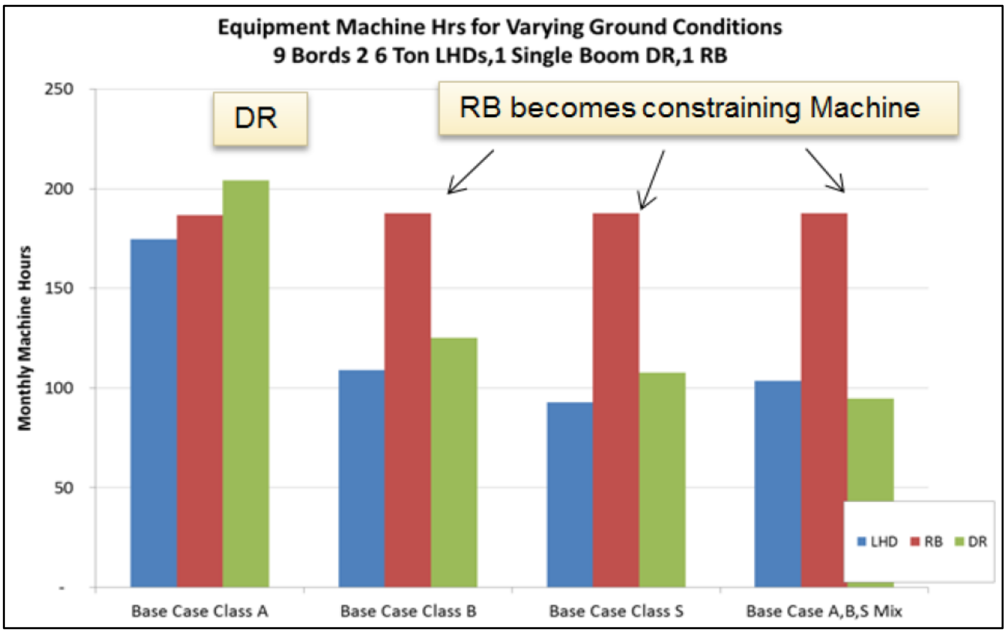


Figure 2i: LP Equipment efficiency under varying ground conditions (Source: Valicek et al. (2012))

Experienced mine operators normally claim that Roof bolting is the bottleneck or constraint of all activities in the mechanised mining system. But when asked to explain why, very few can unpack the reason. Valicek et al. (2012) analysed the results presented in **Figure 2i** and came to the following conclusions:

"The modelling found that if the current equipment availabilities and fleet configuration were taken into account, the following monthly production rates could be achieved per an LP team for A, B and S ground classification conditions:

- Class A ground condition: a production rate of 2151 m^2/month was achievable for a 9m panel length.
- Class B ground condition: 1431m^2 /month was achievable for a 9m panel length.
- Class S ground condition: 1236m^2 /month was achievable for a 6m panel.

The study also found that, based on the geological mix of A, B and S ground in the observed section, an average of 1 714m^2 /month would be achieved in the bord and pillar section."

The ground classification method at Booysendal Mine is the same as Anglo American Platinum Mines. The categorisation is the same, only the naming differs.

According to Valicek, Fourie, Krafft and Sevenoaks (2012):

Class A means normal ground conditions in which no undue rock fall risk is posed.

Class B and S are areas where there is an increased risk of rock falls and which require additional support and mining strategies over and above the normal standards.

Booysendal's normal conditions are named TARP1 (i.e. Trigger Action Response Plan), TARP2 and TARP 3. The latter two are complex ground conditions where interventions of geotechnical personnel are required. In most cases, they end up recommending the installation of long cable anchors to supplement the resin bolts.

The author can confirm that the modelling conducted by Valicek et al. (2012) is 100% accurate. At Booysendal Mine, Johan Schoombee, a Mine Overseer in the LP part of the UG2 is a consistent top performer in terms of m^2/month and tons/drill rig section. He was affected by TARP3 ground for over two months and the section production dropped from the range of 2 000m^2 to 1 250m^2 /month. When the ground conditions normalised, this section returned to levels of 1 850 – 2 000 m^2.

Valicek et al. (2012) explains the drop in production as directly attributed to the bolter performance: "It can be seen in **Figure 2i** that when the ground conditions change from the favourable Class A to less favourable B and S ground conditions, the LP Roof bolter (RB) becomes the critical machine within the mining cycle."

2.6 Effect of bolting on Mining cycle

Hattingh, Sheer and du Plessis (2010) explain the following implementation dynamics regarding mechanisation: Lonmin has reported several issues with its implementation projects ranging from equipment and supplier issues to human factors related specifically to the determination of appropriate cycle and standard times, learning curves, training, change management and the setting of realistic production targets.

According to Harrison, cited in Hattingh et al. (2010) the aim of Anglo Platinum's mechanisation strategy is to improve safety by removing the Operators from the face and to increase labour productivity and operational efficiency. Completion of the production cycle is critical and daily supervision and discipline are necessary to ensure the mining cycle is completed within the planned time.

Research by Strong, Terblanche, Gohre and Andrews (2006) points to a critical trap that mines using mechanised equipment should not fall into.

When mining operations introduce mechanised equipment, they continue to think on a consecutive basis and operate around conventional mining processes – drilling, bolting, loading, and tramming are viewed as separate cycles and not as fully integrated processes in the underground mining system.

Strong et al. (2006) further explains that for mechanised mining to be successful – drilling, bolting, loading, and tramming activities should be occurring underground all the time to make capital assets sweat. For this to happen there first has to be a holistically-planned total cycle where the KPIs of each individual machine and its mini-cycle are factored into the total time taken to complete the full cycle of loading, bolting, drilling, charging up and blasting.

To simplify the concept of the holistic cycle, Strong et al. (2006) asserts that at any one time there should be an end being drilled, another being loaded, an end being supported, and yet another end being charged so that the planned ends are ready for blasting.

This eliminates costly machines standing idle. Because the interaction between the cycles is so interdependent, if the end has not been prepared at the planned time the machines cannot be operated.

Clearly, for the GHH Roof bolter project, how long it takes to completely install a single bolt, how long it takes to install seven Roof bolts required in a single line as per Booysendal Mine standard and how long it takes to complete a single bord/end's support needs to be clear. Both Hattingh and Strong highlight the need to plan the whole production cycle in its entirety. But if one is not sure what to expect from the bolting cycle, the drill rig machines will stand idle having no ends to drill.

Since the GHH Roof bolter is completely new to the Booysendal Mine environment, neither the Management nor the Operators have experience on its performance, so predictions on its impact on the mining cycle cannot be made or even properly planned.

A simple, well planned trial is necessary to determine the equipment's capabilities and then an appropriate target for its own mini-cycle needs to be set.

According to Valicek, Krafft, Strydom and Fourie (2014) it is inevitable that there will be time lost while executing a task if machines are being used. If so, then areas prone to lost time are:

- At the start and end of shifts
- Between activities
- Time to report and repair breakdowns
- The reaction time to re-schedule due to breakdown
- The time to identify and then rectify the sub-standard activities

Time study exercises and observations were done during this research to understand and set standard times for:

- Bolter machine set-up
- Installing bolts
- Disconnecting the machine
- Moving out of the face
- Travel to the next face and repeating the process again from set up. (See sub-section **4.5** for the time-and-motion study results obtained in this research).

Time to repair the machine and re-scheduling after breakdowns is out of scope of this research, as we must first prove the GHH Roof bolter (3108a ADE) can efficiently support ends within the expected time frames.

2.7 Conclusion

This chapter has unpacked critical knowledge as to the underlying rationale of why the mines currently mining at stoping heights less 1.9m are still using either conventional hand-held bolting or auto rocks. Through published literature, the author was able to gain insights into what was achieved in the four hard rock mines where the stoping width is ranging between 1.75m to 1.9m.

The chapter also highlighted the common challenges that are associated with mechanised equipment Roll-out. Although a range of issues were dealt with, the two most prevalent ones are dilution control and cycle completion. Dilution and cycle are two most important parameters that directly influence each other in a mining section.

The effect of uncontrolled dilution in a mining project means less metal will be recovered than the planned target. This will have a negative effect on the project viability. A machine that can consistently operate within the specified bord dimensions is therefore critical for the project's financial viability. Once the machine fits into the bord dimensions, it then needs to deliver the expected output within the tolerable range of the standard times.

A blasted bord/end that is diluted, due to over breaking, will increase the bord loading time. The support also may require additional bolts due to increased bord length. The drilling of the bord may take longer due to the several machine set-ups that may be required.

In Chapter 3, the author will explain what was done during the trial stage to perform to the expected bolting rates per shift and give the results.

3. FROM TRIAL TO FINAL MODIFIED MACHINE

3.1 Trial background

This chapter aims at providing an understanding of the original machine (the ADE 3108) trialled at the Merensky Shaft from June 2016 to December 2016.

First, the chapter looks at the basic machine design specifications by introducing the machine as is, the aim of the trial, and the operational gaps it meant to address; mainly coming from the learnings of the four mines reviewed in Chapter 2. Then, a typical fleet working as a suite with the ADE bolter is briefly explained.

The thrust of this chapter is, after introducing the machine, is to unpack the preliminary trial stage time study results, and finally, state the research questions the author aims to address in Chapters 4 and 5. The research questions will primarily be aimed at addressing the use of industrial engineering techniques to validate the suitability of the improvement approach employed in this case study. The industrial engineering techniques will also test the appropriateness of implementation KPIs adopted for this case study.

3.1.1 Bolter Definition

GHH Mining Machines offered the mine the ADE 3108 Roof bolter for trial that along with certified set operational and safety parameters, was also capable of mining in stoping widths as low as 1,7m. The suggested pricing of the unit was hugely competitive and indicated an operating cost that was attractive in a reduced cost environment.

In addition, the following capabilities listed were advantageous for the mine:

(i) A safe position for the Operator in a bolting operation.

(ii) Limited disturbance of surrounding rock due to operational drill hammering.

(iii) Reduction in operational noise levels due to the application of rotary drilling operation.

(iv) Light weight and operationally simplistic drill consumables.

(v) Capability to install long anchors.

(vi) Bolting unit operational flexibility.

If the capabilities in the previous paragraph proved to be correct what did Booysendal Mine want to achieve by using the Roof bolter at the Merensky Shaft and what were the Key Performance Indicators the Mine looking for?

The objective is to produce 1 900m² at 235m system face advance per month in stoping to yield 11 500 tons per rig section at a defined stoping width of 1 900mm.

To achieve the desired output, the 3108 ADE bolter must perform as per the following KPIs:

(v) Drill and install a 1.75m resin applied rock bolt in 8 mins.

(vi) Bolt installation times, including movement between bords, should be in the region of 2 hrs allowing for the flexibility of supporting 3 bords in the available 7 hrs face time.

(vii) For 3 bords to be completely supported, the Roof bolter must install 42 bolts per shift.

(viii) The bolter must be able to install bolts in stoping widths ranging from 1700 to 2000 mm to achieve the defined stoping width of 1900 mm.

At the Booysendal Mine trial from June 2016 – Dec 2016, the bolter did not consistently achieve its KPIs. The objective of this research is to optimise the operation of the bolter so that it can meet the KPIs it has on other mines.

The ADE 3108 has the capabilities (i – iv) listed on page 43 and they were proven to be accurate during the trial stage. It must be noted that Booysendal Mine required that the capabilities (v – vi) also need to be proven. But, bear in mind, Merensky Shaft was not in the financial year 2016 Business Plan, so there was less pressure to optimise productivity.

It’s worth noting that the GHH trainers were training the site bolter Operators concurrently with production outputs enabling these Operators to not only become relatively competent in the operation of the bolter but also to learn to adapt to the required behaviour in the mechanised environment. It also allowed much needed time for any modification necessary to be done on the machine without having the immense operational pressure that, being in the 2016 Business Plan, the UG2 bolter Operators were having.

When modifications are done, does the machine consistently deliver 235m system advance and consistently achieves three bords (42 bolts) supported per shift?

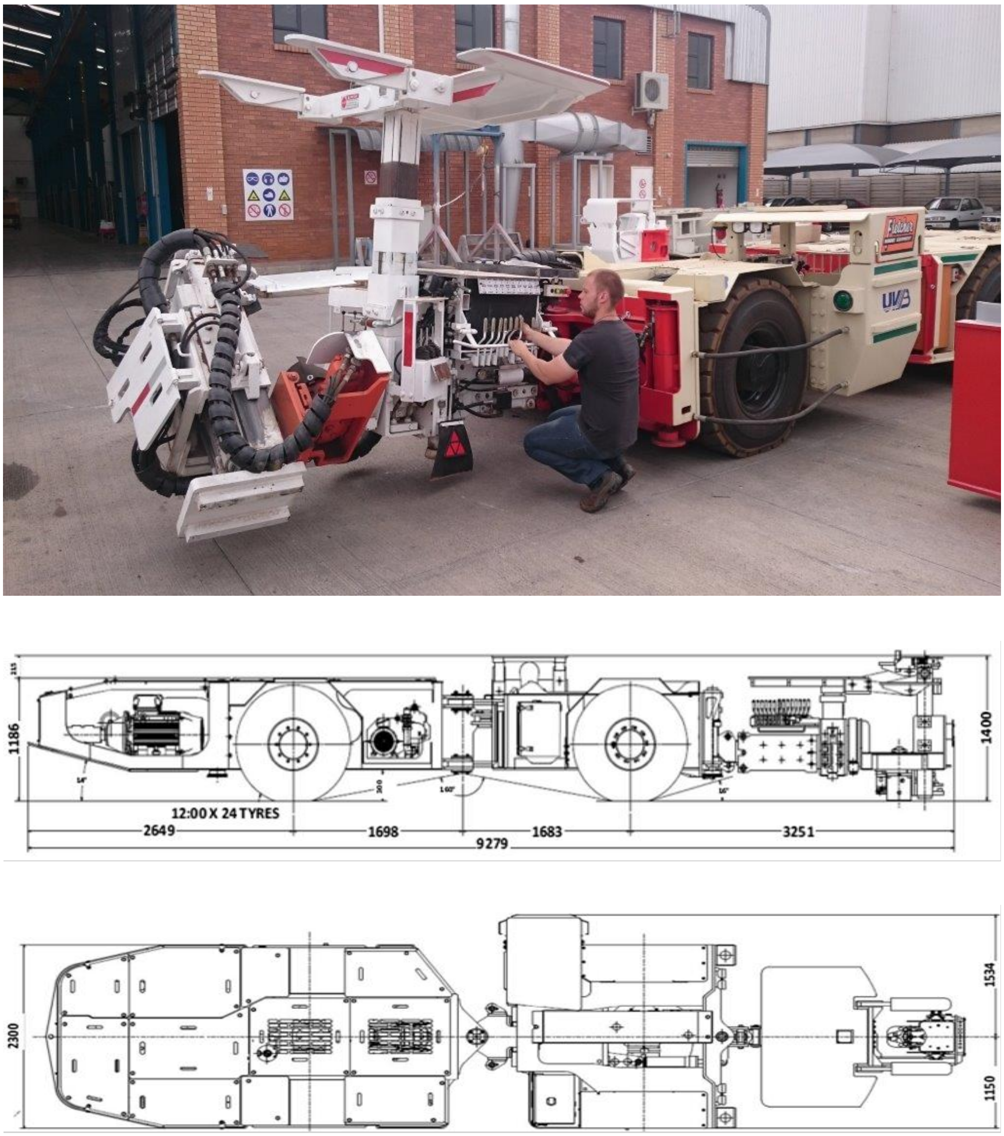


Figure 3a: Unmodified 3108 ADE bolter and its technical drawings (Source: Northam Platinum Limited)

3.2 SLP concept and ADE bolter applications

Figure 3a shows the original, unmodified GHH Roof bolter 3108 ADE delivered to Booysendal Mine at the end of May 2016 along with its technical drawings showing the machine dimensions.

When the unit was delivered, the OEM brochure claimed that this trackless mobile bolting unit was capable of bolting in reefs at 1.7m, and ultimately at stoping widths of 1.9m when taking the over breaks into account. The OEM further claimed the 3108 ADE had maximum protection measures to ensure a safe environment for the Operator. These claims were validated by the MSHA certification issued by structural engineers for the canopy loading capability. The 3108 ADE canopy and its supporting structures (boom, chassis and turret frames) have been proven to take a total load of 12.4tons.

3.3 Project Management and trial stage time study results

3.3.1 Management factors

The Project was managed by independent consultants who applied sound industrial engineering principles under constant mine Management supervision. Through short interval meetings between the project team and Management, we agreed the below mentioned items were to be addressed and then we would take a decision on whether we would purchase the machine as is, or do modifications prior to taking final commercial decisions.

a) Trials to improve installation effectiveness:

- With different GHH observers, we tested different diameter rock bolts, rock bolt lengths and diameters as can be seen in **Table 3**.
- Resin capsule sizing and composition – the trial started with 30cm capsules and different tests were done until we settled on a combination of 0.5m and 0.7m capsules.
- Brow angle support installation – we assessed the capability of the 3108 ADE without the fore and aft tilt.

- Camera holes – we drilled the 4.0m long holes and tested different combinations of drill rods. We also did a time study to determine how long it took. See **Table 3** for the results.

- Long anchors with regard to length and diameter alternatives – we ran different tests, at the time of writing this report we still had residual issues in that the last drill rods of the four was getting stuck in the hole when completing the 4.0m.

- Operator ergonomics with regard to bord down-dip(sometimes referred to as low wall side) bolt installation – we realised we need a bracket to push up the bolt face plate with less physical effort from the Operator.

b) Bolter effectiveness advancement scope:

- Improved bolt installation capability – two versus three bords in a 7 hr face cycle time. When we changed the rods from three combinations to two we started achieving three supported bords more often.

- Complete bolt installation matrix differentiation – a complete matrix looks at the ideal combination of number of rods, resin capsule sizes, diameter of bits and diameter of rods.

- Improved bolter drill head flexibility and Operator ergonomics – we looked at the boom sump, turret tilting angles and Operator comfort when installing Roof bolts on the low wall side of the bord.

c) Bolter structural adaptions:

- Adaptions to bolter design as per learnings from its application (Sub-section **3.4** of the report to explain all the modifications in detail).

d) Operational Management implementation principles:

- Formal systems were put in place to ensure the safe and effective transformation from ‘trial and error’ project norms to a Structured Change Management process which was adhered to and initiated as per the A3 process in Chapter 4.

It must be stated here that although Change management and Implementation rules were well-documented when it came to physical on-the-ground implementation, it turned out to be more difficult and complex than it was initially thought.

In Chapter 4, the author will unpack the complexities the implementation team were faced with because of the A3 process findings and specifications also the actions taken.

The Roof bolter effectiveness-enhancing modifications done by the Engineers, although trivial, had immense impact issues as they weren't communicated back to the Roof bolter Operators. Now a situation arose where the Operator thought he or she wasn't listened to because his or her inputs were not being considered, and the Engineer was wondering why his modifications does not enhance performance. Both the Operator and the Engineers were expecting certain outcomes, but there was no interface planned for sharing their experiences and expectations.

If not handled well, this implementation dilemma had the potential to render the project a failure; not due to machine or Operator capability, but due to lack of a Change management 'bridge' between the two. This research will deal with this issue in depth in Chapter 4.

Deon Miles from GHH observed and recorded a total of 83 installed bolts. In each case he recorded the rig set up time, the bolt drilling time and the bolt installation time. Calculations were then done to quantify the total time for bolting, number of bits used per bolt, bolts installed per hour and the drill rod penetration rate whilst drilling. (Refer to **Table 3** to see results of observations compiled by Deon Miles).

Electrical power vs Diesel

The 3108 ADE can be operated either through an electrical power supply or in the diesel mode. Various tests using two bit makes and sizes – 35mm and 25mm drill bits were done.

Drill rods from Normeco (Bits Supplier) were used. Both the threaded R23 drill stems and the stackable hex rods were trialled and tested.

The bits and the rods from Kennametal were also used. **Table 3** gives the base-case times for the best and average installation times achieved.

Table 3: Summary of time study results of 3108 ADE bolter sometimes referred to as African Bolter

African Bolter - Data Recorded														
	Rotary Drilling - 35mm bits												Rotary - 25mm bits	
	Deon - Kenna (Diesel)		Gert - Normeco (Diesel)		Gert - Kenna (Diesel)		Gert - Kenna (Electric)		Gert - Normeco (Electric)		Camera Holes		Normeco - 25mm - 60 secs	
	Best	Average	Best	Average	Best	Average	Best	Average	Best	Average	Best	Average	Best	Average
No of Bolts	83		74		29		20		69		12		75	
Bolt installation (mins):														
Rig set up	1.13	1.92	0.79	1.23	0.77	1.29	0.91	1.27	1.38	1.88	1.08	1.25	0.78	1.28
Rock bolt hole drilling (1.8m)	4.85	5.76	4.81	6.03	6.93	7.70	6.91	7.78	5.37	6.62	10.87	11.45	3.61	4.63
Resin bolt installation	1.53	2.64	2.41	2.57	2.25	2.51	2.59	3.93	2.47	2.69	**Camera facility only**		1.98	2.23
Total time for bolting	**7.50**	**10.32**	**8.01**	**9.83**	**9.95**	**11.51**	**10.41**	**12.97**	**9.22**	**11.19**	**11.95**	**12.70**	**6.36**	**8.14**
Bolts per bit	1.0	0.6	3.0	2.1	1.0	0.5	1.0	0.5	3.0	2.0			3.0	2.9
Bolts per hour	8.0	5.8	7.5	6.1	6.0	5.2	5.8	4.6	6.5	5.4			9.5	7.4
Penetration Rate (mins/m)	2.7	3.2	2.7	3.4	3.8	4.3	3.8	4.3	3.0	3.7			2.0	2.6

(Source: Northam Platinum Limited, Implementation team records)

3.3.2 Technical factors

Leading factors influencing variants considered in bolting configurations using the 3108 ADE (sometimes referred to as African Bolter by the OEM Engineers) at Booysendal Merensky Shaft operations:

- Rotary drilling and bolting application
- Stackable hex tube drill stem
- Increased drill penetration rates
- Reduced hole diameter and subsequent efficiency effects - Smaller diameter drill stem system
- Bit size
- Lesser diameter Roof bolt
- Lesser resin volume
- Acceptable hanging wall support parameters

In summary – the crux of the exercise was to decrease the support time of the bord ensuring adherence to the envisaged ‘3 bords a shift’ cycle and optimising the Mechanised SLP Fleet to its potential.

In **Table 3,** the first four sets of results were obtained using a Kennametal drill string together with a 35mm drill bit. An 18mm hole diameter was achieved at different times when drilling with a 25mm drill bit.

The time studies were done by different observers and the machine was either operated in the electric or diesel mode. The best time achieved was 7.5 minutes for total bolt installation, while the worst average time was 12.97 minutes.

While the number of bolts ranged from 4.6 to 8 bolts installed per hour, for the machine to achieve the expected operational performance it needs to consistently install a minimum of 6 bolts per hour. This equates to 42 bolts in 7.5 hours available shift time. A single bord requires 14 bolts of two rows of 7 bolts to support a 3.0 m advanced face per blast.

Using the same 25mm diameter drill string but a different make - Normeco instead of Kennametal - improved the results significantly; from best achieved of 7.5 to 6.36 minutes and the average from 12.97 to 8.14 minutes (See the last two columns of **Table 3**).

The question that arises in such a situation is this; is the improvement due the change of drill string make or a different Operator or a change of operating modes from diesel to electric? Only in-depth study consisting of physical observations and time recording can really give an appropriate rationale for the above results.

Before each blast at Booysendal Mine, a 4.0 metres long camera hole is drilled into the hanging wall to observe the hanging wall conditions and the status of the geological features. Camera holes drilling times and effectiveness of the 3108 ADE bolter to achieve this, is not in the scope of this research. However, it must be noted that although the camera hole is twice the length of a support hole, the time to drill these was achieved with times frames of between 11.95 to 12.70 minutes. (See the 3rd and 4th last columns of **Table 3**).

Table 4: Operational performance achieved (ADE 3108 Roof bolter)

African Bolter - Rock Bolting Performance			
	Best	**Average**	**Comments**
Time to drill 1.75m rock bolt hole	3.63 mins	4.94 mins	**Normeco bit**
Time to drill and install bolt	6.37 mins	8.71 mins	
Time to complete panel bolts (2.8m advance)	2hr36mins		
No. of panels completed per 8hr shift	3+ Back support	3+ Back support	
Time to drill camera hole (4.0m)	11.67 mins	12.40 mins	**No times with XX bit**
Time to drill anchor holes (4.0m)	Await performance		
Noise levels at bolter head Noise levels 1 metre from source Noise levels 5 metre from source Noise levels 10 metre from source	95.9dBA 93.3dBA 90.0dBA 88.8dBA		
Bolter availability	90%		

(Source: Northam Platinum Limited, Implementation team records)

As the Operators and the GHH trainers were getting to know each other better, they also started to understand the expected shift output for this 3108 ADE bolter. The best achieved times improved to consistently repeat the performance of 6.37 minutes per bolts, although not all Operators achieved it. The average times started to be consistently 8.71 minutes.

At this stage of the trial, the author did not want to focus on Operator capability or Operator proficiency before he fully understood the machine itself and had ensured all modifications requested by Operators were done.

The next subsections of the report will deal with the modifications that were done. They will also thoroughly scrutinise other industry research papers to understand if they did similar work or are there any other modifications we are not addressing. Only when the modifications and the industry gaps have been fully understood will the author deal with Operator effectiveness and proficiency in Chapters 4 and 5.

3.4 Modifications done as a result of the trial

While doing the 3108 ADE time studies, and during physical observations by various stakeholders (the implementation team, Mine General Manager and Mine Supervisors), a number of recurring problems led to the modifications explained in sub-section **3.4.1**

Prevalent problems were:

(i) Operator ergonomics while installing Roof bolts in the low wall side of the bord – the Operator had to be in a squatting position whilst inserting the bolt in a drilled hole. Besides being uncomfortable to the Operator, this also exposed him/her to the unsupported area.

(ii) A limited boom sump required numerous rig set ups over the target hanging wall grid marks to drill holes on the positions marked off by the miner.

(iii) The ability of the 3108 ADE to negotiate tight turning corners when moving through in-situ 7.0m by 7.0m pillars left for support.

(iv) The ability of the turret to tilt at different angles to support overhanging rocks left in the corner of pillars and also to install as close as 50cm from the sidewall.

The modifications were aimed at addressing the above problems and at the same time accelerate the drilling and the installation times.

3.4.1 Booysendal Initiated Bolter Unit Adaptions

The following requested and approved adaptions to further enhance safety and efficiency have been implemented on the bolting unit, now known as the **3108a ADE bolter**:

a) A similar compact carrier and drill boom configuration with added head unit safety and operational applications at a hugely competitive capital outlay. **Figure 3b** shows the 'man on the platform boom' with a stool provided for the Operator. The operating controls and the accessories loading tray were positioned right in front of the Operator for easy reach.

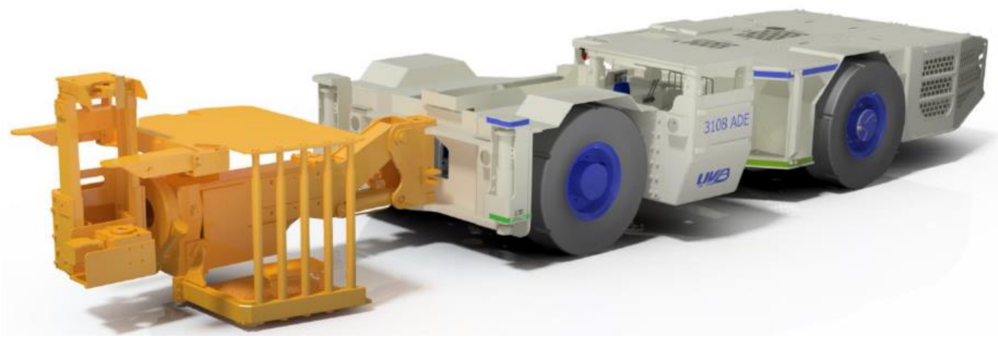


Figure 3b: Operator drilling compartment with low wall side ergonomics taken into account
(Source: Northam Platinum Limited)

b) Similar manoeuvrability due to short boom configuration coupled with a tight turning radius and a reduced boom oscillation while travelling. The overall length of the machine was increased by 859mm, from 9 279mm to 10 138 mm. The boom sump was extended by 407mm and the boom was also modified to be able to swing a maximum of 42º on either left or right-hand side from the centre line. (See **Figures 3c** and **3d** for the exact dimensions).

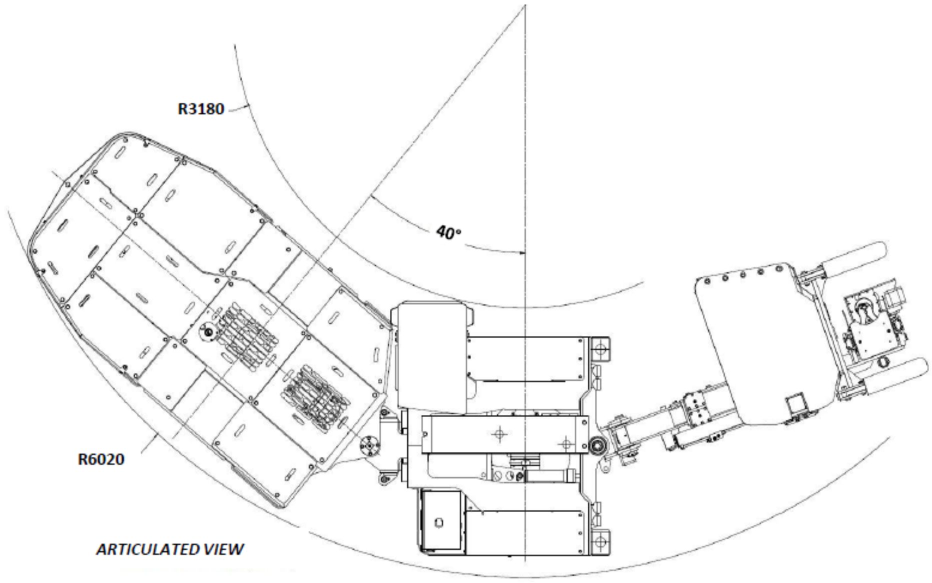


Figure 3c: Turning radius – important for bords negotiation in room and pillar method
(Source: Northam Platinum Limited)

The unit tramming and operational height (See **Figure 3d** for maximum machine height of 1 400mm) is still compatible to the SLP mining concept with regard to the installation of hanging wall support in stoping widths as low as 1.7 metres. But, the limitation with the modification is that if geological features are encountered and the mining height increases above 3.5m, then this bolter will not be able to install support at that height.

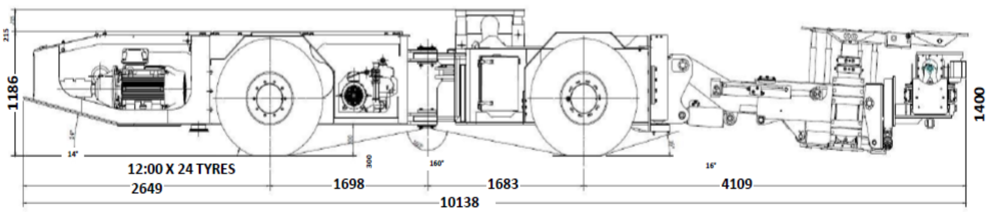


Figure 3d: Unit height – important for bords negotiation in room and pillar method
(Source: Northam Platinum Limited)

c) The boom now lifts, swings and extends to allow for a 4 000mm straight line bolt installation from one chassis position. The fore and aft tilt capabilities of the rotary drill unit, combined with a vertical extendable footwall facility, enables not only 'angle bolting' but also allows for bolting up to heights of 2.6 metres. The configuration also addresses the bolt installation within 50cm from the rock face. (See **Figure 3e** for fore and aft tilt in different directions combined with new boom swings).

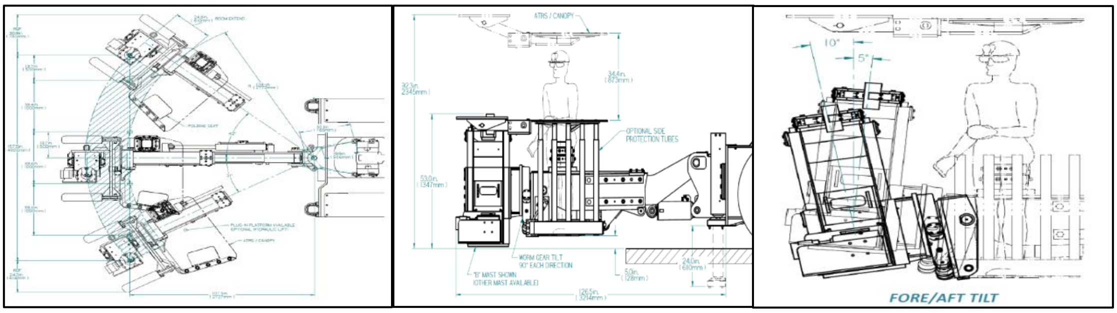


Figure 3e: Fore and aft tilt capabilities of the drill unit
(Source: Northam Platinum Limited)

d) Drilling boom vertical flexibility not only assists in higher operational reach but also provides the ability to negotiate stepped footwall mining conditions. (See **Figure 3f** for the 10º capability for boom lift and lowering).

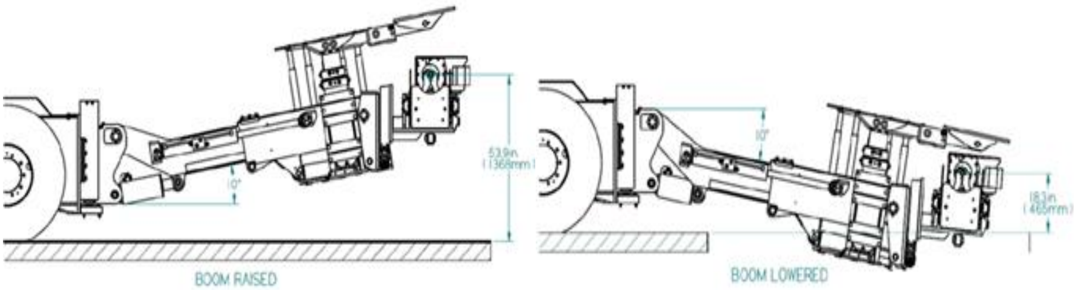


Figure 3f: Drilling boom movements
(Source: Northam Platinum Limited)

e) Drilling, resin insertion and bolting are accomplished from under the TRS canopy (Temporary Roof Support – **Figure 3g**) allowing for the maximum efficiency and safety. Bolter operating controls are now single-sided with an extended canopy protection and an added vertical bar support, complete with an operating stool for Operator comfort.

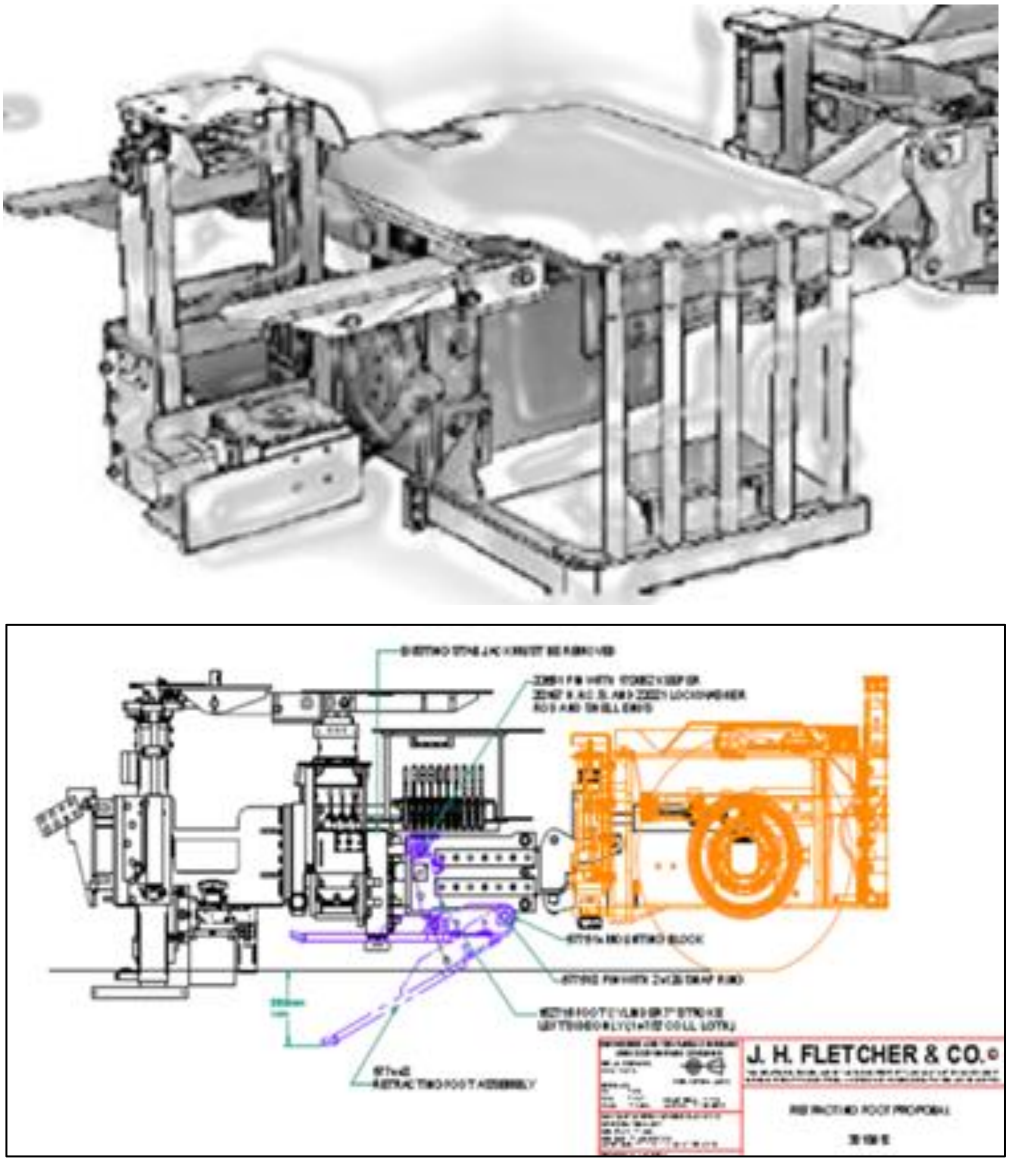


Figure 3g: Operator comfort considered in TRS canopy design (Source: Northam Platinum Limited)

f) When drilling the 38mm long anchor holes, an increase of thrust is required to effectively drill the larger diameter hole. To achieve this, Fletcher (GHH partner for 3108 ADE design and manufacture) has introduced the addition of a valve which, when activated, will increase the thrust.

We started in June 2016 with Machine A (Original 3108 ADE bolter), and with all the adaptations and the modifications done, as per request from Operators and from Engineer’s observations, moved to Machine B (Upgraded to 3108a ADE bolter): See **Figure 3h**.

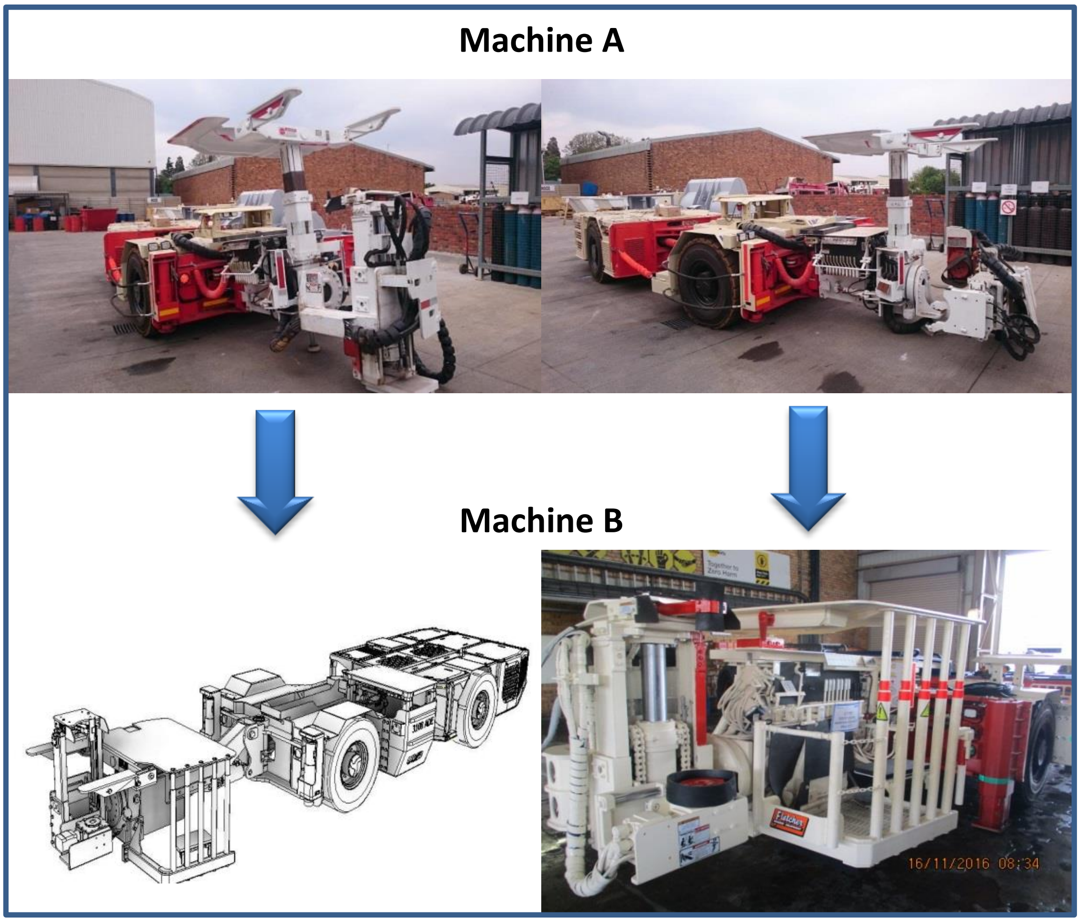


Figure 3h: Upgrading from a 3108 to a 3108a machine
(Source: Northam Platinum Limited)

3.4.2 Lonmin and Anglo Platinum Initiated Bolter Unit Adaptions

According to Webber, van den Berg, Le Roux and Hudson (2010), lessons learned from the mechanisation in Lonmin pointed to the following issues:

- The XLP equipment delivered lower efficiencies than expected.
- The XLP equipment could not effectively deal with geological anomalies, especially on the western side of Lonmin's operations.
- The interdependency of machines in an XLP cycle meant reliability issues were compounded.
- The excessive reef development caused high dilution to the head grade. Larger development ends were blasted to accommodate the mechanised equipment. Excessive stoping widths were caused by the inability of the XLP equipment to deal with rolls in the reef.

While there were other important lessons learned by Webber et al. (2010), the author was really drawn to the fact that the research identified the importance of mining cycle completion and the interdependencies of activities to achieve planned production targets.

Table 5 below shows the KPIs set by Lonmin team to achieve their target. It is important to understand they were actually setting industry standards/benchmarks with regard to mining cycles.

Table 5: Lonmin's XLP Performance KPIs

LP face rig						
	Panel length	**Holes**	**Drilling cycle time**	**Holes per hour**	**Travelling and set-up time**	**Total cycle time**
KPIs	26.5m	156	4.3h	36	45min	5.1h
XLP Bolter						
	Panel length	**Holes**	**Bolting cycle time**	**Bolts per hour**	**Travelling and set-up time**	**Total cycle time**
KPIs (resin bolts)	26.5m	32	4.5h	7	45min	5.3h
KPIs (resin bolts)	26.5m	32	2.9h	11	45min	3.7h
XLP dozer						
	Panel length	**Tonnes for dozer cleaning**	**Cleaning cycle time**	**Tonnes per hour**	**Travelling and set-up time**	**Total cycle time**
KPIs	26.5m	122.4	2.8	44	30min	3.3h

(Source: Webber et al. (2010))

According to Webber et al. (2010), the XLP bolter utilises a single boom to drill and install 1.6m split resin bolts. Roof bolts are installed on a spacing of 1m (dip) by 1.5m (strike). It must be noted this is exactly the same pattern Booysendal Merensky Shaft installs its 1.8m resin bolts.

Webber et al. (2010) further states that according to **Table 5**, the XLP bolter has a total cycle of 5 hours and 20 minutes. So, the XLP can complete the support of a 26.5m panel length (installing 32 resin bolts) in less than a shift.

The bolter's cycle time of 5 hours 20 minutes currently represents the longest cycle time in the fleet of equipment, and options of separating the drilling of support holes and installation of Roof bolts are under investigation. The actual results from Lonmin show the consistent installation of 6 bolts per hour which is similar to Anglo Platinum Bathopele Mine’s 23 bolts in 4.1 hours.

While it is worth investigating separating drilling from installing bolts, the current record of industry gravity-induced fall of ground fatalities means we will face stiff resistance from safety regulators to implement these initiatives.

Although drilling of Roof bolts and installation of bolts are two separate operations, they are closely interlinked. For instance, in all the mines I’ve worked at, the Roof bolter drills the hole, the Roof bolt is then installed and tensioned before the Operator moves to the next hole.

The rock in the hanging wall is not homogeneous, so the Rock Engineers specify the first area drilled needs to be fully supported before drilling the next hole. And for good reason; failure to adhere to this leads to fall of ground fatalities. Drilling a whole row of Roof bolt holes first and installing the Roof bolts later, in a follow-behind operation, will face stiff resistance from the Rock Engineers and the safety regulators.

Why has the industry not looked for ways of improving from 6 to 7 bolts per hour and optimising the whole system to ensure the mining cycle is completed within a shift since 2010?

The author examined extensive work done by M. Andrews and R.G.B. Pickering at Bathopele Mine with regard to machine adaptations and the effects of those adaptations/modifications.

According to Andrews and Pickering (2010), previous trials completed at Anglo Platinum Bathopele Mine and Lonmin identified the performance of the XLP Roof bolter as the primary system bottleneck. Andrews et al. (2010) further asserted the XLP fleet application had been found to be successful. The cost benefits significantly outweigh those of standard low profile mining methods because of the substantial reductions in waste dilution.

Although Booysendal Mine is not implementing the XLP fleet, the author learned from the trial methodology applied by Andrews and Pickering (2010) how to assess the performance of the Roof bolter and address the trial’s challenges.

Andrews and Pickering (2010) state that in terms of XLP mining, the mining system constraints can be identified and mitigated by ensuring, Goldratt's Theory of Constraints (2004) is applied to all activities associated within the XLP mining cycle. This would address system bottlenecks which will have a direct influence on both machine and subsequent mine output.

According to Goldratt (2004), five focusing steps should be adopted to address such a system, defined as:

- Identify the constraint (the resource or policy that prevents the organisation from obtaining more of the goal).
- Decide how to exploit the constraint (make sure the constraint's time is not wasted doing things that it should not do).
- Subordinate all other processes to the above decision (align the whole system or organisation to support the decision made above).
- Elevate the constraint (if required or possible, permanently increase the capacity of the constraint; 'buy more')
- If, as a result of these steps, the constraint has moved, return to step 1.

A detailed time and motion study at Anglo Platinum Bathopele Mine was conducted by Sandvik Trans4mine team looking at the XLP bolter with a system's operations perspective. Andrews and Pickering (2010) state that issues and identified solutions associated with optimising each of the tasks in XLP bolter were analysed and summarised as below:

- The rod coupling procedure was cumbersome and time-consuming, contributing 21% additional time to that associated with a standard non-coupled bolt. Time was required to couple and screw the threaded R23 rods together, prior to relocating the drill string on the drifter and raising the feed back into the hole. This is a manual process, thereby compromising Operator/assistant safety (the assistant runs the risk of injury when coupling the bolt and is in the vicinity of potential rock falls during the process).
- The need to use four rods to attain 1.6m bolt hole length poses the same safety and time constraints as those discussed above with the coupling

process. Any possibility of reducing the coupling requirements would substantially improve the cycle and reduce the potential of personnel injury or harm. In the case of Booysendal Mine trial, we started the process with four rods to achieve a hole length of 1.75 metres and we ran different tests until three ideal couplings were used to achieve the required 1.75m hole.

- Due to the nature of the tramming system at Bathopele Mine, positioning the machine directly over the target where the bolt is supposed to be installed, is difficult to achieve. Tramming currently lacks proportionality, which makes the machine movement relatively 'jerky' and it becomes difficult to carry out the required levels of accuracy.
- The bolt installation process is completely dependent on the XLP Roof bolter due to the added requirement of inserting, spinning, and securing the bolt. The force needed with resin bolts requires mechanical assistance to perform these functions. The injection and installation process therefore reduces the machine's capacity to drill by 36%.

Andrews and Pickering (2010) implemented the following initiatives to address the identified issues:

- **Drilling optimisation**: A new XLP Roof bolter with a longer stroke was designed, ensuring three rods could achieve the desired 1.6m hole length instead of four. Booysendal Mine did numerous tests using rods with different coupling mechanisms ranging from the screw type to stackable hex systems, and eventually also came up with an ideal three rods combination.

  At Booysendal Mine, we went further with the optimisation. We tested the combination of two rods of 0.9 and 1.2m and found it ideal for drilling 1.8m support holes, considering the 21cm that goes in the drifter chuck.

  In the case of Andrews and Pickering (2010), the revised design resulted in a drilling time of 27 seconds per bolt (19%) and a 6% improvement in overall bolt cycle time. Incidentally, the feed was also modified from a chain to a rope-cylinder feed which, to date, has yielded a 50% improvement in reliability.

- **Bolt installation optimisation**: A decision was taken to attempt to ‘de-couple’ the drilling of the bolt from the installation of the bolt. After considering several possibilities, the selected solution was the New Concept Mining’s Hydrabolt - a type of friction bolt which encapsulates water. The bolt is manually installed using a separate water pump and can be carried out after the XLP Roof bolter has completed drilling the hole, allowing the XLP machine to proceed to the next hole and start drilling whilst the previous hole’s bolt is installed.

  Although the implementation of the Hydrabolt does not necessarily optimise the number of personnel at the face, it was viewed as an interim solution, while a mechanised solution was being developed.

  Implementation of the Hydrabolt resulted in a reduction in overall XLP Roof bolter cycle time of 156 per bolt (35% improvement in bolt cycle time). At Booysendal Mine, due to presence of serpentinite infills and sometimes separated chrome stringers in the Merensky Reef’s hanging wall, a ‘decoupling” option was not looked at. In fact, we looked at installing both resin bolts and cable anchors concurrently.

- **Rod coupling optimisation**: To reduce the coupling time associated with the extension drilling process, a newly designed drill rod and couplings were developed. They were called the Infinity range because of their figure eight coupling shape. A shape that was relatively easy to manufacture, and far easier to couple during the drilling process of the bolt.

  The introduction of this steel resulted in a 61second improvement in overall cycle time per bolt, representing an overall improvement of 13% to the bolt cycle time.

  At Booysendal, we realised the R23 threaded drill stems are not ideal, which is why we changed to the stackable hex system. This system is quick and easy to couple. An added advantage is that it reduces the probability of finger injuries.

- **Machine/boom movement optimisation**: To accurately and efficiently position the machine under the required hole, proportional tramming was developed, allowing precise locating of the machine over the bolt hole with minimal effort. This is currently being tested at Anglo Platinum Bathopele Mine. Provisional results show an overall improvement of 10 seconds per bolt (2% improvement in overall cycle time).

During the trial at Booysendal Mine, the Operators gave numerous useful suggestions on how to best position the turret over 'target hole' to be drilled. Some thought a robust on-board camera to show grid positions, others a laser grid like the one used on Fletcher machines in coal mines, and other Operators requested we relook the Standard Operating procedure of marking off both support grids at once so that they could install both bolts sequentially on strike rather than on dip.

All the four initiatives were incorporated in the 3108a modified machine and a new base time for overall bolt cycle time was then determined.

3.5 Research question(s)

As per the coaching from Professor F. Cawood (personal communication, February 02, 2017, Research Methodology course presentation), research will create other research questions, but there is one over-riding, central question that a researcher needs to answer. For the work to be done in this research here is the Central Question:

How well will a set of industrial engineering tools work to improve the modified GHH bolter performance to enable the Merensky shaft to efficiently mine at a stoping width of 1900mm consistently?

Sub-questions to central question:

(i) What type of an improvement approach will the implementation team take to ensure the Roof bolter achieves 42 bolts per shift?

(ii) How will the step approach taken assist in ensuring that 3 bords are supported per shift or put it differently, how will the improvement approach assist in completing the planned mining cycle within the shift?

(iii) How efficient are the modifications done on 3108a machine in ensuring that the 1900 mm stoping width is consistently achieved?

The above set of research questions are mainly directed to address the Roof bolter performance within a mining system in order to achieve:

(i) 235m system advance per drill rig section per month

(ii) 1900m² per drill rig section per month

(iii) 11 500 tons per drill rig section per month

(iv) 1.9m stoping width in all stoping bords

The above results will only be possible if the sub-questions to the central research question is adequately addressed through appropriate industrial engineering techniques. For the mining cycle to be completed the bolter must support three bords or install 42 bolts per 7.5 hours face time, therefore confirming that the techniques used are appropriate the mining cycle completion is the primary requirement.

Preliminary progress in answering the central question during the trial phase follows, pages 65, 66 and 67 details leading questions to assist in answering the above three research sub-questions. These answers will be fully unpacked in Chapter 4 and Chapter 5:

(a) Is the GHH bolter fit for purpose to mine at 1900mm stoping width?

From June 2016 to Nov 2016 we had the GHH bolter **3108 ADE** to test. This bolter type is currently being used in hardrock mines in both Zimbabwe and Botswana. We took this bolter from Botswana as is and implemented it at the Merensky Mine as a trial.

During the trial period, we learned a lot about the capability and the limitations of this machine. Operational observations were done by the Engineers and the operational staff, and we listened to the Operators' concerns and suggestions. From these interactions, we came up with a number of modifications and this led to an upgraded Bolter called **3108a ADE**. At this stage, there is no reason to believe that the 3108a bolter is not capable of operating in a 1 900mm stope.

Although this is out of the scope of the author's research, it must be stated that, if the capability of the 3108a bolter can be proven through solid 12 months' record, it could mine at 1900mm with ease and great efficiency, then all the mines on the Eastern Limb could start looking at the feasibility of mining their Merensky orebodies using the Mechanised Mining Method.

Currently, there is no mine in the Eastern Limb mining the Merensky reef because it is a thin band (1.0 – 1.5m as per **Figures 2e** and **2f**) and will not be profitable to mine through conventional methods. When we have a proven record of a mechanised system capable of mining the expected planned volumes at stoping heights of 1.9m, then the project's viability would swing to profitable zones.

(b) *Are all the bolter modifications requested by Operators done and has it been appropriately communicated to them?*

Although the Mine Overseer of the section and the author have started intensive communications campaign with the Operators and the Artisans to explain the capabilities of the new modified machine, we still have to come up with a structured approach to ensure that all new Operators at the Merensky Shaft are fully inducted on the 3108a bolter operations.

(c) *Are we (i.e. the mining system and Operators) able to efficiently support the blasted bord in 7.5 hours face time - put simply are we achieving 42 bolts/7.5 hours?*

From all the data compiled, as of June 2016 to November 2016, we have seen that the Operators were only able to deliver above 35 bolts per shift 3% of the time. (See **Figure 4b**) Although sometimes they achieved 52 bolts per shift.

However, there remains a lot of work to be done in this area as we still do not understand why some Operators are achieving the target while 50% of the measured time the Operators are only achieving 19 bolts or less per shift. Thorough observations will need to be done and a standardised system drawn up to smooth out and normalise the performance.

(d) *Do we understand why Operators on other operations are able to get 6 bolts/hour (i.e. 42 bolts per shift) whilst we are not achieving this?*

We do not understand how they get 6 bolts/hour, also an important point to note is that even at Bathopele Mine (Anglo American Platinum) where they consistently achieved 23 bolts/4.1 hours face time (according to Fourie et al. (2014)) they still do not state what they are doing differently in either their bolting activity or the cleaning cycle.

Through observations and benchmarking, the author's research must unpack this further and come up with a structured system.

3.6 Conclusion

Sub-section **2.1** in Chapter 2 gave the background of why mines that mine at 1.75 – 1.9m either use a hand-held drilling support system or an Auto rock system. It became clear in the questions asked in **2.1** that there is currently no OEM who has an off-the-shelf machine capable of supporting at this stoping width.

In Chapter 3, the author introduced the GHH Roof bolter model name 3108 ADE. This Roof bolter was trialled for a period of six months at Booysendal Merensky Shaft. Through collaboration of OEM Engineers, Mine Engineers and the Operational Implementation team headed by myself, the modified Roof bolter machine 3108a was "born".

When the modified Roof bolter was designed, the Implementation team, together with Engineers, looked at work that was previously done by Andrews and Pickering (2010) when implementing the XLP Roof bolter at Anglo Platinum Bathopele Mine. Bathopele Mine implemented improvements in the machine to optimise drilling, bolt installation, rod-coupling and machine/boom movement.

Now that a "fit-for-purpose" Roof bolter customised for Booysendal Mine's needs has been delivered, we investigated how to transform its inputs to deliver 42 bolts per shift to optimise its operational performance.

Chapter 4 addresses the central question asked in page 64 through A3 process rolled out in a stepped approach from Implementation stages 1 to Implementation stage 3.

4 IMPROVING THE 3108a SYSTEM TO DELIVER AS PER EXPECTED OUTPUT

The next section will be using the Operations Management tools that the author learned while attending lectures offered by Wits University's Centre of Mechanised Mining Systems (CMMS). (See **Figure 4a**, the Ishikawa diagram, which shows the root-cause analysis method which is used as the sub-part of the A3 process.) The A3 process was also learned at CMMS and is widely used in the Manufacturing sector.

From here onwards in this report when the author pulls in a concept from Operations Management it should be noted that this will be the applied actionable knowledge gained while doing Trackless Mining Courses and its related concepts.

4.1 Operations Management: A3 report of the 3108a

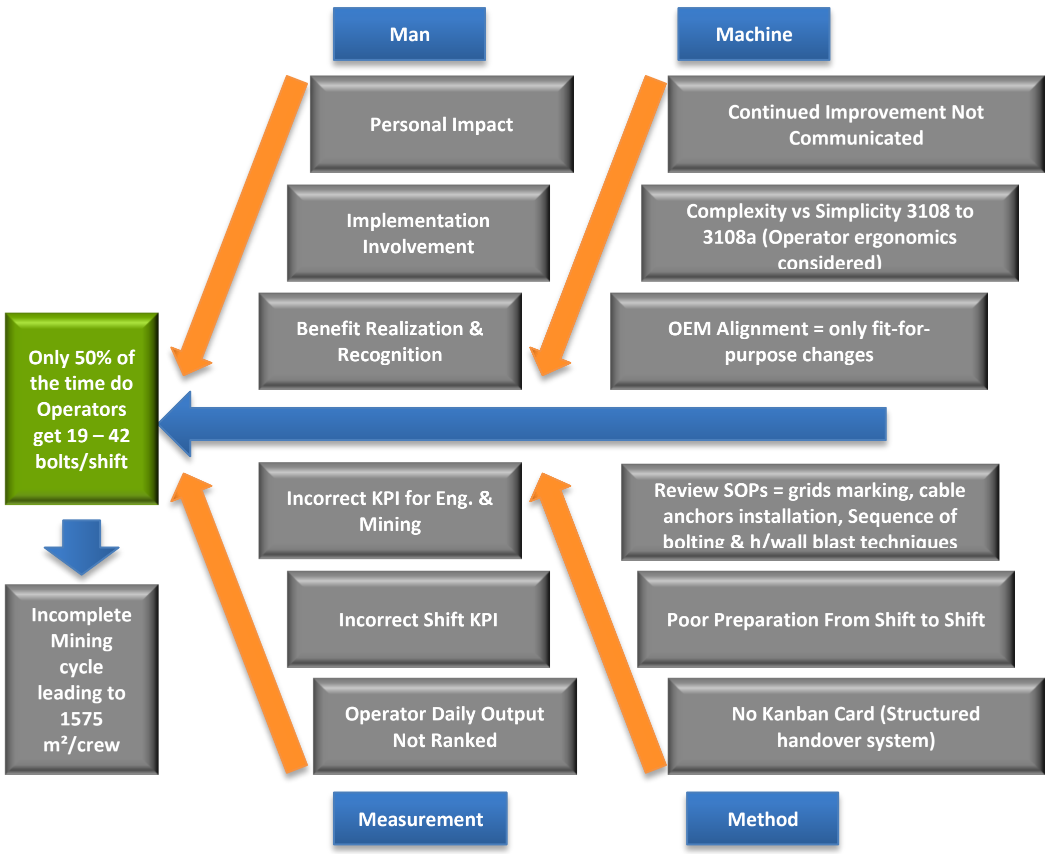


Figure 4a: Ishikawa diagram of the 3108a implementation situation (Source: Northam Platinum Limited)

To fully address the Research questions raised in sub-section **3.5** of this report, the author was guided by issues raised by Webber et al. (2010) in sub-section **3.4.2** and from the implementation route followed by Andrews and Pickering (2010) in sub-section **3.4.2** of this report. Andrews and Pickering (2010) directed the research to critically address the following issues:

(i) Drilling optimisation

(ii) Bolt installation optimisation

(iii) Bolt coupling optimisation

(iv) Machine/boom movement optimisation

Prior to start of physical observations and initiating changes to improve the performance of the 3108a Roof bolter, it was necessary to critically evaluate the current situation (i.e. January 2017 status). So, the research tactic was to follow the process of the A3 report as guided by Operation Management Principles (A3 lecture notes by Hattingh, February 2017). (See complete A3 report of the GHH bolter implementation at Merensky Shaft in **Appendix 2**)

This part of the report will unpack the Ishikawa diagram findings. (The Ishikawa process is the Root-cause Analysis method taught by Hattingh, February 2017)

Sub sections **4.2- 4.4** will detail how the challenges unearthed through the A3 report were addressed.

The root cause analysis was done to understand why the current 3108a performance wasn't reaching the expected, or planned, shift output despite all modifications requested by Operators and those identified by the OEM Engineers were done. The analysis revealed the following shortcomings:

(i) Man

a. Personal impact: The implementation team did several waiting place/start of shift meetings in the first week of January 2017. The aim of these meetings was to see if the maintenance staff, Operators and mining supervisors understood why Management took the decision to use the GHH Roof bolter at the Merensky Shaft. Whilst the Mine Overseer, Engineering Foreman and some Shift Supervisors had some sketchy ideas of the rationale behind the use of the 3108a Bolter, the Roof bolter Operators had no clue and they were even concerned about their safety when comparing this bolter to the other OEM's bolter currently used at Booysendal UG2 North Mine.

b. Implementation involvement: During the waiting place/start of shift engagement with the teams, it was also realised that the teams were looking for a method that would give them continual feedback on the GHH bolter implementation progress and the monthly consolidated results to show whether we were on track or not. Simply put, the employees were asking for Lean Manufacturing tools similar to the ones used by Dunstan et al. (2006) in Rio Tinto case studies.

   Lean tools used by Dunstan are visible performance tracking boards at the shift communication centres. The operational team's main concerns were issues of how would they know if the project was a success and if we were achieving the set target. They also informed the implementation team that they need to be notified on time so they could give their inputs on how to improve.

   Simple issues unearthed during these sessions, despite their seemingly trivial nature had an immense impact on performance. For instance, the maintenance Artisans pointed out to the implementation team that while the GHH Roof bolter is fairly simply to maintain and to do fault finding, the Engineering Schematic diagrams available to them to effect repairs are written in German.

   The Roof bolter Operators had an issue about maintaining the height of the bord on the low wall side at 1.7m while the bolt length to be installed is 1.8m. The implementation team knew the design had already taken into account that a 1.8m bolt can even be installed in a 1.5m height bord and it was realised that the non-involvement of the Mining and Maintenance team was causing all these uncertainties. (See **Figure 2b** for understanding the low wall and high wall sides of the bord.)

c. Benefit realisation and recognition: Operators were concerned about the expected targets of the GHH bolter in terms of bolts installed per shift – had those targets ever been achieved in any South African platinum Mine and if so, they wanted to know the benchmark. They also wanted to know if this bolter changes their condition of employment and what effect would have on their monthly bonus when we consistently get the 42 bolts per shift per Operator.

The Implementation team's selling point here to Operators, bolter Operator assistants or Spotters and Artisans, was that Booysendal Mine planned another two modules of Merensky Shafts to be started in FY 2018 and therefore it placed the Operators, Spotters and Artisans in a good position to be Master Drillers, Operators and Engineering Foreman of the new Merensky Shafts, and provided all current Merensky employees an advantage to be developed and promoted when the new shafts come on stream as they will already have experience of the orebody and its interface with the GHH bolter machines.

(ii) Machine

a. Continued improvement not communicated: When the implementation team started with unstructured Roof bolter bolting activity observations, it was realised a number of modifications that were done when the machine was upgraded from 3108 ADE to 3108a ADE were not used or even understood by the Operators.

   A typical example was when Operators raised concerns about installing Roof bolts on the 1.7m low wall side of the bord. Observations showed the Engineers had already incorporated a bracket on which to mount the Roof bolt washer and face plate whilst the Operator was still in a sitting position on his foldable stool. Intensive work had been done by the designers to improve performance and also make the Operator's bolt installation process better and quicker, but this hadn't been passed on to the Operators. The implementation team realised early on during the project that some of the project's failure wasn't because of machine capability, but mainly due to training, continual communication and the supervisor's ability to identify Operator challenges and address them appropriately.

b. Complexity versus Simplicity (i.e. Operator ergonomics considered): The 3108a machine design was based on making the bolting process simpler and quicker.

   For example, an accessories storage tray was designed and positioned opposite to the operating controls. This means the Operator can drill and insert all the accessories within an arm's reach from his sitting position. Drilling, resin insertion and bolting are accomplished from under the TRS (Temporary Roof Support) allowing maximum efficiency and safety.

   Bolter operating controls are now single-sided with extended canopy protection and there is an added vertical bar support complete with an operating stool to enhance the Operator's comfort.

c. OEM alignment (Only 'fit-for-purpose' changes): OEM designers and Mine Engineers have a tendency to do innovations based on what was seen at a certain international seminar or what was achieved at other mines without understanding why such changes were done.

   In the case of Booysendal Mine, when the 3108a machine arrived, modifications which were operational imperatives had been left out and some minor non-value-added changes had been done instead. This was communicated by the implementation team to the OEM Engineers.

   As a result, it was understood at an early stage of the project that only changes which have been communicated and validated should be done.

(iii) Method

a. Review SOPs (standard operating procedures) for support grid marking, cable anchor installation, the sequence of bolting and hanging wall blasting techniques: The implementation team identified challenges unique to Merensky Shaft. For instance, when the GHH bolter arrived, the SOPs being used with other OEMs machines were deemed to be appropriate, so no grid markings, bolt installation sequences or hanging wall conditions were taken into account.

Through unstructured observations it was realised that with the current support grid marking based on the SOP, the GHH bolter would have to do four set ups while the other OEM bolter was doing only two. An SOP revision for the bolt installation as well as for the cable anchors was definitely required.

The Merensky Shaft hanging wall has closely-spaced flat dipping joints on the low wall side and this makes the hanging wall uneven on the low wall side and poses a challenge of turret stability when drilling the low wall side as the Temporary Roof Support canopy and its support bar cannot stabilise the boom properly. Surely this challenge, while it has no effect on the machine design, has a huge influence on the time taken to install bolts on the low wall side. In addition, it then becomes necessary to call Explosives Engineers to recommend optimised blasting designs for the hanging wall.

b. Poor preparation from shift to shift: The prevailing mind-set of mine middle Management is to measure the supervisors at the end of shift on number of bords blasted, but with no consideration taken or emphasis placed on preparation for the on-coming shift.

   With the GHH bolter, the emphasis was to drive a process where the team is measured on number of bords cleaned, supported and drilled ready to blast at the end of shift. The focus on the activities to be completed with a suite of equipment will ensure the preparation for the on-coming shift is done and the mining cycle is completed. As stated in section **2.5**, if the bolting process reaches its targets, the chance of completing the mining cycle becomes better as bolting is currently viewed as a constraint in the cycle.

c. No Kanban (structured shift handover system): The implementation team wanted to find out from the Operators how the activities were performed by the previous shift; specifically, how many bords were supported and ready for the current shift to pull in machines and start drilling the face. The teams had only rough idea and only the miner knew the facts. The implementation team realised the need for Kanban-type cards to be used from shift to shift as well as a visible information board carrying data on the number of bolts installed, bords cleaned and drilled and charged up for blasting.

(iv) Measurement

a. Incorrect KPIs for Mining and Engineering Maintenance team: The current practice at Booysendal Mine is to measure the Maintenance staff on availability of the machine during shift time of 7.5 hours. Booysendal works a two-shift system of 10.5 hours each. The maintenance staff has to ensure that in a time frame of 24 hours the machine is available for 21 hours.

   There's a flaw in this measurement though. The Maintenance staff can have an 85% availability, but the 15% that is unavailable is the peak in-shift bolting time.

   The same with mining team; it gets measured on utilisation. But at Booysendal Mine, we are not clear on whether we're supposed to track power pack hours or engine hours.

   To be able to get the full benefit of the maintenance and operations teams, both need to be measured on on-shift utilisation. This means the focus should be on how many bords were bolted during the 7.5 hours of available face time, not certain percentages. The number of bords will then be the appropriate team shift measurement.

b. Incorrect Shift KPI: The current measure of performance at trackless mines is the output KPI, such as metres per month, tons per month and square metres per month. This output based approach then automatically directs middle Management to breakdown the monthly target into shifts and demand proportional fractions of the target per shift, taking into account machine service days.

   If middle Management's focus is not on input KPIs such as time machine started to drill, load and support, the approach is flawed. If the mining cycle is completed on time the metres/shift and tons becomes the product not the focus area. The implementation team realised this is the approach needed to drive with the 3108a bolter implementation. The output KPI for the 3108a bolter is now the completed mining cycles.

c. Operator daily output not ranked: During the waiting place engagements, it became clear the Operator's daily performance in terms of bolts installed per shift is erratic and there is significant variation on a shift to shift basis. While the variation bothered the implementation team it did seem to be an irrelevant issue to the Operators at the shaft. It became important to find an approach to encourage the drive where Operators to want to achieve consistent number of bolts installed per shift and if he doesn't, he needs to understand why.

   The Implementation team suggested a visible Operator tracker with a soccer team flavour; the best consistent Operator will be recognised and given a T-shirt of his international soccer role model to show him he's operating at the role model's level. When we tested this approach, we found that it resonated well with the young workforce of the Eastern Limb. The Booysendal Mine workforce has a majority age range between 24 – 30. When the older employees are taken into account, the average age on the mine is 37.

   Ranking of Operators and affirming them in front of the teams was one approach the implementation team thought could be trialled. It's important to note that this is over and above the performance-based bonus.

   The visible performance boards were placed at underground waiting places, and daily bolts installed per Operator were recorded at the end of shift. At the start of every shift, the miner begins by going through the performance with the machine maintenance team present so the team can assist if a machine is identified as experiencing minor breakdowns.

   The same visible performance charts are also available on the surface in front of the Operational Technology Champion's office, and these are also updated daily.

The analysis that was done unearthed the above four main causes as the underlying issues which resulted in the 3108a not achieving the expected target per shift.

The next two tables, although included in the **Appendix 2**, are the actions taken by the implementation team to ensure we can achieve 235m per month, 1 900m^2 per month, 11 500 tons and 1.9m stoping height in a Rig Section at the Merensky Shaft.

Table 6a: Action plan to be tracked by the implementation team

Suspected Cause	Action Item	Responsible	Due	Finding – As of 4 January 2017
i. Personal impact	Structured roll-out involving OEMs, mining crews and maintenance staff	Ops Manager + Impl. team	01/17	Done (Communication poster Appendix 1)
ii. Implementation involvement of operational teams	Structured roll-out involving OEMs, mining crews and maintenance staff	Ops Manager + Impl. team	01/17	Done (Communication poster Appendix 1)
iii. Benefit realisation & Recognition of operators	Visible daily tracked information at U/G waiting place + surface info. centre	Mine Over. Nigel Reeder	01/17	Already started + have recognised 1st Quarter
iv. Incorrect KPI for Eng. and Mining	Measure both for Utilisation and availability not separately	Ops and Eng Mgrs	06/17	We need to get 'buy-in' of organised labour first
v. Incorrect Shift KPI	Measure Cycle completion per shift	Ops and Eng Mgrs	06/17	We need to get 'buy-in' of organised labour first
vi. Operator daily output not ranked	Currently being ranked to set benchmark for bonus scheme specifications	Mine Over. Nigel Reeder	01/17	Already started + have recognised 1st Quarter
vii. Continued improvement not communicated	Physical observations of bolts installation process – not simulations but practical	Impl. Team	06/17	Already started, learnings to be shared in the report
viii. Complexity vs Simplicity 3108 to 3108a (operator ergonomics considered)	Physical observations of bolts installation process – not simulations but practical	Impl. Team	06/17	Early learnings is that modifications or upgrades were not communicated well
ix. OEM alignment = only fit-for-purpose changes	Physical observations of bolts installation process – not simulations but practical	Impl. Team	06/17	Already did a major change to the support canopy' s ducks foot
x. Review SOPs = grids marking, cable anchors installation, sequence of bolting & h/wall blast techniques	Physical observations of bolts installation process – not simulations but practical	Impl. Team	06/17	Already identified three SOPs that are problematic & need for blasting technique change
xi. Poor preparation from shift to shift	Bring a bonus measure component	Ops Mgr	06/17	We need to get 'buy-in' of organised labour first
xii. No Kanban card (Structured handover system)	Formalise shift exchange cards	Ops Mgr	06/17	To be drawn up first

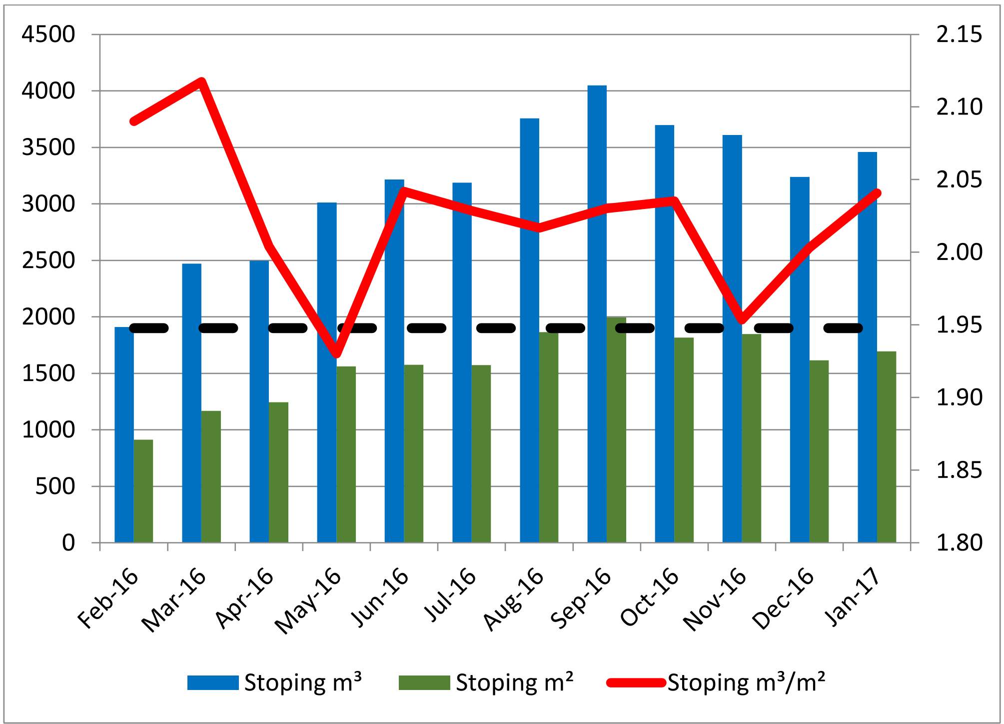
(Source: Northam Platinum Limited, Implementation team records)

Table 6b: Action plan to address Residual challenges

Investigation item	Responsible	Due	Status – As of 4 January 2017
i. Review SOPs = grids marking, cable anchors installation, sequence of bolting & h/wall last techniques	Wonderboy & Zirk Jansen	06/17	To address the gaps identified during physical observations
ii. Scrutinise the Effect of Soccer 'stars' in recognising best performing Bolt operators (Pull effect or not?)	Wonderboy & Nigel Reeder	12/17	Already recognised the 1st Quarter performers
iii. Using on-board camera or lasers for positioning of the turret over 'target' support holes	Robbin Pearce & Cules Kolbe	12/17	Do proposal to the OEM and Senior Management approval
iv. Visit to Mimosa and Bathopele Mines to learn if they have any further enhancements (SOPs, Bonus system, machine modifications or handover system)	Wonderboy & Nigel Reeder	06/17	OEMs are willing to facilitate these visits as they currently have machines in these operations

(Source: Northam Platinum Limited, Implementation team records)

4.2 Implementation stage 1: Structured Project Roll-out



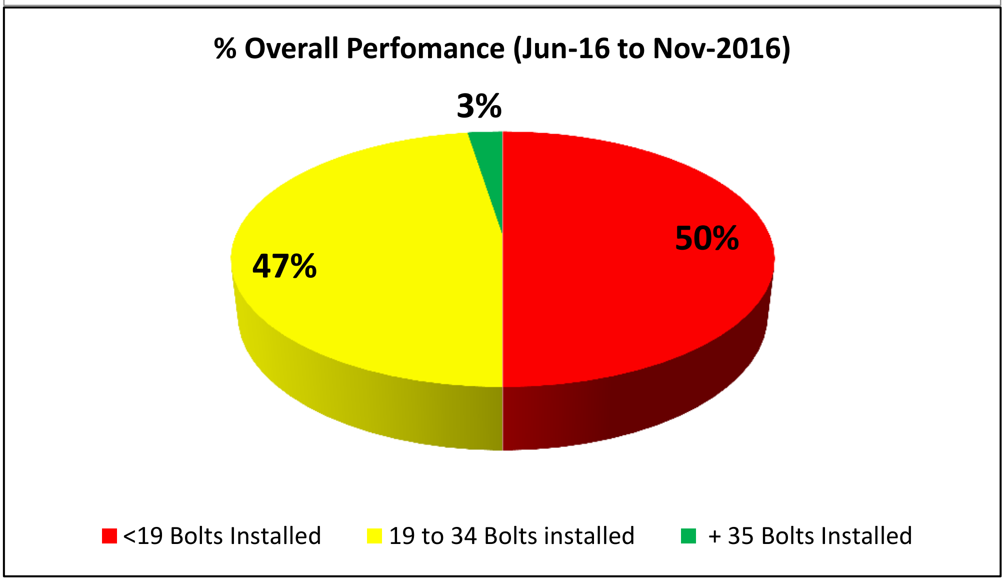


Figure 4b: Rig Section monthly output as at January 2017 (Source: Northam Platinum Limited)

The graph and the pie-chart in **Figure 4b** gives a picture of where the Merensky Shaft performance stood when the two modified 3108a machines arrived at the mine. It must be noted that from February 2016 to May 2016, the production results start as low as 900 m² till to 1 500 m² levels because the barrels development fleet from another OEM was used to develop and start the ledging faces. In fact, the results from February 2016 to May 2016 are ledging square metres broken, not stoping production.

To fully analyse the state of stoping performance it is appropriate to do the evaluation from June 2016 as that is the month when the Merensky Shaft start using the GHH Roof bolter 3108 ADE in the newly established stoping section.

The average production in the twelve months period including the ledging months is 1 575 m² which is 17.25% below the expected output of 1 900 m². For the Merensky Shaft to be profitable after paying back the initial capital expenditure, it needs to produce a consistent 1 900m² at 1.9m stoping height at a shaft head grade of 2.55g/t.

What was of concern to the implementation team was when the data collected from June 2016 to November 2016 showed the 3108 ADE bolter Operators only achieved the 35 - 42 bolts installed per shift 3% of the time, installation of between 19 and 34 bolts per shift was achieved only 47% of the time, and 50% of the time the performance was below what was expected. According to mine Management this performance level was unacceptable.

Although the information collated on the pie-chart painted a gloomy picture, the implementation team realised there were areas where it could significantly improve this performance.

Facts that were unearthed through collected data:

(i) There were Operators who capable of installing from 47 to 52 bolts per shift.

(ii) The very same Operators have times when they installed only 20 bolts per shift. So, what conditions existed which allowed them to install 52 bolts and what changed so they now only install 20?

(iii) Operators were not aware of what their daily target was in terms of number of bolts.

(iv) Operators were not ranked to be able to benchmark themselves against best performers and ultimately share learnings.

(v) From August 2016 to Jan 2017, the stoping output ranged between 1600 & 1900 m^2, An improvement of even 50% of Operators currently getting less than 19 bolts per shift will have significant impact on achieving consistent GOAL of output above 1900 m^2.

Figure 4c: Structured GHH Roof bolter Roll-out
(Source: Northam Platinum Limited)

The fundamental action identified in the A3 report in **Table 6a** was the implementation involvement. A poster was drawn up to address four key areas of the project, giving a summary of:

- The main intent
- The current performance status as at January 2017
- Best Roof bolter performance in a South African underground mechanised platinum mine
- The expected performance levels (See **Appendix 1** for the Communication poster that was used by the implementation team)

The implementation team was mindful not to give the team too many technical machine details and in-depth Merensky Shaft design details. A lot of technical details and unexplained target rationale would not have appealed to a young workforce of the Eastern Limb.

As the team has a keen interest in football, the best mine performance in South Africa was linked to the South African Premier League Champions and consistent monthly performance was upgraded to International European League Championship.

This approach resonated well with the operational team (See **Appendix 3**, it gives the impression of the Safety Manager's observations when the implementation team was engaging the operational teams as seen in **Figure 4c**). The football theme rolled the project ownership onto the operational teams, however, moving forward, the implementation team will still guide the process.

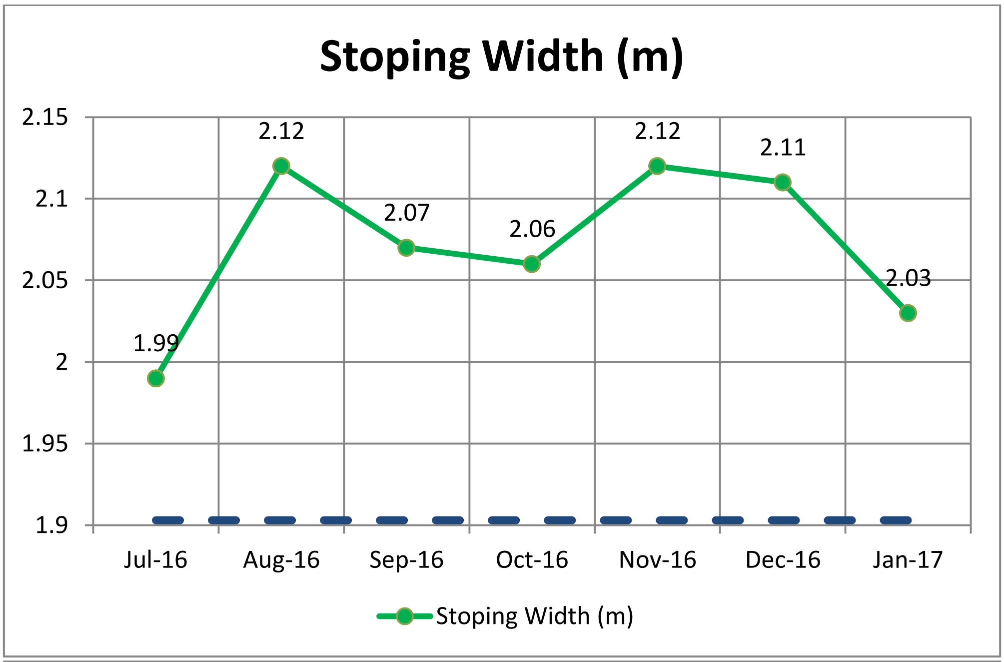
The structured Roll-out did ensure the following:

(i) From the Mine Overseer right through to the Operator there was alignment on what the intent for the GHH 3108a bolter was meant to do at the Merensky Shaft.

(ii) Operators would not feel offended or belittled when they saw their daily performance displayed on underground and surface performance boards. The reason for tracking the daily input KPIs was explained to all Operators and they rightly felt the tracking is there to assist them to perform better, rather than being used to as a "stick" against them.

(iii) When the implementation team did observations on the physical bolting process, Operators were not bothered since they understood that these observations were meant to identify areas of improvement and it was not going to be used against them.

(iv) The approach by Operators towards the 3108a bolter changed completely. When the bolter was in for scheduled maintenance, Operators were keen to assist the maintenance staff with fault finding and even giving tips on what to look for to repair recurring breakdowns.



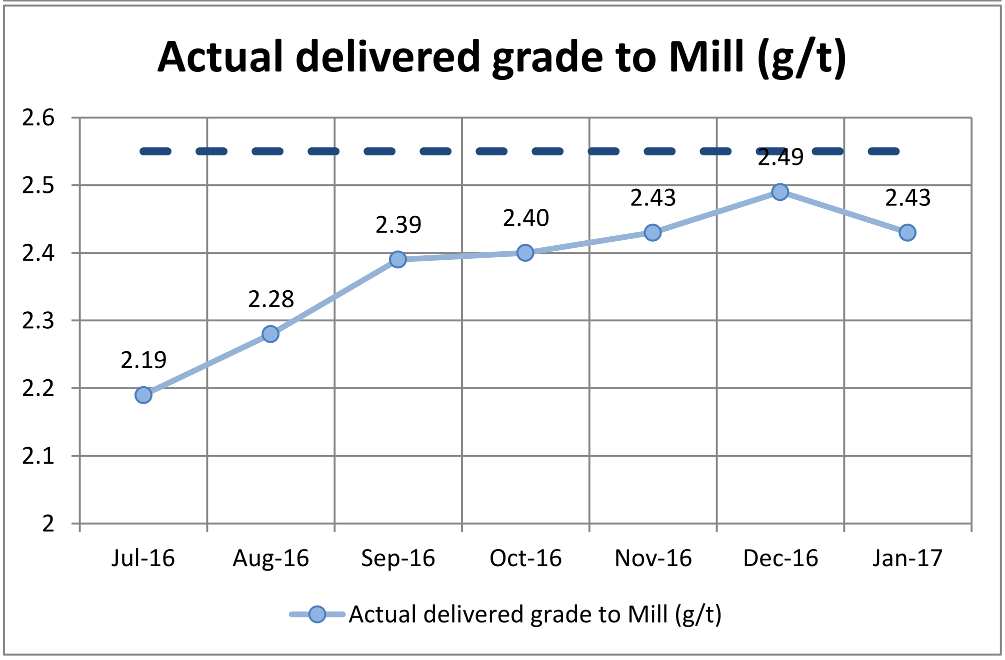


Figure 4d: Stoping width and grade trends up to January 2017 (Source: Northam Platinum Limited)

Besides achieving the required 1 900m² per month per Rig Section, there are two other significant quality factors the GHH Roof bolter performance will be evaluated on. (See the trend graphs at **Figure 4d**). The first graph **Stoping Width (m),** shows the variation in stoping width from 1.99m to 2.03m and the second graph, **Actual delivered grade to Mill (g/t)**, shows an improvement from 2.19 to 2.43g/ton. The main aim is to consistently mine at 1.9m stoping width as per the blue dotted target line. This shows there is still work to be done to reduce the additional 0.13m to reach the target of 1.9m. If this is not addressed the dilution will increase.

As at January 2017, the shaft head grade was at 2.43g/ton and this is still 0.12g/ton below the planned 2.55g/ton target.

Mining at 1.9m with the current drill rigs at Booysendal Mine is a non-issue. The challenge comes with bolting activity.

First, after the faces have been blasted, the LHDs must load all the flydirt properly to allow bolting to be carried out unhindered. Bolter Operators then have to comply with Booysendal Mine Support SOP and install all the required bolts on the marks and according to the required angles. The bolter Operator also has to know and understand the reef stratigraphy well, so that where there are deviations he can alert the miner and the shift supervisor.

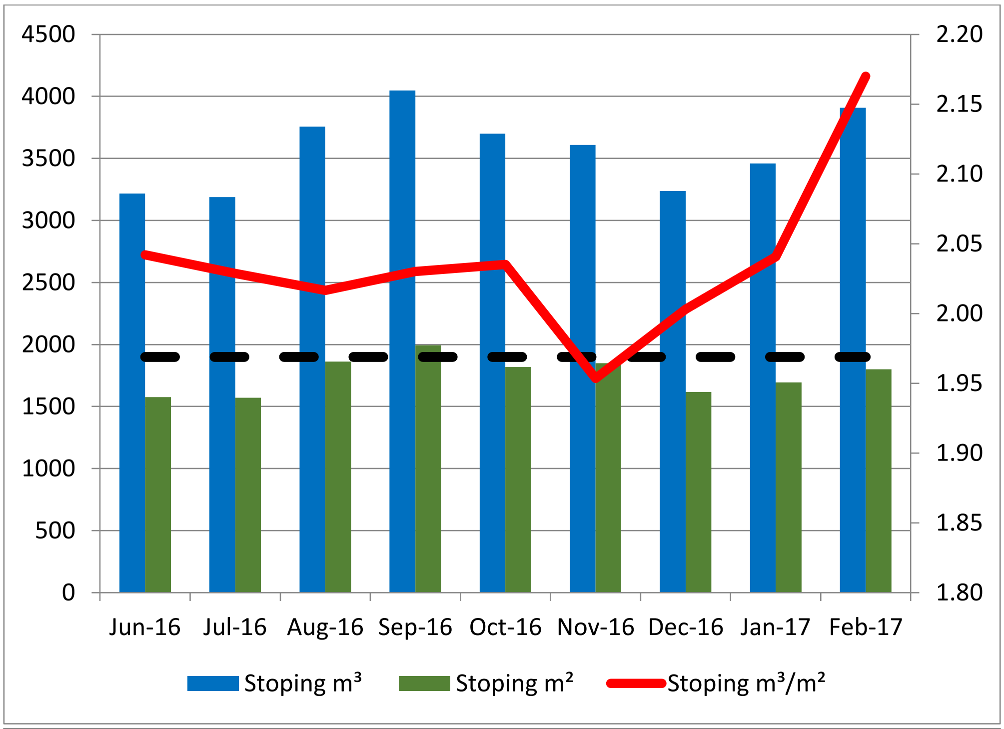
While supporting on daily basis, the bolter Operator has to be made aware of the bord dimensions on the high wall and low wall sides. The 3108a Roof bolter has a 1.56m drill feed (i.e. the turret) which is the best machine to deliver on 1.90m stoping width target.

The last issue to be resolved to ensure 1.9m stoping width is a bolter Operator who is capable of communicating either good work observed or anomalies with LHD Operator, drill rig Operator, miner and shift supervisors.

To ensure this challenge is addressed, the implementation team involved the Merensky Shaft Mine Technical Services observer and made him aware of the importance of teaching Merensky reef stratigraphy not only to miners but also to Operators.

The Mine Technical Services observers are employees trained to identify strata and its associated complexities – the observers are allocated per drill rig section. The observers play an important role of interpreting strata communicate to Operators and supervisors. In the case of the Merensky Shaft, we had the best observer on the mine coaching Operators on how to identify strata, stoping width anomalies and how to correct for those anomalies.

4.3 Implementation stage 2: Physical observations



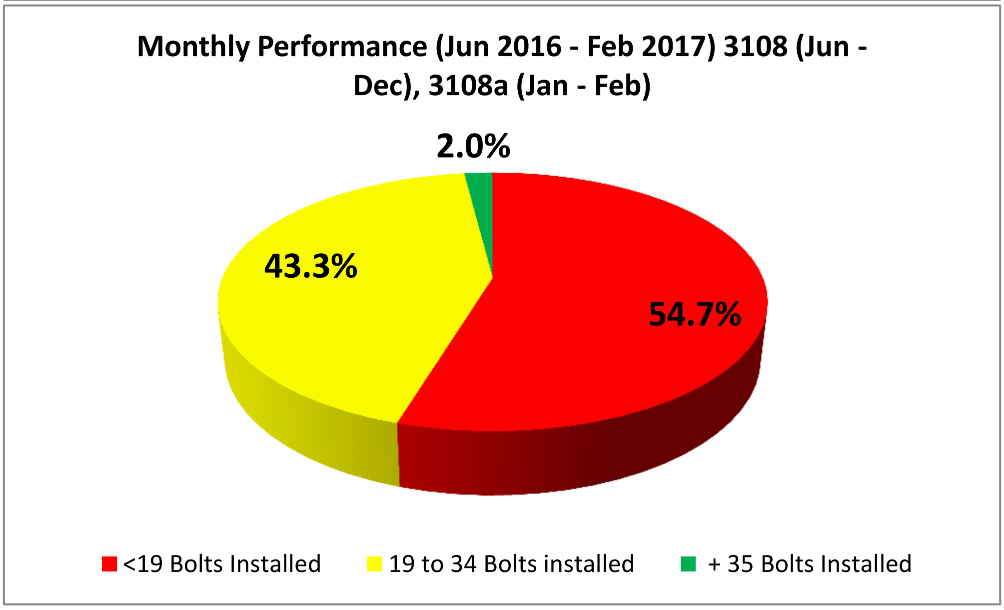


Figure 4e: Rig Section monthly output as at February 2017 (Source: Northam Platinum Limited)

It must be noted that there is significant difference between the results shown in **Figure 4b** and **Figure 4e** above. **Figure 4b** results are a mixture of ledging and stoping square metres produced using another OEM Roof bolter machine from February 2016 to May 2016. But, from June 2016 to Dec 2016, the results were obtained using the unmodified GHH Roof bolter 3108 ADE. The average production during this time was 1 575m² per month.

The trends shown in **Figure 4e** are the results of a combination of 3108 and 3108a Roof bolters. From June 2016 to December 2016, the performance is from GHH Roof bolter 3108 ADE. From January 2017 to February 2017, the results were obtained using a modified version of the GHH bolter called 3108a ADE.

This section discusses improvements following the Roll-out discussed in the previous section and looks particularly at performance in February 2017; although there's a 200 m² improvement from December 2016 to February 2017 to 1 750 m² average production when comparing **Figure 4b** and **Figure 4e** performance. The implementation team realised that there's a challenge here – the 'bolts installed' pie-chart shows there has been a regression in the bolter Operators' performance. The identified performance deterioration is contradicting what the implementation team were expecting. It was expected, due to machine modifications done and the high awareness level of all Operators at the Merensky Shaft, the actual Operator performance would significantly improve.

Analysis of the underlying issues for this underperformance will be fully unpacked in Chapter 5, but for this chapter the research will leave the results as they are.

Figure 4f: Physical observations done by the implementation team, the above photographs summarises six months' worth of underground structured inspections
(Source: Northam Platinum Limited)

As mentioned in sub-section **1.7** of this research and also in **Table 6a**, the implementation team did physical observations to look at the bolting process to see if the modifications done are yielding expected results, and if not, where do the residual challenges lie.

The author's *modus operandi* was, together with the implementation team, to observe the best performing Operators and, after doing a total of 24 underground inspections, to draw up a process flow directive for all Operators to adhere to as best practice (see **Figure 4f**).

The author was advised by the research project supervisor Dr Vogt (personal communication, January 2017) that it would add value to also observe the worst performers to identify what doesn't work. When the process flow directive is issued it would then have a well-rounded view of both best and poor performance. As a result, the implementation team observed a mixture of Operators' best performers, average and worst performers.

Initial observation findings: What did not work?

(i) The Operator’s head and limb was exposed to an unsupported area when he changed the drill steel, inserted resins and installed the Roof bolt into the drilled hole. The duck’s foot which was requested when the 3108 ADE was modified was not incorporated in the design of the 3108a bolter. The Mine Engineering team in charge of commissioning new machines on mine failed to identify this critical omission.

When the implementation team realised the Operator risk exposure when operating this equipment without a protection mechanism, it was decided to stop the machine. OEM Engineers and Mine Engineers had some design change sessions where a risk assessment, Change management and commitment to deliver the Temporary Roof Support canopy incorporating the extended duck’s foot was agreed upon.

(ii) Operators raised a concern that when they are installing Roof bolts on the low wall side of the bord it becomes difficult and risky to push the bolt into the hole due to 1.5 – 1.7m height when the bolt length is 1.8m (See **Figure 2c** to understand the configuration and dimensions of the low wall side of the bord).

During their observations, the OEM Engineers realised the steel bracket mounted on the side of the drifter to ensure pushing the bolt becomes easier was not communicated to Operators, although this feature is now available in the 3108a Roof bolter.

It was physically demonstrated by the OEM technicians in a 1.6m height that once the Roof bolt is pushed slightly into the hole, one needs to ensure that the face plate and the conical washer rests on the steel bracket. Then, as the drifter moves up, the bracket assists in pushing the Roof bolt into the hole. After the demonstration, the Operators immediately started using the bracket. The implementation team recommended that this bracket functionality be included in the lesson plans and even in the Roof bolt installation SOP.

(iii) Trial time studies indicated a variation in times taken to move and set up the machine from one hole to the other and also a variation in boom movement times (See **Table 7a**). The implementation team was keen to understand what led to this time variation.

Observation showed that moving the boom from one hole to the next and positioning the cross hair for commencing to drill varies significantly from one Operator to the next. The motion and time study results to be discussed in sub-section **4.5** of this report, show the time for boom movement and positioning the turret on the support marks varies from 1 minute 45 seconds to sometimes 6 minutes.

Any bolting cycle improvement initiatives must be directed into reducing the movement and positioning time variation. Operators gave the implementation team a number of practical solutions on how to address the gap. This will be dealt with later in the report.

(iv) A gap was identified in the current support grid marking off SOP. Although the support grid had been risk assessed and changed for the Merensky Shaft as compared to the Booysendal Mine UG2 Shaft, the marking off SOP was not amended.

The support lines are spaced 1.5 metres apart on strike both on UG2 and Merensky Shaft. At the UG2 Shaft, the support marking off SOP restricts the miner to marking off one at a time. After the installation of the row of bolts, then the second line can be marked off – this is mainly due to stoping heights of 2.2 – 2.6 metres.

Now, without even considering that the 1.7 – 1.9 metres height in the Merensky Shaft allows the miner to mark off two lines with a charging stick whilst the miner is in one position, it was decided to have the same marking off SOP as that of the UG2 Shaft.

The effect of this means the GHH Roof bolter has to do four machine set ups to drill and install 14 Roof bolts required for 3.0 metres face advance compared to two set ups on the UG2 operation. This definitely needs to be reviewed to align to the Merensky Shaft conditions and to optimise drilling so the machine only needs to be set up twice.

Initial observation findings: What worked well and why?

(i) With the 3108 ADE Roof bolter, the support accessories (i.e. Roof bolts, resins and drill steel) used to be placed at the rear of the machine on top of engine top covers. This meant the Spotter had to take accessories from the rear and pass it to the Operator at the front who was busy operating the controls. With the modification from 3108 ADE to 3108a ADE a simple rectangular storage tray was incorporated into the design.

When the implementation team did its observations, it was obvious how such a simple, trivial innovation could impact the bolting cycle. The accessories were now within arm’s reach of the Operator while he is sitting in his foldable stool inside drill platform.

The process improvement brought about by this addition, meant the Operator has all the accessories for drilling and installing all 14 Roof bolts without requiring any assistance from the Spotter/Roof bolter Operator assistant. While the bord is being supported, the Spotter can co-ordinate with the utility vehicle Operator on the material required for the next bord support, and arrange that when the Roof bolter gets to that bord accessories are loaded into the storage tray.

(ii) A drill mast or platform with a foldable stool has now been incorporated into the 3108a design. The OEM claimed the following when they designed this platform: “Drilling, resin insertion and bolting are accomplished from under the TRS (Temporary Roof Support) allowing maximum efficiency and safety.

Bolter operating controls are now single-sided with an extended canopy protection and an added vertical bar support, complete with an operating stool to enhance Operator comfort.”

The implementation team observed Operators carrying out the Roof bolt installation while sitting down on the foldable steel stool is not ideal, it does however make a huge difference when installing Roof bolts on the low wall side as compared to the previous machine (3108 ADE) where the Operator had to squat when working at these heights.

(iii) Another claim by the OEM reads: “The boom now lifts, swings and extends to allow for 4 000mm straight line bolt installation from one chassis position. Fore and aft tilting capabilities of the rotary drill unit, combined with a vertical extendable foot well facility, enables not only 'angle bolting’ but also allows for bolting up to heights of 2,6 metres.” The implementation team did physically observe the ease of installation of bolts 0.5m from the sidewall and from the face.

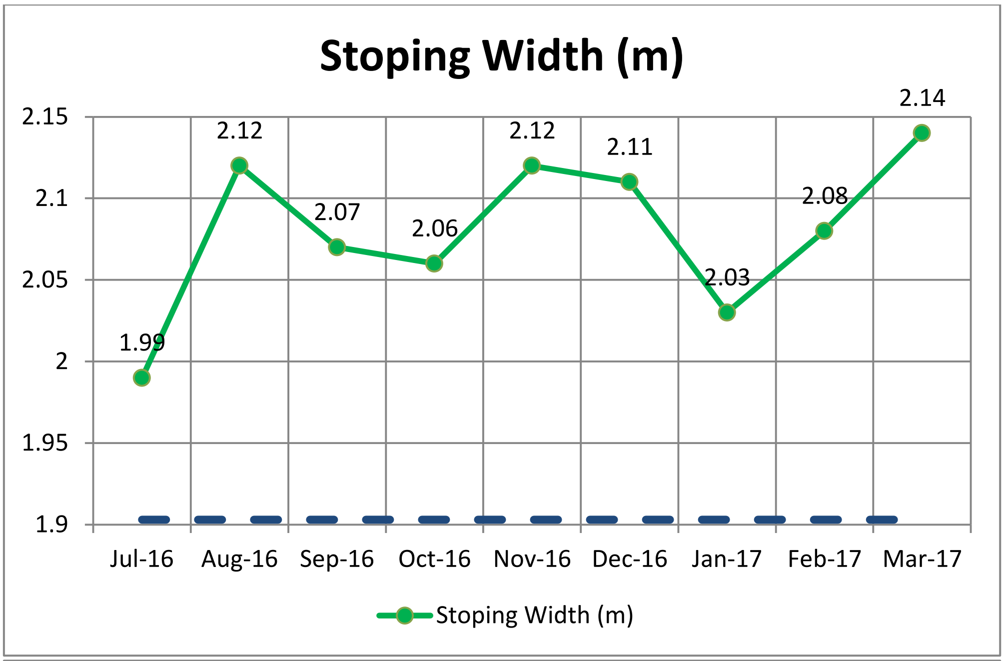
Something which was difficult with the 3108 ADE, had now been made simpler through the combination of a steel bracket on the drifter, fore and aft tilting modification and a sitting provision to enable the installation of the Roof bolt on the low wall side even in 1.5 - 1.7m heights.

(iv) Different tests and trials were done on alternative resin size combinations. Different size bolts were also tested. The observations done by the implementation team were to verify if the 18mm Roof bolt diameter size and 23mm resin capsules were an ideal combination in practice.

The resin capsule length was now a combination of two: one quick-setting capsule 500 mm long and the normal setting 700 mm long. This combination basically translated in resin installation, bolt insertion and spanner time to 1 minute. New Operators battled to properly insert the plastic parachutes in the resin capsules and so struggled to complete the task in 1 minute. However, once they got used to handling the parachutes they also came in around 1 minute.

(v) The 25mm drill steel is a lightweight easy-to-handle Kennametal Stackable hex tube drill stem. A simple combination of 1.2m and 0.9 m drill rods is used to drill the required 1.75m hole. Features that made this combination possible are:

- The vacuum chuck/bit seat where the tungsten drill bit is coupled.
- The vacuum rod coupler which connects two drill stems together.
- The vacuum chuck adaptor which fits into the drifter and in turn connects the combined drill stem to the turret system.



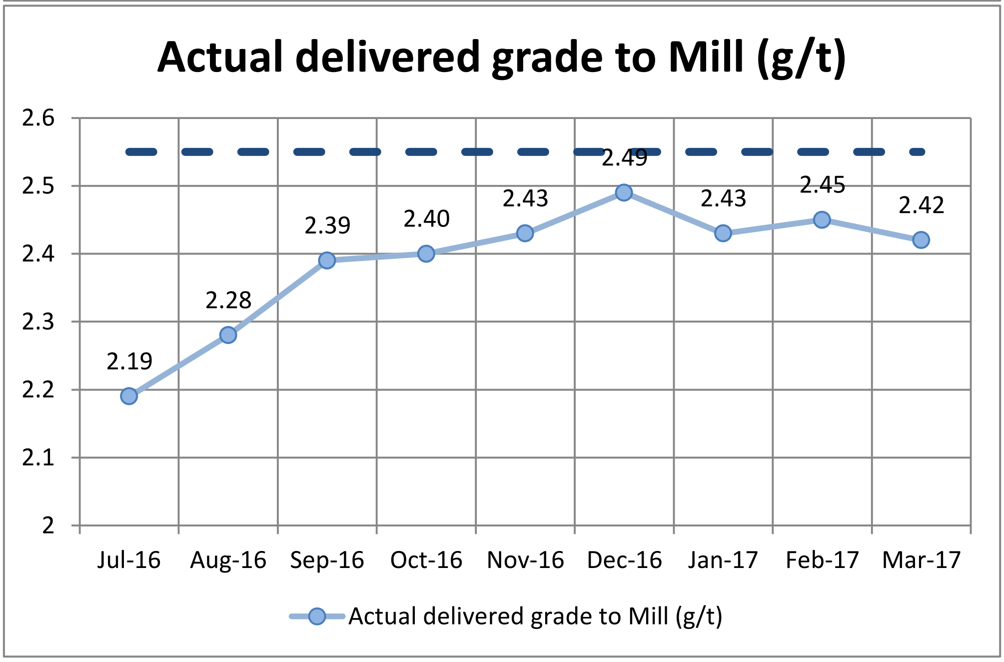


Figure 4g: Stoping width and grade trends up to March 2017 (Source: Northam Platinum Limited)

As explained previously in sub-section **4.2** besides achieving the required 1 900m² per month per rig section, there are two other significant quality factors on which the GHH Roof bolter performance will be evaluated.

The first graph at **Figure 4g**, **Stoping Width (m),** shows a further deterioration in terms of stoping width from 2.03m to 2.14m.

The second graph, **Actual grade delivered to Mill (g/t)** shows a flat performance in the region of 2.42g/ton. The main aim is to consistently mine at 1.9m stoping width as per the blue dotted target line. The picture above shows that instead of an expected improvement of 0.13m, the stoping width further deteriorated by 0.14m to result with an effective overbreak of 24cm.

The implementation team had already observed the challenge posed by closely spaced flat dipping joints on the low wall side of both North and South sides bords (See **Figure 2c**). These structures in the hanging wall resulted with some bords exceeding the 1.7m required on the low wall side. This does not mean the 3108a is not capable of delivering 1.9m planned stoping width (See **Appendix 4** for best cut bords). It does, however, need further geological mapping consolidation and the involvement of the Explosives Suppliers experts in designing appropriate rounds and low density explosives for charging up top holes.

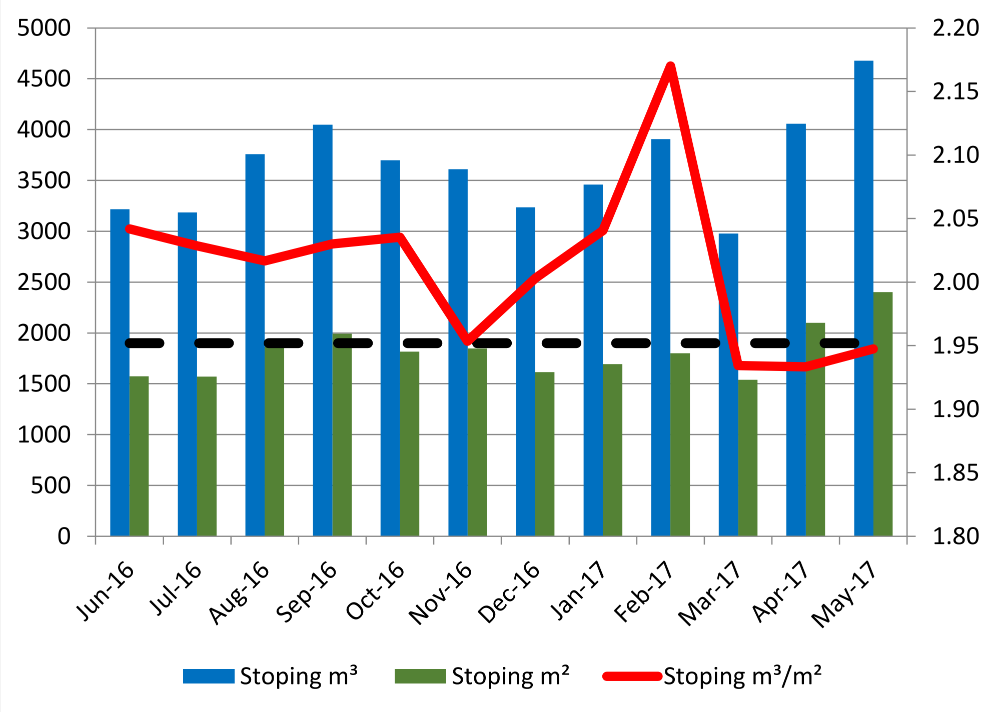
Another significant finding which came to the implementation team's attention was that because of difficulties experienced by the bolter Operators in drilling and installing long anchors using a 3108a machine, they were arranging with drill rig Operators to open up the stoping width so they could use another OEM hybrid bolter to install the long anchors.

There are two issues the author wish to bring to your attention here.

Firstly, as at January 2017, the shaft head grade was 2.43g/t which is not the planned head grade of 2.55g/t. The fact is, we are below plan.

Secondly, the average stoping width as at January 2017, deteriorated when compared to the previous months. As a result, one would expect the grade to deteriorate even further. But, looking at the graph it can be seen that it didn't. This was because some of the bords were mined way better than the average 1.9m stoping width required. (See **Appendix 4.** Here it can be seen that some bords do in fact have an effective stoping width of 1.7m).

4.4 Implementation stage 3: Process scrutiny and effects on mining cycle



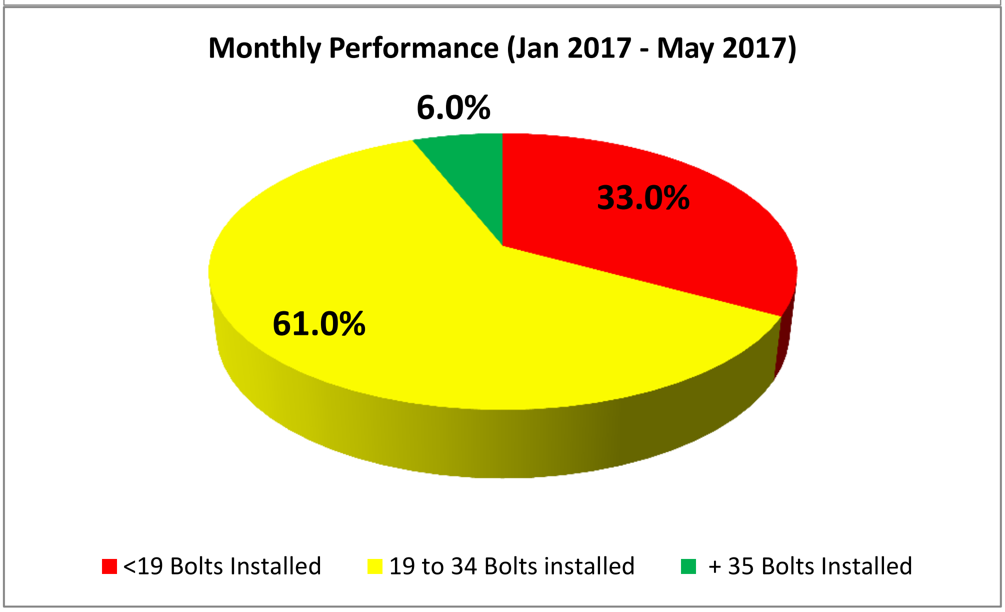


Figure 4h: Rig Section monthly output as at May 2017
(Source: Northam Platinum Limited)

The trend graph and the installed bolts pie-chart in **Figure 4h** are now a mid-way test for this study (i.e. A six-month test of the twelve months' Roll-out). These results link to sub-section **4.1, Table 6a,** where the implementation team identified the corrective actions to optimise 3108a implementation. The graphs are a further validation of actions effected as per sub-section **4.3** as the results revealed if the actions were appropriate to effect the change required.

When comparing the April and May 2017 production results to the 12 months' average of 1 575m^2 it's clear the 1 750m² target set, as per **Appendix 2**, have already been surpassed. In fact, on close scrutiny of the May 2017 results, 300m system advance was achieved instead of the planned 235m.

In terms of bolts installed per shift per Operator, it was planned that by December 2017, a 13% improvement on both 35 – 42 and 19 – 34 bolts category is required. The target for 19 – 34 bolts has already been exceeded by 1% to achieve 61% in May 2017.

This achievement affirms the actions of sub-section **4.3** are appropriate and need to be reinforced further.

While a concern can be raised with regard to the 35 – 42 bolts category - in that the study is already half-way and the improvement is only 3% instead of 6.5% - the implementation team realised the improvement in the 19 -34 category has already made it possible for the section to achieve 2.5 bords supported per shift consistently.

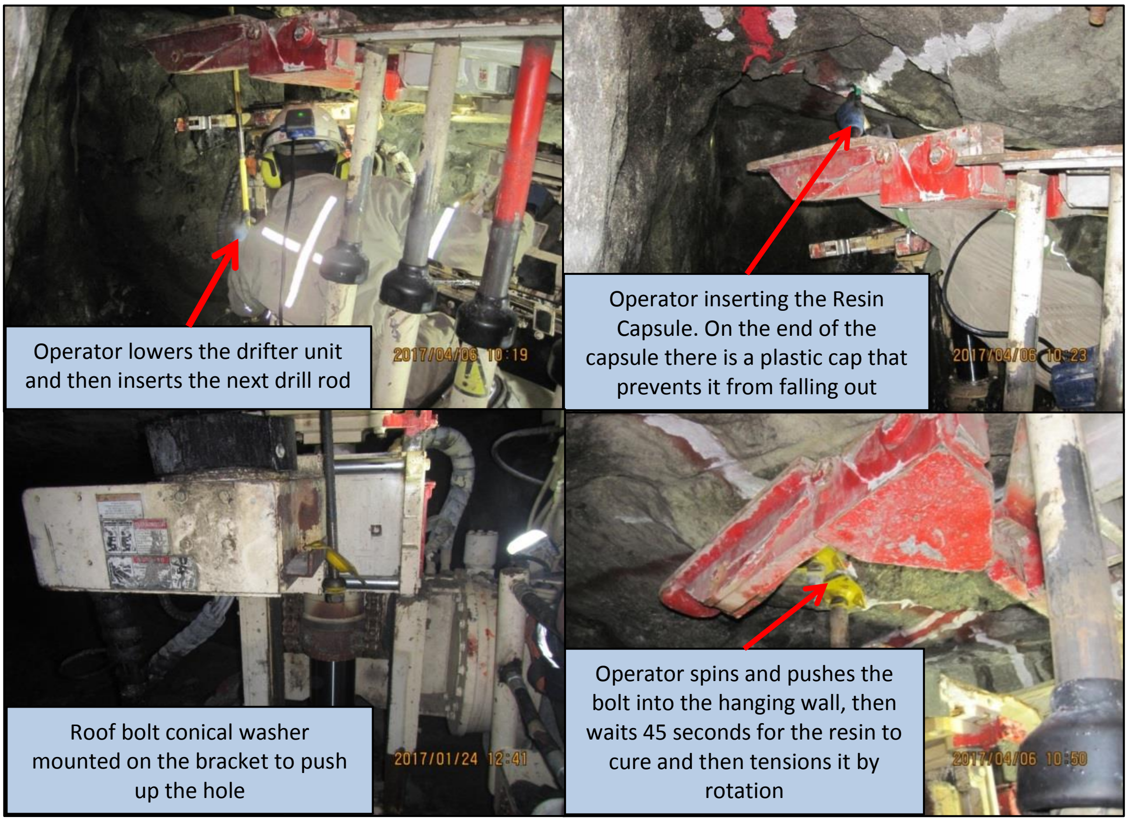


Figure 4i: Operator installed both Roof bolts and cable anchors in the above observation, although it is a sequential process as both are done in series
(Source: Northam Platinum Limited)

Final observation findings: What did not work?

(i) With each blast on both the UG2 and Merensky Shafts, a 4.0m camera hole was drilled into the hanging wall to identify any separation in the hanging wall strata prior to blast. Once strata separation was observed, the section gets issued a technical instruction to install two lines of 4.5m cable anchors. The implementation team observed, drilling 4.5m was fairly simple with a 41mm bit and using the Kennametal hex stackable drill steel.

The challenge was when the Operators retract the drill steel. On numerous occasions it was observed that the last drill steel gets stuck and only experienced Operators could retract it. Last drill steel getting stuck could be attributed to two issues:

- The stem sticks as the blade configured bit gets worn out as it drills the last part of the 4.5 m hole, curving that part of the hole.

- The second issue is maybe the stackable system is only effective for holes less than 3.0m. Above 3.0m, a screw type drill steel has to be used.

At this stage, the implementation team doesn't have a solution to this. But, it has been seen it makes the cable anchor installation process onerous and difficult to complete within a shift, posing significant delays to the mining cycle. The combination of all drill rods to achieve an effective 4.5m hole is four 1.2 m drill rods.

The recommendation that is currently underway to deal with this challenge is: <u>Hole size</u> – the long anchors have an OD (outer diameter) of 38mm (expansion shell). We have changed our bit diameter to 41mm so there is no interference on installation of the long anchor.

According to the Mine Overseer, after changing from 35mm to 41mm bit, both the drilling and drill steel retrieval have been achieved without any challenges.

(ii) The SOP for marking off and the installation of cable anchors at the UG2 Shaft calls for one line at a time. The learning point for the implementation team and myself was that the Merensky Shaft imported the UG2 SOPs without fully understanding the rationale underlying the risk assessment done at the time, nor the rationale for adhering to a certain sequence.

If the cable anchor process is to adhere to the current SOP then it means the machine has to do four set ups to enable it to install 10 bolts installed at 5 bolts per line.

Any trackless orientated miner will definitely notice that the impractical number of set ups will encourage the Operators to develop at-risk behaviours in order to complete their daily allocated task.

The implementation team agreed the cable anchor marking off and installation SOP for the Merensky Shaft using the 3108a bolter will need to be reviewed. It can't be a 'copy and paste' of the UG Shaft without analysing the impact on the support installation process and its negative effect on the mining cycle.

(iii) The OEM claimed the following: “The bolter unit has an operational flexibility with regard to an alternative power source. Usually the unit operates on a dedicated power plug in system. It can alternatively operate on diesel power through its tramming power unit.” In practice, the unit experienced frequent cut outs when tramming from one bord to the next when powered by electricity. As a result, most Operators preferred to use diesel power when tramming as it was much more reliable than electricity.

Initial observation findings: What worked well and why?

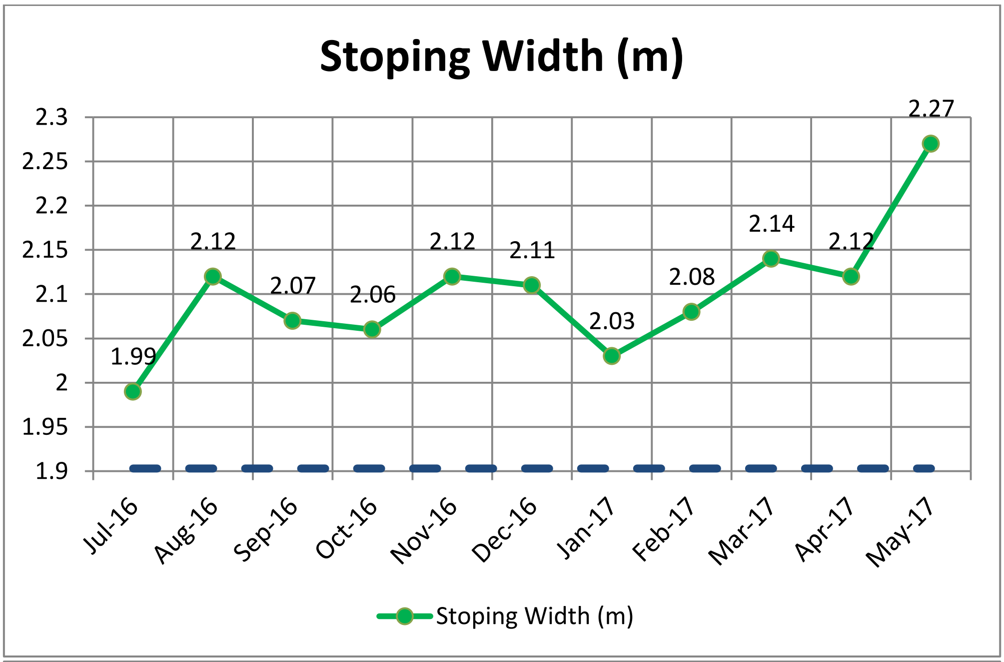
(i) The 3108 ADE Roof bolter machine did not have the capability to install cable anchors. This was a significant limitation because it meant that once the strata separation was identified, footwall ripping had to be done to allow a minimum height of 2.1m, so that a different OEM Roof bolter capable of drilling and installing cable anchors could be brought in into the bord.

The author mentioned previously that additional waste will increase dilution and this will make the Merensky Project financially unattractive. It’s a business and operational imperative to find a solution to this issue.

The 3108a has the capability of installing both the 18mm Roof bolts and the 18mm cable anchors. This capability was made possible by the cable anchor supplier who was able to change the anchor diameter from 38mm to 18mm, but still has the ability to take a 38 ton load.

(ii) Both the Roof bolts and the cable anchors are installed while the Operator is under cover or protection of the TRS (Temporary roof support) canopy. This canopy protection may be a simple addition when operating in stable hanging wall conditions such as UG2 hanging wall, but when considering the Booysendal Merensky Shaft’s closely spaced flat dipping joints in the hanging wall, then this addition is really adding value.

Both primary support and secondary support can be done in series. In other words, in terms of Rock Engineering principles, both beam building and suspension can be achieved while the Operator is safe under the canopy and the duck's foot.



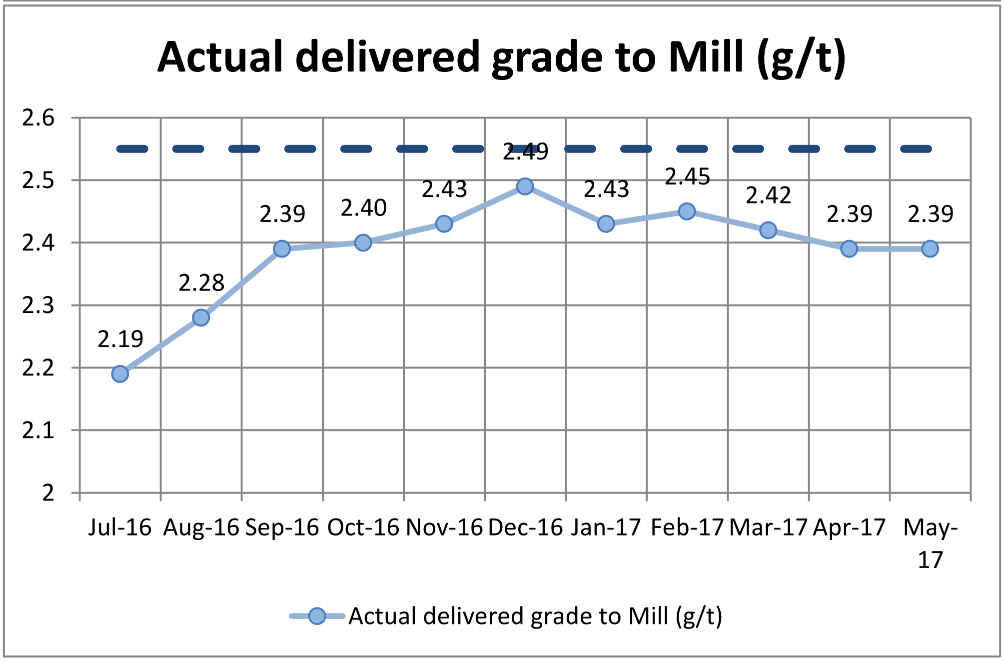


Figure 4j: Stoping width and grade trends up to May 2017 (Source: Northam Platinum Limited)

The final stoping width and shaft head grade results above shows there's still work to be done to get the dilution to acceptable levels and ensure that the Merensky Shaft remains profitable.

There was a further regression of 0.13m in the stoping width from March to May 2017. However, as mentioned in sub-section **4.3,** the implementation team is aware of the challenge posed by the Geology and that is being addressed.

The stoping width is off plan by 37cm and in a profit-orientated organisation like Northam Platinum, the pressure is on to ensure all bords are the same quality as those seen in **Appendix 4**.

Geology mapping, in terms of understanding the hanging wall strata and blast design change, are not in the scope of this study. This presents an opportunity to the Northam Platinum Technical Services technical staff to take this further.

With no improvement in the stoping width, the shaft head grade is also not improving. It is staying flat around the 2.40g/ton mark. This actual head grade is 0.15g/ton below the planned grade and, when considering the 11 500 tons delivered per month, this equates to 1.84kg 4E below plan per month. Once again, with Northam Platinum being a Lean company focused on Continuous Improvement, the 22kg 4E below business plan per annum will definitely need to be attended to and sorted out. Especially considering there are already two other Merensky modular shafts planned as of FY 2019.

4.5 Progress on the A3 report implementation plan

To validate the time-and-motion study results achieved during the project trial stage, the author arranged an implementation time-and-motion study to be done by experienced Booysendal Mine trackless mobile machine instructors. He drew up templates to be used by the instructors and then briefed the HRD Training Head, Thys Marais, on what was the expected data to be collected.

The two instructors, together with Thys Marais, observed six different Roof bolter Operators over a period of 4 weeks. The six Operators involved in this exercise had varying experience levels on the bolter machine varying from 4 months (i.e. the least experienced) to 14 months (best experienced).

This section (**4.5.1**) gives the consolidated results of the time study done.
Table 7a gives the daily data recorded over period of four weeks.
Table 7b gives the summarised weekly data recorded per Operator.
The page after **Table 7b** gives the raw observations of the observers who recorded the data.

The author made it clear to Thys Marais and his instructors that they must only observe and record activity times without interfering or interrogating the Operator on why he carries out his functions the way he does. Thys and his team went further than required, by also noting down their observations (see page 106).

4.5.1 Time study results

Table 7a: Actual Times Observed

Machine Number	GHH Bolter 203							GHH Bolter 202							
Day	Day 1	Day 3	Day 4	Day 2	Day 3	Day 4	Day 3	Day 1	Day 4	Day 1	Day 3	Day 4	Day 5	Day 1	Day 2
Date	20-Mar-17	22-Mar-17	23-Mar-17	28-Mar-17	29-Mar-17	30-Mar-17	05-Apr-17	20-Mar-17	23-Mar-17	27-Mar-17	29-Mar-17	30-Mar-17	31-Mar-17	03-Apr-17	04-Apr-17
Board Number	Board 1														
Hole Number	Duration														
1	00:10:28	00:09:50	00:07:03	00:14:48	00:14:38	00:10:11	00:08:03	00:07:36	00:13:08	00:17:31	00:10:50	00:09:05	00:12:09	00:12:07	00:09:33
2	00:08:05	00:09:01	00:07:21	00:12:08	00:09:05	00:09:38	00:08:05	00:10:13	00:11:45					00:11:22	00:08:21
3	00:07:55	00:09:15	00:07:58	00:12:01	00:10:28	00:10:43	00:09:48	00:11:32	00:11:48					00:13:48	00:08:00
4	00:07:38	00:07:05	00:09:28	00:10:01	00:10:25	00:09:33	00:12:20	00:13:08	00:12:30					00:10:20	00:11:53
5	00:08:03	00:09:40	00:10:31	00:10:55	00:13:45	00:11:21	00:08:06	00:14:26	00:12:16					00:14:07	00:10:16
6	00:08:05	00:07:23	00:08:33	00:12:46	00:09:28	00:12:36	00:07:18	00:10:38	00:08:16					00:12:21	00:07:46
7	00:09:43	00:09:00	00:11:58	00:16:03	00:11:20	00:09:58	00:08:10	00:13:58	00:11:51						00:10:23
8	00:07:13	00:10:16	00:10:50	00:12:40	00:08:23	00:10:34	00:11:10	00:11:15	00:11:39						00:09:27
9	00:13:36	00:08:26	00:09:43		00:09:41		00:09:07								
10	00:07:36	00:17:36	00:11:33		00:09:33										
11		00:10:51	00:08:43		00:10:41										
12		00:09:36	00:10:28		00:09:36										
13			00:10:03												
Board Number	Board 2														
Hole Number	Duration														
1		00:06:55													
2		00:09:05													

3		00:06:06													
4		00:11:45													
5		00:10:10													
6		00:08:45													
7		00:08:11													
8		00:07:20													
9		00:08:51													
10		00:10:16													
11		00:09:11													
12		00:07:21													
Average duration of bolt installed	**00:08:50**	**00:09:15**	**00:09:33**	**00:12:40**	**00:10:35**	**00:10:34**	**00:09:07**	**00:11:36**	**00:11:39**	**00:17:31**	**00:10:50**	**00:09:05**	**00:12:09**	**00:12:21**	**00:09:27**
Best duration of bolt installation	**00:07:13**	**00:06:06**	**00:07:03**	**00:10:01**	**00:08:23**	**00:09:33**	**00:07:18**	**00:07:36**	**00:08:16**	**00:17:31**	**00:10:50**	**00:09:05**	**00:12:09**	**00:10:20**	**00:07:46**
Worst duration of bolt installation	**00:13:36**	**00:17:36**	**00:11:58**	**00:16:03**	**00:14:38**	**00:12:36**	**00:12:20**	**00:14:26**	**00:13:08**	**00:17:31**	**00:10:50**	**00:09:05**	**00:12:09**	**00:14:07**	**00:11:53**
Holes Drilled	**10**	**24**	**13**	**8**	**12**	**8**	**9**	**8**	**8**	**1**	**1**	**1**	**1**	**6**	**8**
Average duration to move and set up machine from installed bolt to collaring of hole 2	**00:01:07**	**00:02:04**	**00:01:04**	**00:01:18**	**00:00:56**	**00:00:11**	**00:00:59**	**00:02:16**	**00:02:15**	**00:04:01**	**00:02:07**	**00:00:29**	**00:01:02**	**00:00:59**	**00:01:07**
Duration to position boom	**00:00:29**	**00:00:33**	**00:00:45**	**00:00:46**	**00:00:50**	**00:01:04**	**00:00:41**	**00:01:15**	**00:01:33**	**00:02:06**	**00:02:49**	**00:01:25**	**00:00:52**	**00:00:26**	**00:00:28**

Duration to drill a hole	**00:04:20**	**00:04:23**	**00:05:22**	**00:07:08**	**00:06:03**	**00:05:34**	**00:04:57**	**00:04:58**	**00:05:12**	**00:07:40**	**00:04:44**	**00:04:24**	**00:07:37**	**00:06:56**	**00:05:12**
Duration resin installed, insert the bolt and spanner	**00:00:59**	**00:01:38**	**00:01:11**	**00:01:36**	**00:01:20**	**00:00:48**	**00:01:20**	**00:02:15**	**00:01:06**	**00:01:10**	**00:01:11**	**00:02:02**	**00:01:46**	**00:02:09**	**00:00:58**
Duration spinning and tension the bolt	**00:01:08**	**00:00:47**	**00:00:47**	**00:01:48**	**00:02:10**	**00:01:21**	**00:00:56**	**00:01:46**	**00:01:48**	**00:02:30**	**00:00:59**	**00:01:16**	**00:01:13**	**00:01:20**	**00:01:32**

(Source: Northam Platinum Limited, Bolter Time Study Results)

Table 7b: Weekly Summary of the observed times

	Weekly Comparison					
	Operator Name					
Operator Comparisons	Jeffery Simelane	Ganghthol Sithole	Richard Mathonsi	Rovers Ratau	Widney Pilusa	Alfred Mashilo
Holes drilled	47	15	28	1	14	9
Average time of bolt installed	00:09:13	00:11:37	00:10:57	00:10:50	00:10:54	00:09:07
Best time of bolt installation	00:06:47	00:07:56	00:09:19	00:10:50	00:09:03	00:07:18
Worst time of bolt installation	16:05:20	00:13:47	00:14:26	00:10:50	00:13:00	00:12:20
Boards drilled	2	1	1	1	1	1
Average Time to move and set up machine from installed bolt to collaring of hole 2	00:01:07	00:02:16	00:00:48	00:02:07	00:01:03	00:00:59
Time to position boom	00:00:36	00:01:24	00:00:53	00:02:49	00:00:27	00:00:41
Time to drill a hole	00:04:42	00:05:05	00:06:15	00:04:44	00:06:05	00:04:57
Time resin installed ,insert the bolt and spanner	00:01:16	00:01:40	00:01:15	00:01:11	00:01:34	00:01:20
Time spinning and tension the bolt	00:00:54	00:01:47	00:01:46	00:00:59	00:01:26	00:00:56

(Source: Northam Platinum Limited, Bolter Time Study Results)

Observer's Comments (TMM Instructor Observations):

Depending on the stoping width, it could take a long time to setup the machine for drilling.

One drill bit can drill only 2 holes and the jumper exchange takes a lot of time.

Because of the confined space in the bolting cap and rods, it takes longer to insert the bolt if the stoping height is low.

Spanner bolting could become loose.

Barring can take longer than expected.

Power could trip at the rig box.

Second rod could get stuck in the hole, and take almost 15+ minutes to remove.

Water leaked onto machine and after fixing, the Operator bent the rod in the second hole.

Machine had a problem when moving forward on electrical power. When moving, the machine cuts off.

Low water supply on machine. Problem was fixed

Hanging wall was very low and the Operator took a long time using short jumpers and fitting in the bolt.

Machine stopped due to high temperature.

Operator struggled to remove the first rod.

4.5.2 Recognition of Best Performing Operators: Soccer stars theme (mainly EU and RSA Premier League)

Figure 4k: Best Operators up until February 2017 being rewarded by the Operational Technology Champion
(Source: Northam Platinum Limited)

As mentioned in sub-section **4.1**, recognising Operator performance is a key issue that was implemented. While recognising the star performers heightened the morale of the Merensky team, Management was gathering practical implementable output targets against which to benchmark the Operators.

The best top three Operators from December 2016 to March 2017 were ranked and recognition was given to them by the Operational Technology Champion Nigel Reeder (**Figure 4k**).

It must be stated clearly that none of the top three Operators achieved the planned 42 bolts per shift.

Operators 1 and 2 consistently achieved 34 bolts installed per shift. This is still 8 bolts less than the planned target. However, although the Operators were made aware that we are not on planned target yet, the implementation team decided that recognition would be given for the results they did achieve.

Operator 3 consistently achieved 30 bolts per shift but also had days when he reached 35 bolts per shift. The implementation team gave them all football T-shirts as a token of encouragement for self-improvement.

As stated in the action plan in **Table 6a** in sub-section **4.1** of this report, meagre benefit realisation and Operator recognition was one of the root causes of poor performance that had to be addressed. 2017 Quarter 1 recognition was meant to start delivering on the promise made by the implementation team to Operators during the structured project Roll-out.

4.6 Conclusion

The actions carried out by the implementation team and the time study carried out in sub-sections **4.3** and **4.5** respectively delivered the following results:

(i) April 2017 measuring month, the 235m milestone, 1 900m² and 11 500 tons were achieved.

(ii) May 2017 measuring month, the 235m milestone was surpassed and 300m, 2401m² and 14 532 tons was achieved.

(iii) An increase of 3% to bring the total to 6% the number of times Operators installed 35 – 42 bolts per shift.

(iv) An increase of 14% to bring the total to 61% the number of times the Operators installed 19 – 34 bolts per shift.

(v) An increase from April's two bords supported per shift to 2.5 bords supported per shift.

(vi) Deterioration in the stoping by total of 37cm by May 2017 measuring month.

(vii) Shaft head grade remains unchanged at 2.40g/ton level.

5 SCRUTINY OF THE 3108a ACHIEVED RESULTS

5.1 Analysis of results – minutes per bolt installed

At this stage, are the Booysendal Mine implementation results comparable to results achieved in Bathopele Mine XLP trials, Lonmin projects and Booysendal trial?

Table 8 will show the available results so far and the differences will be explained in the paragraphs to follow.

Table 8: Comparison of 3108a performance with other similar or same category Roof bolters (Bolts installation times)

Bathopele Mine XLP	Lonmin XLP project	Booysendal 3108 trial	Booysendal 3108a implementation
Simulated times: 9.84 minutes/ bolt **Actual times:** 10.7 minutes/bolt	 **Actual times:** 10 minutes/ bolt	**Best:** 6.31 minutes/bolt **Average:** 8.05 minutes/bolt **Worst:** 13.04 minutes/bolt	**Best:** 8.69 minutes/bolt **Average:** 10.54 minutes/bolt **Worst:** 13.17 minutes/bolt

(Source: Author's own performance consolidation from different sources)

According to Pickering and Leon (2008), the trial of the XLP Mechanised Breast at Bathopele Mine (previously known as Waterval Mine) was based on three eight-hour shifts per day and effective equipment available times of 6.2 hours per eight-hour shift.

Although the Bathopele bolt length is different from Booysendal Mine bolt length, both the simulated and rated performance, including the actual results achieved, give a base from which to start for the Booysendal Mine implementation. The Bathopele Mine Roof bolt is a 1.6m resin bolt, the XLP Roof bolter has to install 24 bolts per panel in a 25m face length including the advanced strike drive (ASD).

Inside the panel, the Roof bolt has to install total of 18 bolts and it did this in 3.2 hours. This means that in one shift an XLP Roof bolter will complete one face and then travel to the next panel to set-up and install a minimum of 5 bolts for the next shift.

Pickering and Leon (2008) asserts that the Bathopele trial was a success as it consistently and safely delivered the planned 2 400m^2/month. However, what they did not disclose is that the 2 400m^2/month was delivered using two suites of equipment – an LP fleet for the advanced strike drive (ASD) and an XLP fleet for the panel.

It was shown in the Implementation stage 3 (i.e. **Figure 4h**) that a single suite of an LP fleet at Booysendal Merensky Shaft produced 2400m^2 whilst at Bathopele Mine both the XLP and LP fleet combination is required to produce the same.

Webber et al. (2010) explain Lonmin's aim with the Roll-out of XLP fleet at the Hossy shaft. Although their actual results are actually setting the industry benchmark, they don't seem content with what was achieved. The following statement from Webber unpacks this "The XLP bolter utilises a single boom to drill and install 1.6m split resin bolts. Roof bolts are installed on a spacing of 1m (dip) by 1.5m (strike). The XLP bolter has a total cycle time, taking account of 45 minutes of tramming and set-up, of 5 hours and 20 minutes. As a result, the XLP bolter can complete the support of a 26.5m panel length (installing 32 resin bolts) in less than a shift. The bolter's cycle time of 5 hours 20 minutes currently represents the longest cycle times in the fleet of equipment, and options of separating the drilling of support holes and installation of the Roof bolts are under investigation".

Lonmin wanted to prove that separating the two activities would have resulted with a cycle time improvement of 1 hour 40 minutes. This was not taken further. However, they would have achieved more if they had done time studies and optimised the same sequential activities, instead of going for the total process change they decided upon.

The objective of the Booysendal Mine trial of the 3108 ADE Roof bolter and the 3108a Roof bolter implementation was the same; it was planned that the bolter should install a 1.8m bolt in 8 minutes. The only difference between the two phases was that the trial phase was first to proof if the 3108 Roof bolter can mine consistently at 1900 mm stoping width.

The trial stage results are mixed as these are the combined results of the GHH trainer/Operator and Booysendal Operators. Bolt installation times achieved during the trial averaged at 7.45 bolts per hour translating to 8.0 minutes per bolt. While this was a phenomenal and world class performance, the reality is that it was done under a controlled environment. The trial section was given to GHH and the author chose an area with the least geological features as the test site.

As soon as the implementation started, the 3108a was tested under a ‘real/harsh mining’ environment (i.e. production pressure, geologically complex, mine machine Operators not GHH trainers, effect of overall equipment efficiencies), the results were different. The average installed bolt time was 5.7 bolts per hour, translating to 10.54 minutes per bolt. Booysendal Mine did not achieve its own target of 8 minutes per bolt as planned. However, the actual results compared fairly well with the Bathopele and Lonmin Mines results of 6 bolts per hour (10 minutes/bolt).

From the time studies conducted in this research, two areas were identified within the bolting cycle where improvements could be made to achieve the 8 minutes per bolt.

Although the 8 minutes was not achieved, the research at this stage gives a credible benchmark across the South African Mining industry to have firm and confirmed Roof bolter performance figures, especially when doing mechanised mine feasibility studies, or when intending to change from auto rock machine bolting to mechanised bolting. It also gives OEM machine designers actual figures to work with as a base for their design assumptions rather than relying solely on simulated performance figures.

5.2 Human factors affecting the 3108a performance and why

Through the root cause analysis method (i.e. the Ishikawa diagram in **Figure 4a**) it was realised that Operators and maintenance staff wanted the 3108a project to be a success, but they had concerns regarding the personal impact, implementation involvement and benefit realisation. Before investigating what other researchers have concluded with regard to the people side of a technology Roll-out, it must be stated that the Operators at Merensky Shaft are new to the industry. Although their years of service in the industry ranges between 1 – 12 years, all of the 3108a Roof bolter Operators had 4 to 14 months experience since being appointed to the Roof bolter Operator occupation.

Pickering (2004) outlined the following critical issues with regard to people in technology implementation projects:

(i) People at all levels in an organisation must see the benefits of the technology for themselves.

(ii) Training people in the application of a new technology requires a professional approach.

(iii) People must be educated in the concepts on which the new technology is based.

(iv) Unanticipated consequences during the introduction of new technologies can lead to failure of the technology transfer process.

(v) Champions are essential at all levels in the mining hierarchy. They must be identified early and adequately supported by their superiors and the staff involved in the technology transfer. In **Figure 4k**, it can be seen that the Merensky Mine Overseer has taken seriously what Pickering (2004) asserts in his research paper.

(vi) The introduction of new technology, although a complex social process, can and must be carefully planned and managed. The structured Roll-out process in **Appendix** 1 and the A3 process in **Appendix 2** show that 3108a implementation team really took heed and acted as per the guidelines given by Pickering (2004).

(vii) It is easier to transfer incremental change than it is to transfer technologies which result in significant changes in the work practices. Evidence to this is that the trial was used to introduce the 3108 ADE as is, then, with the upgrades requested by Operators were incorporated in the modified 3108a, it was not a totally new machine requiring Operators to be trained from scratch.

Vogt and Hattingh (2015) explain the following with regard to technology Roll-out in the platinum mines; miners in the platinum sector have often commented on the relative ease of introducing new technology on the Eastern Limb of the Bushveld Complex compared with the Western Limb. Miners on the Eastern Limb are usually new from local communities, with no previous history of mining. They have no choice but to learn, as they have no prior experience. Companies can introduce new technologies because the workforce is willing to learn.

What the implementation team did when they realised the Operators were fairly new to the production environment, was to find a theme that would automatically appeal to them when implementing the 3108a machine. The Operators at Merensky Mine are between 24 – 30 years' old, and they are really keen football team supporters. It was realised that if the Operators are to own the 3108a process, then we should give them a football flavour they will relate to even after working hours. It was then that the implementation team brought in the 'soccer role model' theme. The best Operators were compared to local soccer players and consistent performers were compared to international soccer players (Refer to **Appendix 1**).

The people in the Eastern Limb area are highly religious so any theme that is brought in must not be seen to contradict their belief system. The implementation team found the 'soccer role model' angle resonated very well with the Eastern Limb Operators.

When the TPS (Toyota Production System or Lean Manufacturing) principles were rolled out as stated by Vogt and Hattingh (2015) it found Operators and maintenance staff who were willing to adopt the principles and practice them according to the four frames:

i) Performance mind-set

ii) Problem awareness

iii) Solving problems the right way

iv) Developing people through problem solving.

Macfarlane (2001) explains an aspect the Roll-out team needs to take into account is that new technology may bring about new work practices, and to address this properly the implementation team has to actively engage the organised labour. The A3 process actions in **Table 6a** state that some of the KPIs and bonus agreement changes need organised labour to be consulted and for new agreements to be structured and signed off.

Macfarlane (2001) raises the safety and business training part for the Operators over and above the technical competence. Macfarlane states, "A critical component of whether technology is appropriate is the issue of competency and skill level. An early imperative is to assess the profile of the workforce required for the technology or new work method, and to provide selection procedures and training which will allow the development of the required competencies identified during work cycles, task listing and structure, to be done timeously.

The training requirement should address the issues such as:

- Competency to operate the technology
- Understanding of the business and contribution to it by productive and efficient work
- Understanding of any risks and hazards associated with the technology
- Adequate levels of cross-skilling, commensurate with the work system."

Issues raised by Macfarlane (2001) were addressed in this research through structured Roll-out posters, A3 report findings and the resulting action plan, physical on-site observations to address machine and training gaps. Lastly, it was also addressed through communicating results to Operators and recognising the outstanding performers.

Botha (2016) identifies that the integration of mining and Engineering staff targets can yield positive results. Addressing integration is a key challenge for improving productivity and requires an approach that breaks down the silos and adopt an end-to-end perspective. Achieving this will require empowering the workforce, finding new solutions to existing problems, and using data and technology to support this.

Catchpole and Robbins (2015) states that PwC (PricewaterhouseCoopers) analysis has argued mining employees are the key to the biggest productivity gains; the research identifies synergy between mining and mineral processing teams.

The author confirms the same can be true for synergy between mining and engineering personnel at mine operational level.

Catchpole and Robbins (2015) identifies significant productivity gains will be realised if work practices are improved. The Booysendal Mine implementation team also realised that the SOPs and minor machine modifications can yield significant productivity gains if addressed on time.

Here are extracts from Catchpole and Robbins (2015) that supports a focus on systems rather than solely on people: “Productivity is heavily dependent on the way people act. A better-rated piece of equipment might deliver 5 – 10 percent output improvement and require additional capital, but, changes in the work practices can, in our experience, deliver 20 percent + gains, often at little or no cost. (PwC 2014, p 2).

Recent mining industry productivity analysis focuses on the central importance of people in connecting the various elements of mining activity so that potential improvements are realised.

KPMG analysis notes the opportunities in integration of mining and mineral processing activities. It argues that integrated production planning brings together both the mining and processing functions to create greater efficiency through better governance, planning, communication and execution, viewing the mine’s value chain as a single system. (KPMG 2013, p 11). It discusses the central role of careful planning and the development of performance measures and performance monitoring to achieve the desired behaviours on the ground.

The previous two paragraphs show that if the Booysendal implementation team continually does physical on-site observations, and amends the SOPs to identified processes, it could yield long-lasting performance solutions.

Figure 4h shows that through structured system and process enhancements, an 18% improvement in square metres produced has been achieved.

5.3 Mining Process gaps and mining systems issues identified

It was identified early in the research, in sub-section **4.1** under the A3 countermeasures that physical observations had to be done to optimise the bolt installation process. In subsections **4.3** and **4.5** observations and time-studies were done, and it was also realised there is potential to improve the bolt installation cycle time by 2.0 minutes.

Areas identified that can be improved are:

(i) Reduced average duration to move and set up machine from installed bolt to collaring of hole 2

(ii) Reduce duration to position boom

What the implementation team observed is that the support Standard Operating Procedures (SOPs) of another OEM Roof bolter on the mine were taken as is without assessing the impact on the actual practical operation of the 3108a Roof bolter. The team concluded that an issue-based risk assessment and drafting of ‘fit-for-purpose’ SOPs would be done to align the following SOPs:

(i) Marking off Roof bolts support grids

(ii) Sequence of Roof bolts installation

(iii) Marking off Cable anchors

(iv) Sequence of Cable anchors installation

Over and above the support installation process optimisation through work practices change, the author scrutinised the research articles of highly efficient mechanised mining operations to understand what areas of systems optimisation were looked at and how was it done. The following few paragraphs will be unpacking practical examples to be emulated at the Booysendal Merensky Shaft.

According to Dunstan et al. (2006), Rio Tinto Aluminium introduced Lean Manufacturing to complement an existing Six Sigma business improvement program and to achieve continuous improvement activities at a workplace level.

In a short time, Lean has achieved good and sometimes spectacular results improving productivity and efficiency at all sites, including the mining site. The author mentioned this Lean process to the implementation team and they were sceptical as some of the team members have been on the mines for more than 25 years and they have seen impractical processes being imposed on mining teams by Consultants without success. However, in this case, the team, although sceptical, looked at how the Rio Tinto team applied Lean practically.

Dunstan et al. (2006) explains what was done at Northparkes Mines as follows: "Development of underground excavations follows a cyclical process that is repeated every 12 to 24 hours. The development cycle, undertaken by a crew of five to six miners, consists of:

(i) Drilling a pattern of blast holes into the rock face

(ii) Charging blast holes with explosives and firing

(iii) Mucking out broken rock

(iv) Supporting the new section of the tunnel with ground support elements including meshing, rock bolts and spray-on concrete".

Lean was called in to control and improve advance rates which vary between three and five metres per cycle. A key feature of Lean is its ability to manage a large number and a variety of issues simultaneously, using visual prompts to assist the communication of issues.

A Lean information centre was established in the project's shift change centre. The metrics the development team chose to track were:

- Safety
- Environment
- Employee availability
- Cycle completion times
- Weekly development targets
- Utilisation of resources

The Merensky Shaft Operational Technology Champion, Nigel Reeder sprang into action and changed the traditional waiting place to a Lean information centre. The underground waiting place was now used by both the mining team and the maintenance staff to jointly review and assess production progress both at the start and end of a shift.

The Merensky team decided they will track the following metrics with regard to 3108a implementation:

- Number of bolts installed by an Operator per shift
- Number of bords supported by an Operator per shift
- Time the machine started bolting
- How many faces were blasted due to bolter bolting on time.

The implementation team was amazed by the level of interest and participation that came about at the Merensky Shaft just from turning the waiting place from a traditional gathering centre into a Lean Information centre. However, one needs to understand the main 'draw point' of this system lies in the visual Management of information. For example, Nigel Reeder took photographs of all 3108a Operators and recorded the number of bolts installed per shift next to their photographs.

It was a magical innovation as every Operator wanted to see outstanding results next to his photograph. Performance focused conversations started emerging between Engineering staff and the Operators on how they could get better results than the previous shift and at the end of shift they debriefed on their agreed actions.

Yingling, Detty and Sottile JR (2000) explains the main difference between a traditional production control using push system used at mines versus a pull production control using a just-in-time system. The author first studied the principles brought forward by Yingling et al. (2000) and then drew up a mining customised pull system. It produced outstanding results. Here are the principles as set out by Yingling et al. (2000):

(i) Traditional production control that is utilised at mines is push. In such a system, work is scheduled by initiating the job at the beginning of the production sequence. The job orders respond to committed or anticipated delivery dates and the timing calculation involves an estimate of the production lead times.

(ii) In contrast, just-in-time systems employ a pull production control. Pull differs from push in that jobs are authorised, not scheduled. The authorisation is often communicated in the form of a Kanban card.

First, the definition of a ‘workstation’ in a pull system differs from case to case. A group of sequential operations in a continuous flow would typically be treated as a single workstation in a pull system and a secondary production control system would be utilised between the operations within the workstation.

Second, variants of this system are available for operations that, because of extensive setup requirements or process operating characteristics, must produce in large batches. Called signal Kanban systems, the production authorisation is sent when inventory of a particular product drops below a particular level.

With the above principles in mind, the implementation team customised a Kanban-type card system used between miners at the start of shift. The miner from the previous shift would write all the activities that have been completed in a formalised card, detailing bords that have been cleaned, supported and drilled to be charged up. This information is co-ordinated by the section Mine Overseer at the start of the shift and the number of bolts installed per shift is assessed.

This simplified activity authorisation system not only checks the effectiveness of the support installation process, but it also guarantees the mining cycle optimisation as the mechanised mining process execution is cyclical and sequential.

5.4 Correlation of stoping width and dilution

Throughout the period of this study, the planned stoping width of 1.9m was not achieved. It was identified as at July 2016 that stoping width still needed to improve by 9cm. By May 2017, instead of improvement, we had a further deterioration of 28cm. The 37cm overbreak was due to hanging wall challenges on the low wall side. This overbreak resulted in the achieved shaft head grade consistently staying between 2.39 – 2.42g/ton. This dilution challenge meant that since the start of the Merensky Shaft Project, the planned shaft head grade of 2.55g/ton was not achieved. The dilution challenge ends up negatively impacting the profitability of the project. It is critical that this issue is addressed.

Besides the hanging wall challenge on the low wall side of the bords, it was realised that there will always be two bords in the rig section of 9 bords that will be mined at 2.5m mining height. The first bord to be mined at 2.5m within the section is the belt/tip strike drive to ensure conveyor infrastructure installation. The second one is the first bord above the belt strike drive to ensure transportation of bulk infrastructure into the section.

To maintain the profitability of the Merensky Project, the stoping width planned target stayed at 1.9m with the two bords mined at 2.5m. This could be done by mining the other seven bords between 1.8 – 1.7m stoping width (See **Appendix 4** to understand how this is a realistic, achievable target). It can be seen that in **Appendix 4** stoping mapping reports there are proven instances where the low wall side was between 1.6 – 1.8m, and the high wall was mined between 1.8 - 2.0m. The actual stoping width achieved here proved that mining between 1.7 to 1.85 m is realistic and achieved frequently in some of the bords at the Merensky Shaft.

5.5 Effect of 3108a utilisation on mining cycle

Mid-year results of bolts installed per shift shows a shift from 50% to 67% for the 19 - 42 bolts. Already by mid-year the achieved square metres are above the planned 1 900 due to 2.5 bords supported per shift.

The December 2017 forecast based on the actions planned in **Table 6a** shows that the 19 – 42 installed bolts category will be standing at 84%. This forecast is based on incremental planned actions.

When completed, this will result in the planned 3 bords per shift. Six bords blasted in a day will yield a total of 2 566m² achieved per month consistently, compared to the desired 1 900m². What is fundamental to note here is that Lonmin achieved 2 400m² per month consistently in an XLP system with two suites of equipment because the XLP mining system still required development to be done with LP equipment.

Now, Booysendal Mine has already achieved the 2 401m² and it is planned to achieve 166m² above this level with a single suite of LP equipment. Many mechanised mining implementers fail to take suite requirement into consideration when deciding between XLP and LP method, so a fair comparison is not made before the Roll-out of new systems.

5.6 Residual 3108a challenges

The remaining challenges that will need to be considered to further optimise the 3108a implementation over and above the **Table 6a** actions are:

- Positioning of boom

  Moving the machine from one completed hole and positioning the drill feed/or turret over the new marked position to be proved to vary significantly from one to another, at times having 4 minutes difference. This is the area that provides a significant chance to improve in order to achieve 8 minutes per bolt from the current average of 10.54 minutes.

- Laser or camera

  This also has to do with moving the machine from one hole to the next and positioning the Drill feed on the target. Operators suggested that a camera or lasers be looked at in order to make it easy to position on target.

- Capsule gun to insert resin into the drilled hole

  Other OEM Roof bolters at Booysendal Mine have resin shooting capsule guns. The GHH machine does not have this feature due the length of capsules used at Merensky Shaft. Investigate the machine mounted compressors with the capability to shoot 500mm – 700mm resins. This will eliminate the manual handling of resin capsules.

- Critical spares availability and construction of underground satellite workshop

  GHH need to consider setting up a warehouse in Lydenburg or Steelpoort. This warehouse must be better resourced to ensure machines don’t wait unnecessarily for spares. Also, an on-site critical spares list is to be drawn up to ensure items are kept in stock. A satellite workshop is to be planned and be blasted on time while advancing the production faces. This will improve the MTTR (mean time to repair) units after breakdown is reported.

5.7 Conclusion

It is significant to note in Chapter 5 that the results in **Table 8** can be used by OEMs, Strategic Planning teams and Mining Fund Analysts to benchmark when doing Equipment selection, Production Optimisation and Mine Efficiency Analysis.

This chapter further unpacked how the people/human issues identified in **Figure 4a** were addressed and how the method of addressing these issues confirms or contrasts what other industry studies have revealed. The modus operandi of addressing the people issues was further reinforced/affirmed by Lean or TPS tactics used in the industrial manufacturing sector.

6 CONCLUSIONS, RECOMMENDATIONS AND RESEARCH OPPORTUNITIES

6.1 Conclusions

The introduction of new technology, as in the case with Roof bolter 3108a, although a complex social process, can and must be carefully planned and managed. The Structured Roll-out process in **Appendix 1** and the A3 process in **Appendix 2** show that 3108a implementation team really took heed of the guidelines given by Pickering (2004), and acted accordingly.

The 3108a technology transfer route followed by the implementation team delivered the following results when linked to the study objectives and questions:

- What worked well in this case study was the use of Lean visual indicators, the use of visual representation of key production performance data was well accepted by Operators as means to communicate and improve their performance.

- The implementation team realised early when the project started that the key feature of Lean is its ability to manage a large number and variety of issues simultaneously using visual prompts to assist in communication of issues. This was done successfully through use of posters (e.g. **Appendix 1**) and the performance tracking boards at underground waiting places/information centres.

- The value of observational methods used in this case study is that it provided answers to ‘what’ phenomena occurred, particularly when Operators are involved in the process, along with insights into ‘why’ it occurred. Through observational methods the implementation team understood the exact operational gaps that led to failure to consistently achieve 8 minutes per installed bolt. From the time studies conducted in this research, two areas were identified within the bolting cycle where improvements could be made to achieve the 8 minutes per bolt.

- The results of time studies combined with experience gained from observational methods provided the implementation with practical, proven solution to address the gap between the planned 8 minutes per installed bolt and the actual achieved 10.54 minutes per bolt. The fusing of time studies and observational tools provides a ‘Solving problems the right way’ mindset from the Operators right through to the Project Champion.

- The A3 process followed in this case study allowed a stepped approach that recognised the unacceptable performance level that the 3108a Roof bolter initially delivered. The process allowed two main implementation stages stating detailed actions that could be tracked to realise first the 1750 m^2/month and then ultimately 1900 m^2/month. Through the stepped approach in this case study we managed to deliver exceptional production results six months ahead of planned timeframe, in May 2017 we surpassed 2400 m^2.

It must also be stated that there were failures in the implementation of the 3108a bolter. The first failure as the fact that the 1900mm stoping width was not achieved. Second failure, instead of achieving the planned 8 minutes per bolt the Operators were consistently achieving only 10.54 minutes per bolt.

The initial plan was to increase the number of times Operators installed 35 – 42 bolts per shift from 3% to 15% by December 2017. Mid-year results show the final results will be 9% in this category.

The planned increase in the 19-34 bolts per shift was from 47% to 60% by December 2017. Mid-year results show the final results will be 75%.

The conclusion the author reached is that the number of times Operators achieve 19-42 bolts per shift will improve from mid-year achieved results of 67% to 84%. This will have a positive impact on the operation achieving its planned mining cycle on shift to shift basis. As a result, the 2401m^2 achieved in May 2017 will be repeated and even surpassed as of December 2017 when all the actions identified in **Tables 6a** and **6b** have been completed.

Although the 8 minutes per bolt was not achieved, the research confirmed the 10 minutes per bolt achievements of both Lonmin and Anglo American Platinum mines. Fundamental areas of improvement for achieving the much needed 2 minutes improvements were identified.

The results of this study can be used by Project Planning teams when doing Mine Feasibility studies for Mechanised underground mines, and operational mines

Engineers when convincing their Executives on what will they achieve if they convert from conventional Roof bolting methods to mechanised methods.

The study also gives OEM machine designers actual figures to work with as a base for their design assumptions, rather than relying solely on simulated performance figures.

6.2 Recommendations

Through physical observational methods and time studies conducted it became clear that 3108a technology still required some minor modifications which will be listed below. Before dealing with further modifications it must the stated that it became evident that for successful technology transfer an experienced implementation team must assess and evaluate the appropriateness of the current SOPs and its impact on the Roll-out. In this case study it was identified that there were two to three SOPs that had to be amended.

Challenges experienced when drilling and installing 4.5m long anchors, as explained in sub-section **4.4**, will require a separate study. Through interrogating the OEM Engineers and the mine Operational team I gathered suggestions and areas that can be recommended for this study. OEM Engineers directed that GHH Roof bolters designers must look at:

- Incorrect chuck adaptor for the 1 1/8 steel
- Feed pressure is too high resulting in a curved hole making retrieving the rod difficult

The Operational team recommended the following actions be effected:

- Thrust pressure

  An OEM specialist to come on-site to check the pressure and if necessary adjust it to ensure we don’t have over thrusting. To reduce breakages on the Drill steel, we need to ensure the cutters maintain the correct hole diameter. In order to do that, we need to reduce the wear on the outer edge of the cutters. Excess wear is caused by over thrusting. We are monitoring the results.

- Correct chuck adaptors are also on site to reduce Drill steel breakages and we addressed the extraction of the Drill steel. The Drill steel should be rotated on extraction to ensure ease of extraction. Clips have been reintroduced to aid with this. A slide hammer will also be issued to aid in the extraction of broken steel.

6.3 Further research opportunities

This study has proved that the 3108a bolter can deliver a highly efficient system which can consistently deliver above 1900m² per month. However, earlier in the report it was made clear that if the Merensky operation is to remain profitable and appealing to investors, the system must also reduce dilution.

The hanging wall Geology on the low wall side poses a significant risk to the dilution reduction target. The author suggests two separate studies be undertaken to solve this.

The first study will focus on understanding the hanging wall jointing in the Booysendal Lease area. There are no mines mining the Merensky reef in the Eastern Limb. As a result, there are no written technical papers on this subject, so this study will have to start from scratch.

The second study will use the hanging wall mapping results to design a blast round and its matching explosives for the Merensky hanging wall strata.

Booysendal Mine UG2 Shaft is currently rolling out a support system that combines both a primary and secondary support function through a single unit. On completion of this project, the results should be analysed and a ‘fit-for-purpose’ support system, similar to the one of the UG2 Shaft, should be adapted to the Merensky Shaft.

In sub-section **4.4**, the challenge posed by long anchors drilling and installation was identified. This challenge results in counter-productive behaviour amongst Roof bolter Operators as they start planning with the Drill rig Operators to open the stoping width above the planned 1.9m.

The author recommends the planned actions in sub-section **6.2** be completed and closed out while the flexibolt support system project is in progress at the UG2 Shaft.

REFERENCES

Andrews, M. and Pickering, R.G.B. (2010). A systematic approach to the optimisation of extra low profile (XLP) mine productivity for narrow reef platinum mines. *The 4th International Platinum Conference, platinum in transition 'Boom or Bust',* The Southern African Institute of Mining and Metallurgy, pp 267 – 276.

Botha, W. (2016, February). *Towards a more productive mining sector*. Africa Mining and Metals Leader, EY Johannesburg. Retrieved February 19, 2017, from http://www.ey.com/za/en/newsroom/news-releases/news-ey-towards-a-more-productive-mining-sector

Catchpole, M. and Robbins, W. (2015). *The productivity challenge*. The AusIMM Bulletin, Retrieved February 19, 2017, from https://www.ausimmbulletin.com/feature/the-productivity-challenge/

Dunstan, K., Lavin, B. and Sanford, R. (2006). The application of Lean Manufacturing in a Mining Environment, International Mine Management Conference (Melbourne, Vic, 16 – 18 October 2006), pp 145 – 157.

Department of Health and Human Sciences, (CDC), (2008). Data Collection Methods for Program Evaluation: Observation, Evaluation Briefs number 16. Retrieved March 12, 2017, from Centres of Disease Control and Prevention, https://www.cdc.gov/healthyyouth/evaluation/pdf/brief16.pdf

Egerton, F.M.G. (2003). The mechanisation of the UG2 Mining in the Bushveld Complex, *The South African Institute of Mining and Metallurgy, SA ISSN 0038–223X/3.00 +0.00. Address presented at the Annual General Meeting on 11 August 2004.*

Franklin, C.E. (2008). *Optimisation of a Mechanised Platinum Mining Section*, Pretoria: BSc (Industrial Engineering) Project, University of Pretoria.

Fourie, F., Valicek, P., Krafft, G., and Sevenoaks, J. (2014). Narrow reef mechanized mining layout at Anglo American Platinum. *The 6th International Platinum Conference, 'Platinum–Metal for the Future',* The Southern African Institute of Mining and Metallurgy, pp 261 – 279.

Goldratt, E.M. (2004). The Goal: A process of Ongoing Improvement, First Published in 2004 by Gower Publishing (I used the hardcopy for reference).

Hattingh, T.S., Sheer, T.J., and du Plessis, A.G. (2010). Human factors in mine mechanization. *The 4th International Platinum Conference, Platinum in transition 'Boom or Bust',* The Southern African Institute of Mining and Metallurgy.

Jordaan, J.T. (2002) Bord-and-pillar mining in inclined orebodies, *The South African Institute of Mining and Metallurgy, 2003. SA ISSN 0038–223X/3.00 +0.00. First presented at SAIMM Student Colloquium:* Oct 2002.

Kawulich, B.B. (2005) Participant Observation as a Data Collection Method, Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, Volume 6, No. 2, Art. 43

Leicht, R.M., Hunter, S.T., Saluja, C. and Messner, J.I. (2010). Implementing Observational Research Methods to Study Team Performance in Construction Management, Journal of Construction Engineering and Management, pp 76 – 86. Retrieved March 12, 2017, from

http://www.qualitative-research.net/index.php/fqs/article/view/466/996#g7

Macfarlane, A.S. (2001). The implementation of new technology in Southern African mines: Pain or panacea, The South African Institute of Mining and Metallurgy*, 2003. SA ISSN 0038–223X/3.00 +0.00. First presented at SAIMM Colloquium:* Mining Methods and occupational hygiene for the new millennium, Feb 2001.

Menasce, J.R., and Thorley, S.C. (2004). Design constraints on trackless mining equipment in low and extra low stope hard rock mining. *International Platinum Conference 'Platinum Adding Value',* The South African Institute of Mining and Metallurgy.

Merriam, B. (1998). Qualitative Research: A Guide to Design and Implementation, Chapter Three Methodology, 4th Edition, Kindle Edition

Neingo, P.N. (2014*). Drivers, measures and rewards for productivity and financial impacts/benefits in the mining value chain at Bathopele, Kroondal and Mototolo Mines: An investigation of impacts from short term planning to mill*. Johannesburg: MSc Thesis, School of Mining Engineering, University of the Witwatersrand. Retrieved February 13, 2017, from http://wiredspace.wits.ac.za/bitstream/handle/10539/17638/MSc%20Project%20Report%20Neingo%20Paskalia%20Ndapandula.pdf?sequence=2&isAllowed=y

Nong, S. (2010). *Review of Successes and Failures of Mechanisation Trials on Platinum Mines of the Bushveld Complex*. Johannesburg: MSc Thesis, School of Mining Engineering, University of the Witwatersrand. Retrieved February 08, 2017, from http://wiredspace.wits.ac.za/bitstream/handle/10539/10681/S_Nong_MSc_Research_Report_10Dec2010.pdf?sequence=1&isAllowed=y

Pickering, R.G.B. and Leon, F. (2008). The implementation of mechanized breast mining and the development of XLP equipment. *Third International Platinum Conference 'Platinum in Transformation',* The Southern African Institute of Mining and Metallurgy, pp. 269 – 275.

Pickering, R.G.B. (2004). The optimization of mining method and equipment. *International Platinum Conference 'Platinum Adding Value',* The South African Institute of Mining and Metallurgy, pp 111 - 115

Strong, G., Terblanche, C., Göhre, B.J. and Andrews, M. (2006). A symphony of collaboration between mining and engineering. *International Platinum Conference 'Platinum Surges Ahead',* The South African Institute of Mining and Metallurgy, pp 121 – 128.

Vogt, D. and Hattingh, T. (2015). The importance of people in the process of converting a narrow tabular hardrock mine to mechanization. *The 23rd International Symposium on Mine Planning and Equipment Selection* (MPES), The South African Institute of Mining and Metallurgy, pp 265 – 274.

Valicek, P., Krafft, G., Strydom, S. and Fourie, F. (2014). Management operating systems to optimise mechanisation within Anglo American Platinum. *The 6th International Platinum Conference, 'Platinum–Metal for the Future',* The Southern African Institute of Mining and Metallurgy, pp 247 -259.

Valicek, P., Fourie, F., Krafft, G. and Sevenoaks, J. (2012). Optimization of Mechanized Mining Layout within Anglo American Platinum. The Southern African Institute of Mining and Metallurgy. Retrieved February 09, 2017, from

http://www.saimm.co.za/Conferences/Pt2012/1-34_Valek.pdf

Webber, G., van den Berg, A.A., Le Roux, G.G., and Hudson, J.H.K. (2010). Review of mechanization within Lonmin. *The 4th International Platinum Conference, Platinum in transition 'Boom or Bust',* The Southern African Institute of Mining and Metallurgy.

Yingling, J.C., Detty, R.B. and Sottile JR, J. (2000). Lean Manufacturing Principles and their applicability to the Mining Industry. Mineral Resources Engineering, Vol. 9, No. 2., pp 215 -238

APPENDICES

APPENDIX 1: STRUCTURED ROLL-OUT POSTER

GHH Bolter application at the Merensky Shaft

GHH Bolter Application at the Merensky Shaft

NPL needs Merensky reef to blend with UG2 concentrate at the Smelter

Merensky reef also has important minerals such as Cu and Ni

Successful execution of this shaft output will lead to opening up of additional Merensky shafts

We need and value your constructive input, criticism and participation for this Endeavour.

Why is it so critical that we use the GHH Bolter?

The main objectives for introducing the ADE Bolter at Merensky Shaft and related Key Performance Indicators are:

The objective is to produce 1 900 m² at 235 m system face advance in stoping to yield 11 500 tons per rig section at a defined stoping width of 1900 mm.

In order to achieve the desired output as specified per rig section of 235 m per month, the 3108a ADE Bolter must perform as per the following KPIs:

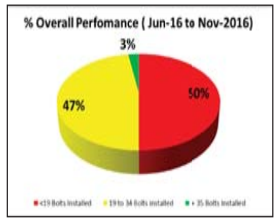
(i) Drill and install a 1.75 m resin applied rock bolt in 8 min.

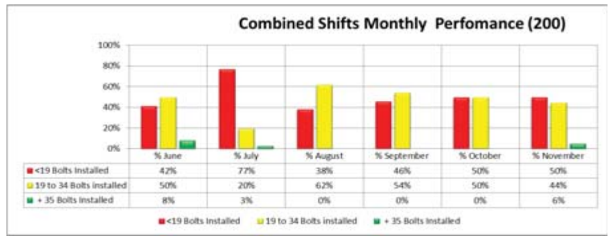
(i) Bolt installation times, including movement between bords, should be in the region of 2 hrs thus allowing for the flexibility of supporting 3 bords in the available 7 hrs face time.

(i) The bolter must be able to install bolts in stoping widths ranging from 1700 to 2000 mm in order to achieve the defined stoping width of 1900 mm.

(i) The bolter must be capable to install hanging wall rock bolts at least 0,5m from the development bord face or sidewall.

From June 2016 to date : What is the actual output per operator?





	% June	% July	% August	% September	% October	% November
<19 Bolts installed	42%	77%	38%	46%	50%	50%
19 to 34 Bolts installed	50%	20%	62%	54%	50%	44%
+ 35 Bolts installed	8%	3%	0%	0%	0%	6%

What is the expected output (i.e. Leagues) for different operator calibre?

League	Output
Premier League	42+ Bolts
First Division League	19 – 35 Bolts
Relegation Squad	Less 19 Bolts per shift

League	Output (three months consistent)
Elite League (EP/ EU / NIG. / CAM. squad)	42 and occasionally touching the 50 mark

Has this expected output ever been done consistently in South Africa?

Table I
The trial XLP mechanized Breast at Waterval

Equipment rating	Planed performance	Actual Feb-Sept 06
Drill rig – holes drilled/shift/rig (rated - 40 holes/hr) (1.5 min/hole; 1.3 m/min)	126 holes/face/shift (21 m face/3.2hrs)	114 holes/face/shift
Roofbolter – 1.6 m bolts/shift/bolter (rated - 6 bolts/hr)	25 bolts/face/shift (21 m face/4.1hrs)	23 bolts/face/shift
Dozer – tons cleaned/shift (rated - 31 tons/hr) 180tons/face blasted – 40% throw blasting (72 tons) = 108tons/face/shift	108 tons/face/shift (21 m face/3.5hrs)	102 tons/shift (21m face/2.0 hrs) 36tons/hr
LHD – tons loaded/shift/LHD (rated - 25 tons/hr) 180 tons/shift blasted + 65 tons dev/shift blasted = 245 tons/shift / 2off LHDs = 123 tons/shift/LHD	123 tons/shift/LHD (Face+ASD/4.92 hrs)	130 tons/shift/LHD (Face+ASD/4.6hrs) 28 tons/hr/LHD 3.2t bucket factor 8 trips/hr
Axcess dev drill rig (ASD) (Raise) Total 2.87 m/shift/4 m = 72% x 4.28 = 3.08 hours/shift Bolting - rated 10 bolts/hr (ASD) (Raise) Total 15bolts/shift/1.9hrs = 72% x 1.9 = 1.37 hrs/shift Total drilling and bolting	39 holes/shift –1.62 hrs 34 holes/shift – 1.46 hrs Total ASD/Rse - 3,08 hrs 6 bolts/shift – 0,72 hrs 5 bolts/shift – 0,65 hrs Total ASD/raise -1.37 hrs 4.45 hrs	80 holes/shift 2,8 hours drilling 13 bolts/shift 1.2 hrs bolting 4 hours drill and bolt

Beat

SA Premier type and World class Elites .....

Before thinking World class elites first crack the SA best record.....

"Best of the Best" : World Class

World Class

How will we know if we have achieved our MAIN GOAL?

Measured parameter	Actual Required
m/month or m2/month per Stoping Section	235m /1900m²
Stoping width/height (S/W)	1900 mm
Grade	2,85 g/ton
Tons/month per Stoping Section	11 500 tonnes
Bolts per operator per shift	42
Bords Supported per operator per shift	3

APPENDIX 2: A3 REPORT OF THE GHH BOLTER IMPLEMENTATION AT MERENSKY SHAFT

Theme : 3108a Implementation at Merensky

W Kekana 9512907N

NORTHAM BOOYSENDAL

Background

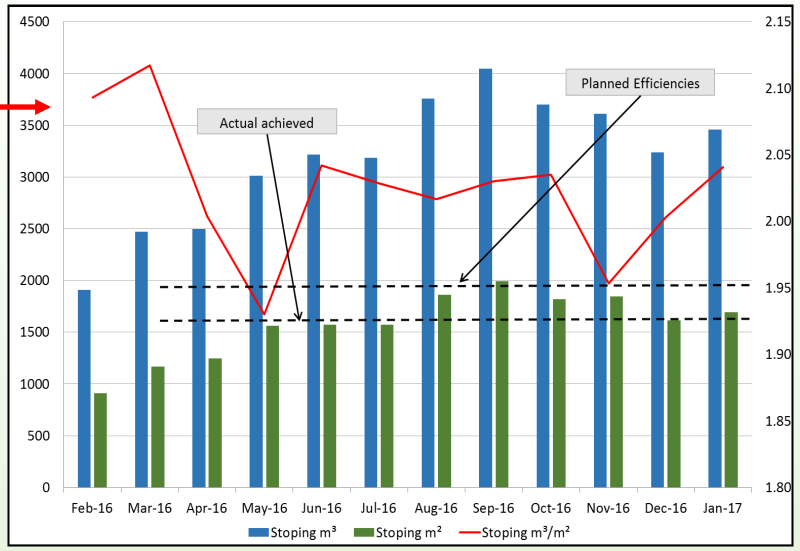
1. Company Goals FY 2022

- Improved Safety = reduced exposure to risky zones
- Increase annual output to 75 kozpa 4E
- Crew performance per section 1900 m²
- Lower cost per ton (ZAR 500.00/ton)
- Modular roll out of new mechanised shafts

2. Booysendal Platinum Goals FY 2017

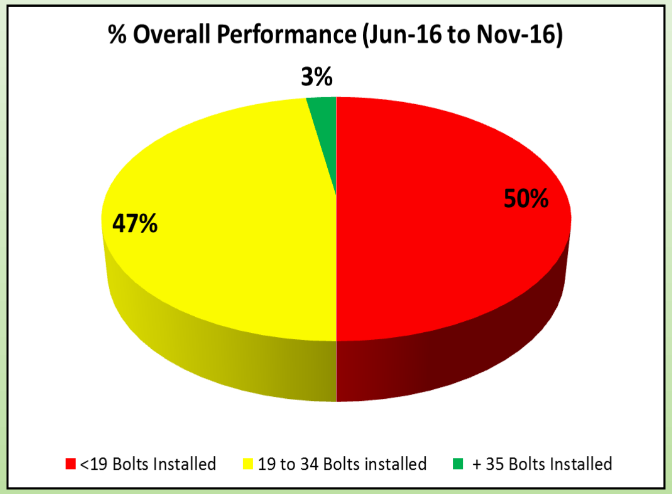
- OPEX ≥ ZAR 15,000.00/4E oz
- Increase productivity by 17,25% (Current 12 average 1575 m²/crew)
- Maintain stoping width at 1900 mm to control dilution
- Install 42 bolts per 7,5 hours face time
- Complete Mining cycle per shift

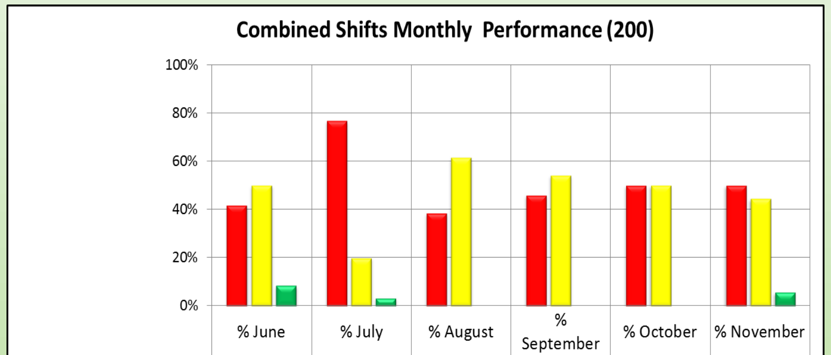
3. Current equipment utilization status



Current Condition

50% of the bolter operators are achieving less than 19 bolts per shift whilst using an upgraded 3108 machine : Is it a machine or operator or process issue?





	% June	% July	% August	% September	% October	% November
<19 Bolts Installed	42%	77%	38%	46%	50%	50%
19 to 34 Bolts installed	50%	20%	62%	54%	50%	44%
+ 35 Bolts Installed	8%	3%	0%	0%	0%	6%

<19 Bolts Installed 19 to 34 Bolts installed + 35 Bolts Installed

Goal

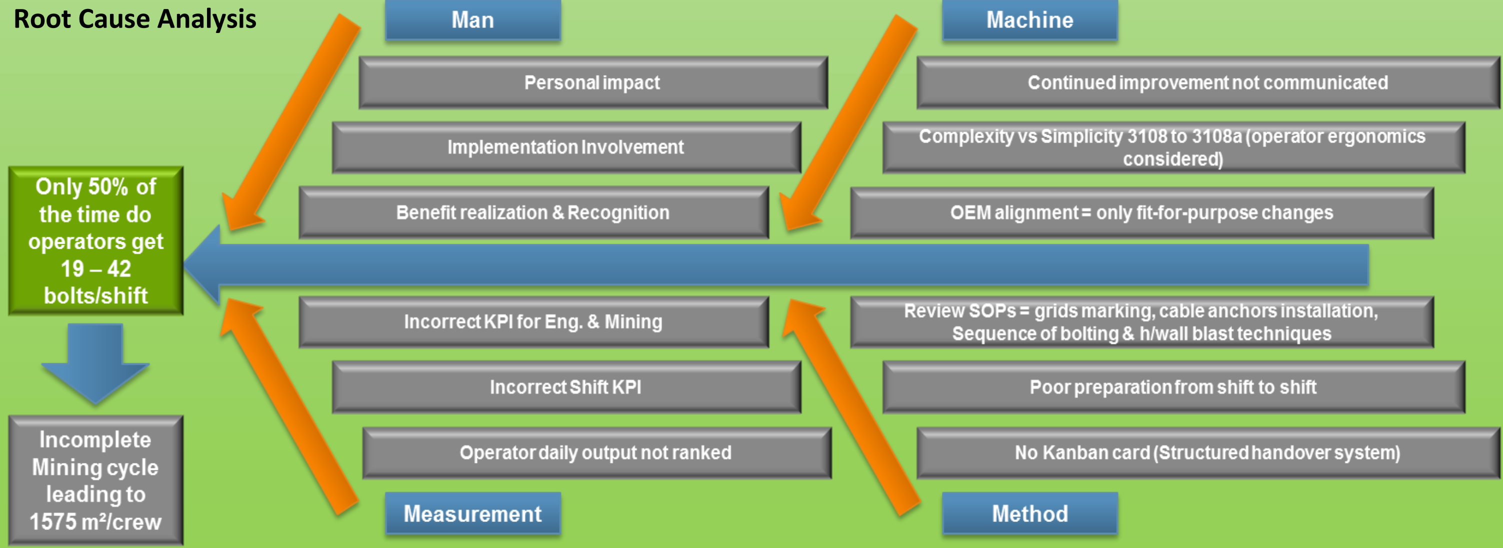
By December 2017:

I. Increase number of times operators get +35 bolts from 3% to 15%

II. Increase number of times operators get 19 – 34 bolts from 47% to 60%

III. Achieve 1900 m²/crew from the current 1575 m²/crew

Root Cause Analysis

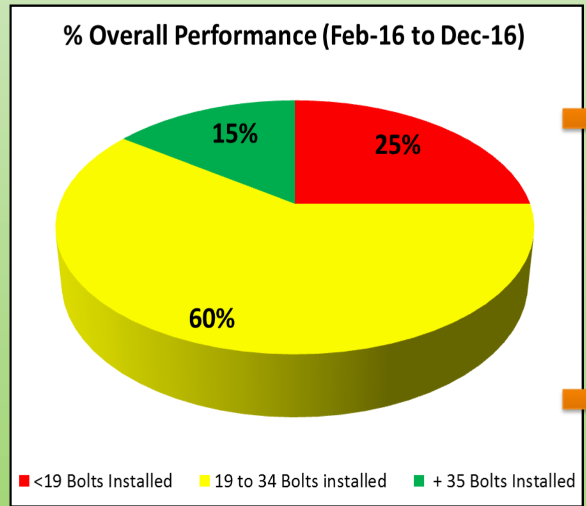


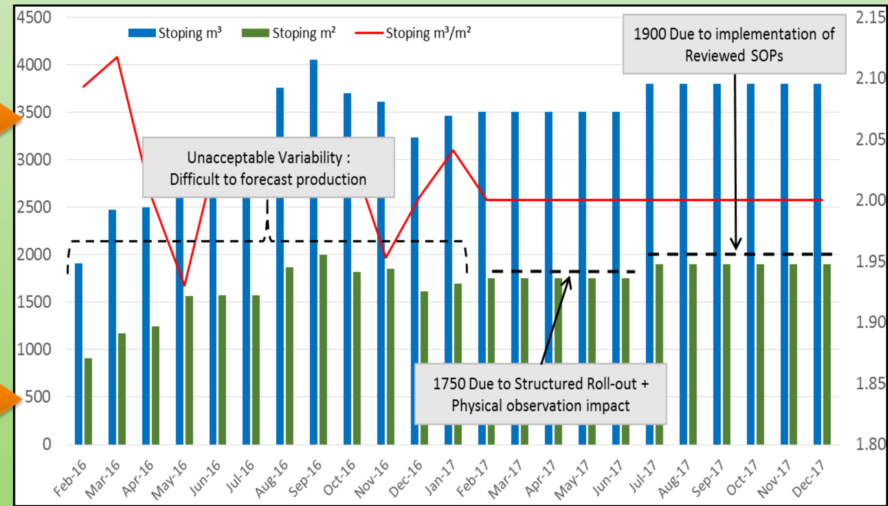
Countermeasures

Suspected Cause	Action Item	Responsible	Due	Finding
i. Personal impact	Structured roll-out involving OEMs, mining crews and maintenance staff	Ops Manager + Impl. team	01/17	Done (Communication poster Appendix 1)
ii. Implementation involvement of operational teams	Structured roll-out involving OEMs, mining crews and maintenance staff	Ops Manager + Impl. team	01/17	Done (Communication poster Appendix 1)
iii. Benefit realisation & Recognition of operators	Visible daily tracked information at U/G waiting place + surface info. centre	Mine Over. Nigel Reeder	01/17	Already started + have recognised 1st Quarter
iv. Incorrect KPI for Eng. and Mining	Measure both for Utilisation and availability not separately	Ops and Eng Mgrs	06/17	We need to get 'buy-in' of organised labour first
v. Incorrect Shift KPI	Measure Cycle completion per shift	Ops and Eng Mgrs	06/17	We need to get 'buy-in' of organised labour first
vi. Operator daily output not ranked	Currently being ranked to set benchmark for bonus scheme specifications	Mine Over. Nigel Reeder	01/17	Already started + have recognised 1st Quarter
vii. Continued improvement not communicated	Physical observations of bolts installation process – not simulations but practical	Impl. Team	06/17	Already started, learnings to be shared in the report
viii. Complexity vs Simplicity 3108 to 3108a (operator ergonomics considered)	Physical observations of bolts installation process – not simulations but practical	Impl. Team	06/17	Early learnings is that modifications or upgrades were not communicated well
ix. OEM alignment = only fit-for-purpose changes	Physical observations of bolts installation process – not simulations but practical	Impl. Team	06/17	Already did a major change to the support canopy' s ducks foot
x. Review SOPs = grids marking, cable anchors installation, sequence of bolting & h/wall blast techniques	Physical observations of bolts installation process – not simulations but practical	Impl. Team	06/17	Already identified three SOPs that are problematic & need for blasting technique change
xi. Poor preparation from shift to shift	Bring a bonus measure component	Ops Mgr	06/17	We need to get 'buy-in' of organised labour first
xii. No Kanban card (Structured handover system)	Formalise shift exchange cards	Ops Mgr	06/17	To be drawn up first

Effect Confirmation

12.5 % improvement over 9 months is quite steep but can be achieved!





Follow-up Actions

Investigation item	Responsible	Due	Status
i. Review SOPs = grids marking, cable anchors installation, sequence of bolting & h/wall last techniques	Wonderboy & Zirk Jansen	06/17	To address the gaps identified during physical observations
ii. Scrutinise the Effect of Soccer 'stars' in recognising best performing Bolt operators (Pull effect or not?)	Wonderboy & Nigel Reeder	12/17	Already recognised the 1st Quarter performers
iii. Using on-board camera or lasers for positioning of the turret over 'target' support holes	Robbin Pearce & Cules Kolbe	12/17	Do proposal to the OEM and Senior Management approval
iv. Visit to Mimosa and Bathopele Mines to learn if they have any further enhancements (SOPs, Bonus system, machine modifications or handover system)	Wonderboy & Nigel Reeder	06/17	OEMs are willing to facilitate these visits as they currently have machines in these operations

APPENDIX 3: EXTERNAL PARTY OBSERVATIONS WHEN THE ROLL-OUT WAS DONE

Wonderboy Kekana

From:	kassie.kasselman@murrob.com
Sent:	Thursday, January 19, 2017 12:01
To:	Wonderboy Kekana
Subject:	Merensky

Wonder,

Herewith the observations and notes made during the Merensky presentation/Interactive session this morning:

- Immediate interest from the team
- All people wanted to participate once the session started
- People started making notes
- Some employees had an astonished face expression when information sharing took place
- Evident visible that the members feel proud to be associated with the project
- When the presenter Mr Kekana related the unknown to the known through the sport initiative /relation new and even more interest could be seen and was clearly visible
- Face expression of proud
- Mr Kekana kept the subject alive through two way communication and making use of different means of communication tools and media
- Attention was kept throughout the session by passion, assertiveness, subject knowledge and being a team player
- Team members agreed that the initiative is in interest of the all and also their families, children and the community
- Body language was of a very positive expression and in acceptance of the information and goals shared
- People showed ownership
- The explanation of the support team and the role all stakeholders and each individual play showed ownership and willingness/passion to participate and willingness to share
- Nodding of heads in agreement when objectives and goals was mentioned
- Smiling faces on agreement

Questions from audience

- Q 1 – Will time studies be conducted
- Q2 – Are all the machines going to be modified
- Q3 – Are the old machines (not modified) also going to be used

Questions from presenter

- **Q 1– What do you think the project mean to us NPL, MRC as a business**
- **Answers –**
- Will give the team development opportunities
- Experience
- Using GHH give MRC and NPL opportunities
- Job / employment opportunities
- Growth and investment for NPL
- New records
- Opportunity to became a world class mine
- Financial revenue through better grade
- **Q 2– Which other Mine did the same project**
- **Answer –**
- Bathopele / Waterfal
- **Q 3 – Which is the leak you think we want to operate in**
- **Answer –**
- **Premier leak**
- **General comments**
- We need Engineering to be sufficient
- Availability of spares
- Distance to workshop
- Standing time of machines
- To improve efficiency

1

- Are you happy as management with the current performance in order to become a World class leader
- What else can we do to assist to become a world class leader
- What other improvement is necessary (Answer from presenter, It will be a continuous improvement process and alignment will be done on intervals – after the CEO went to the market – 6 monthly
- Continuous feedback will be given – and strategy will be aligned - Presenter

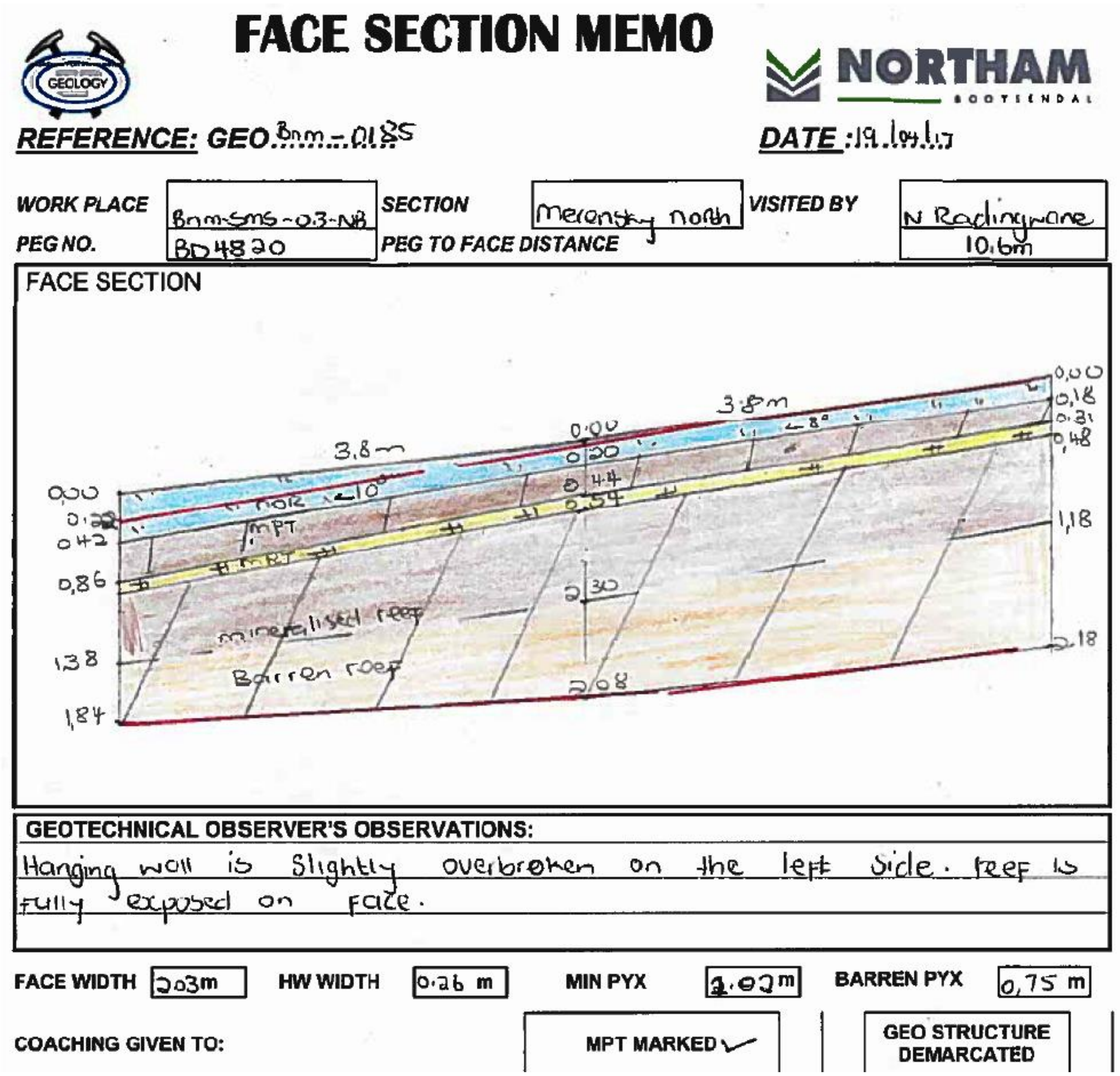
Yours in Safety

Kassie Kasselman
Safety Manager

Murray & Roberts

Murray & Roberts Cementation (Pty) Ltd
Private Bag 3010, Bedfordview, 2008, South Africa
Tel: +2711 201 5181 | Cell: +2782 305 0868 | Fax:
E-mail: kassie.kasselman@murrob.com | Web: www.cementation.murrob.com

APPENDIX 4: EXTRACTS OF MAPPING REPORTS SHOWING 1.9M STOPING WIDTH



FACE SECTION MEMO

GEOLOGY — NORTHAM BOOYSENDAL

REFERENCE: GEO Bnm-0185 DATE: 19/04/17

WORK PLACE	Bnm-Sms-03-NB	SECTION	Merensky north	VISITED BY	N Radingwane
PEG NO.	BD4820	PEG TO FACE DISTANCE			10,6m

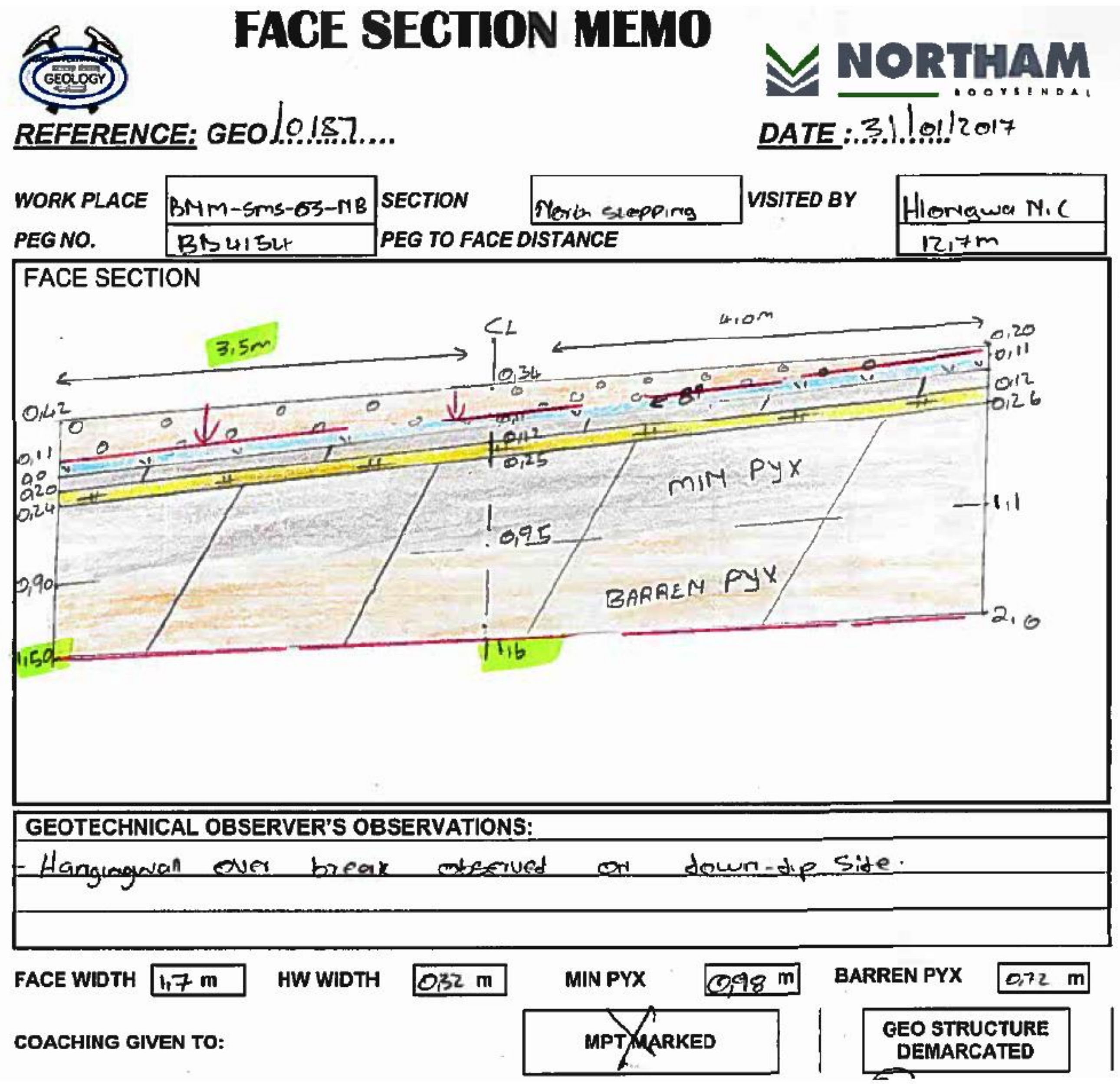
FACE SECTION

GEOTECHNICAL OBSERVER'S OBSERVATIONS:

Hanging wall is slightly overbroken on the left side. reef is fully exposed on face.

FACE WIDTH 2.03m HW WIDTH 0.26 m MIN PYX 1.02m BARREN PYX 0,75 m

COACHING GIVEN TO: MPT MARKED ✓ GEO STRUCTURE DEMARCATED



FACE SECTION MEMO

GEOLOGY — NORTHAM BOOYSENDAL

REFERENCE: GEO 0187 DATE: 31/01/2017

WORK PLACE	BMM-Sms-03-NB	SECTION	North stepping	VISITED BY	Hlongwa N.C
PEG NO.	BD4154	PEG TO FACE DISTANCE			12,7m

FACE SECTION

GEOTECHNICAL OBSERVER'S OBSERVATIONS:

- Hangingwall over break observed on down-dip side.

FACE WIDTH 1,7 m HW WIDTH 0,32 m MIN PYX 0,98 m BARREN PYX 0,72 m

COACHING GIVEN TO: MPT MARKED GEO STRUCTURE DEMARCATED

FACE SECTION MEMO

NORTHAM BOOYSENDAL

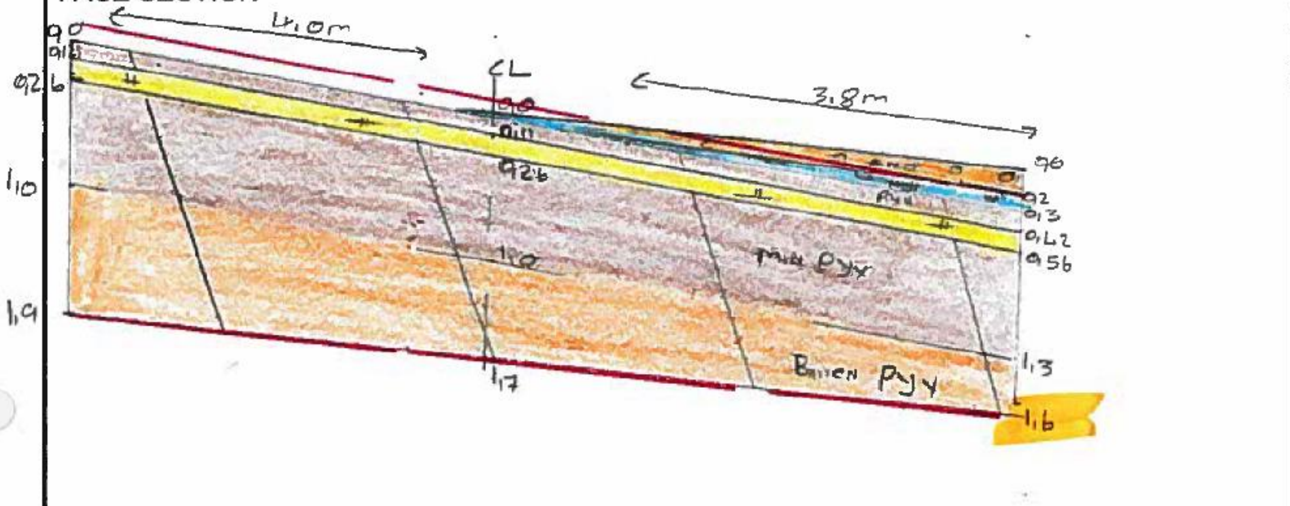
GEOLOGY

REFERENCE: GEO.10184...

DATE: 03/03/2017

WORK PLACE	BNU-SMS-03-SB	*SECTION*	South Stepping	*VISITED BY*	Hlongwa N.C
PEG NO.	BS4101	*PEG TO FACE DISTANCE*			17,7m

FACE SECTION



GEOTECHNICAL OBSERVER'S OBSERVATIONS:

-A 1,6m & 1,7m Stepping height observed ~~from~~ centre line to the down dip side.

FACE WIDTH	1,8 m	HW WIDTH	0,1 m	MIN PYX	1,0 m	BARREN PYX	0,7 m

COACHING GIVEN TO: PHEKO

MPT MARKED

GEO STRUCTURE DEMARCATED

FACE SECTION MEMO

NORTHAM BOOYSENDAL

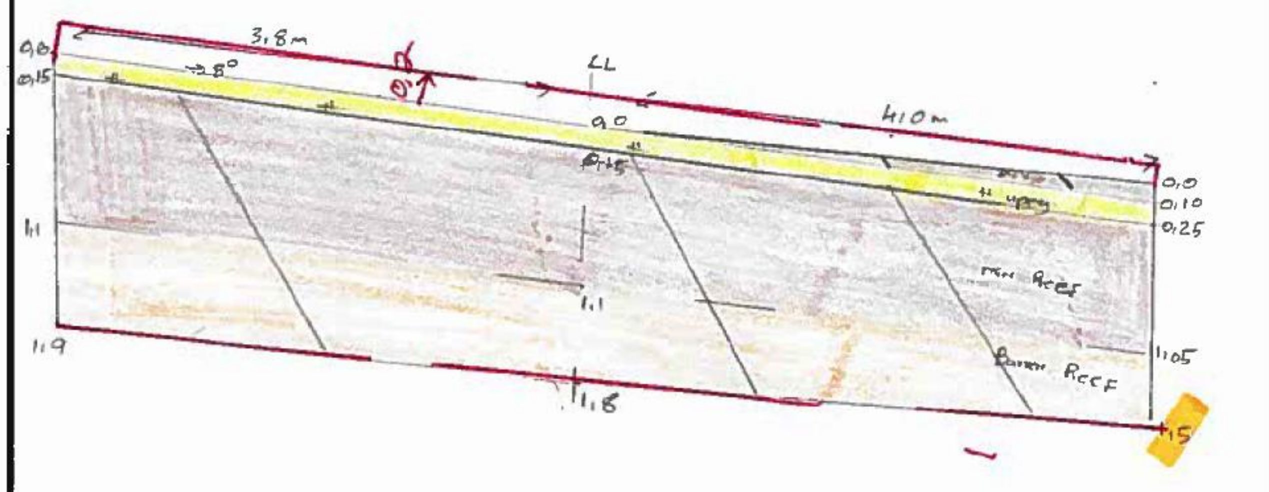
GEOLOGY

REFERENCE: GEO/0183...

DATE: 22/03/2017

WORK PLACE	BNM-SMS-03-SB	*SECTION*	South Stepping	*VISITED BY*	Hlongwa M.C
PEG NO.	BS4101	*PEG TO FACE DISTANCE*			20,7m

FACE SECTION



GEOTECHNICAL OBSERVER'S OBSERVATIONS:

-Reef observed on hangingwall at the face due to poor mining.

FACE WIDTH	1,7 m	HW WIDTH	0,0 m	MIN PYX	1,1 m	BARREN PYX	0,6 m

COACHING GIVEN TO: PHeKo

MPT MARKED

GEO STRUCTURE DEMARCATED

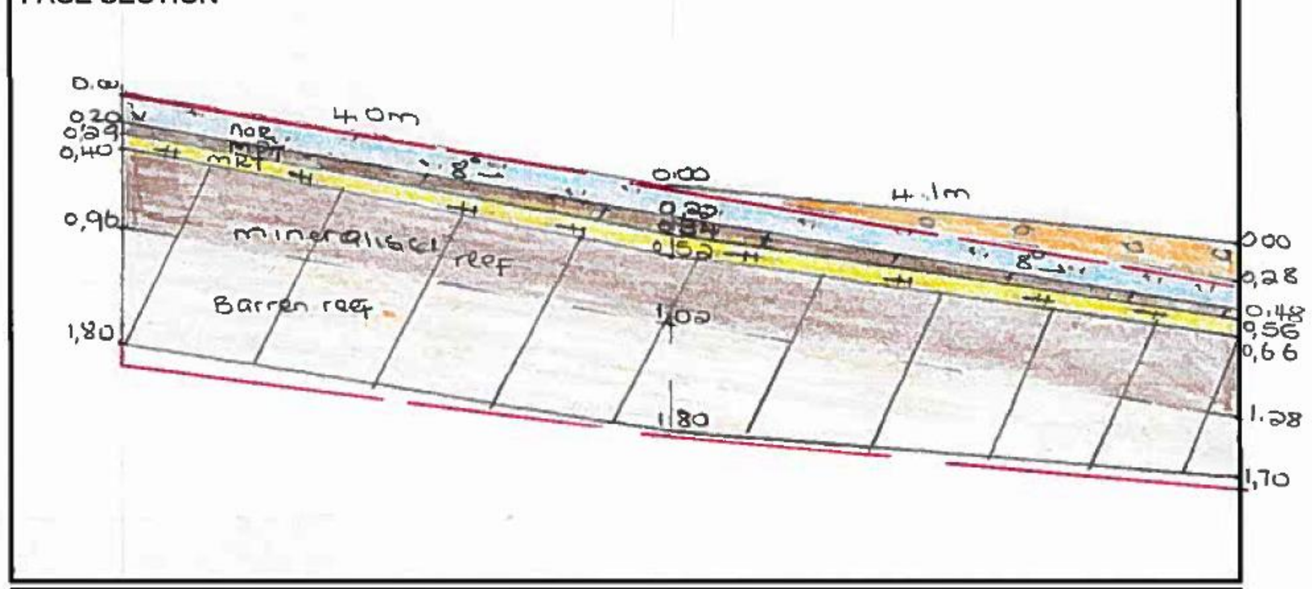
FACE SECTION MEMO

NORTHAM BOOYSENDAL

REFERENCE: GEO. Bnm-226 **DATE :** 08/06/17

WORK PLACE	Bnm-Sms-02-SH	SECTION	merensky South	VISITED BY	N Radingwane
PEG NO.	BD.52	PEG TO FACE DISTANCE			18.6m

FACE SECTION



GEOTECHNICAL OBSERVER'S OBSERVATIONS:

Hanging wall overbreak on the down-dip Side (right Side) is observed
Pillar overbreaking by 0.1m on the right side is also Observed

FACE WIDTH 1.76m **HW WIDTH** 0.29 m **MIN PYX** 0.78 m **BARREN PYX** 0.69 m

COACHING GIVEN TO: Charles mojalodi **MPT MARKED** **GEO STRUCTURE DEMARCATED**

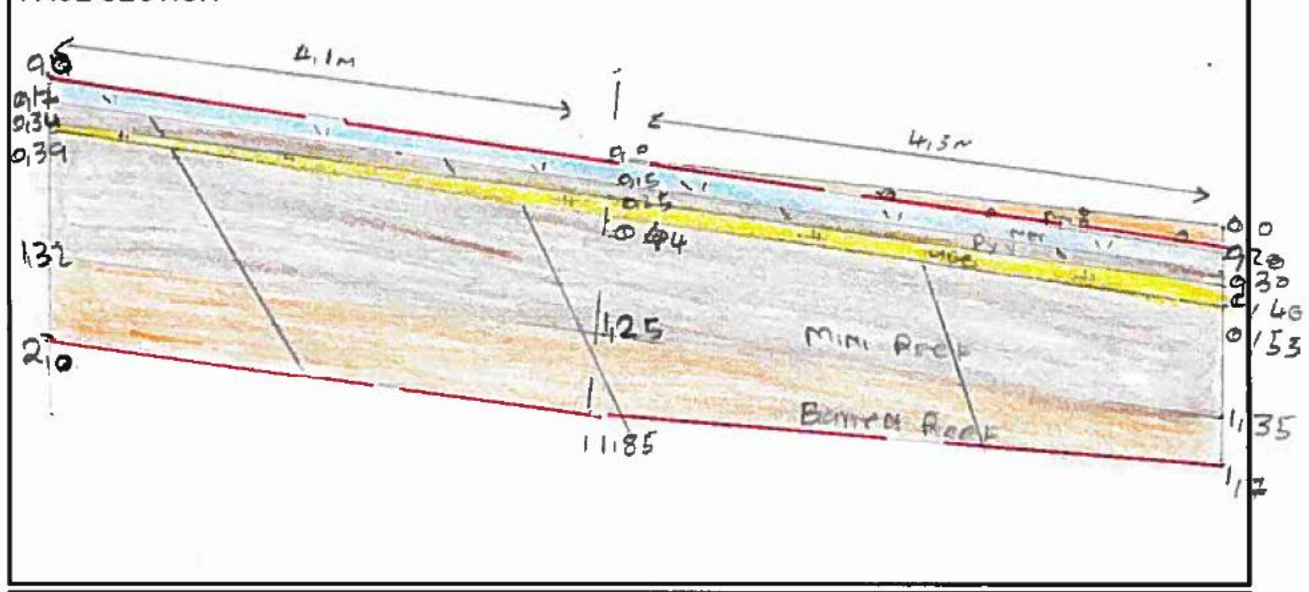
FACE SECTION MEMO

NORTHAM BOOYSENDAL

REFERENCE: GEO. 191 **DATE :** 22/05/2017

WORK PLACE	BNM-SMS-03-SB	SECTION	South stopping	VISITED BY	Hlongwa M.L
PEG NO.		PEG TO FACE DISTANCE			

FACE SECTION



GEOTECHNICAL OBSERVER'S OBSERVATIONS:

- Good mining practice observed no hangingwall overbreak.

FACE WIDTH 1,85m **HW WIDTH** 0,1 m **MIN PYX** 1,1 m **BARREN PYX** 0,65 m

COACHING GIVEN TO: Tshehla **MPT MARKED** **GEO STRUCTURE DEMARCATED**

APPENDIX 5: MERENSKY SHAFT PLANNED CAPEX AND THE EARLY WORKS DONE PRIOR TO GHH ROOF BOLTER PROJECT START UP IN JUNE 2016

BOOYSENDAL NORTH

BNM (Merensky) – Performance to date

Resource	1.8 Moz 4E
Reserve	1.4 Moz 4E
Commenced	February 2015
Tonnes mined	135Kt
Concentrator recovery	86%
Phase 1 operation with 2 mining crews 1 stoping crew 1 development crew 25 000oz/annum 4E	
Capex	R300m over 2 years
Allows modular production growth	
Essentially swing producer with low fixed opex	

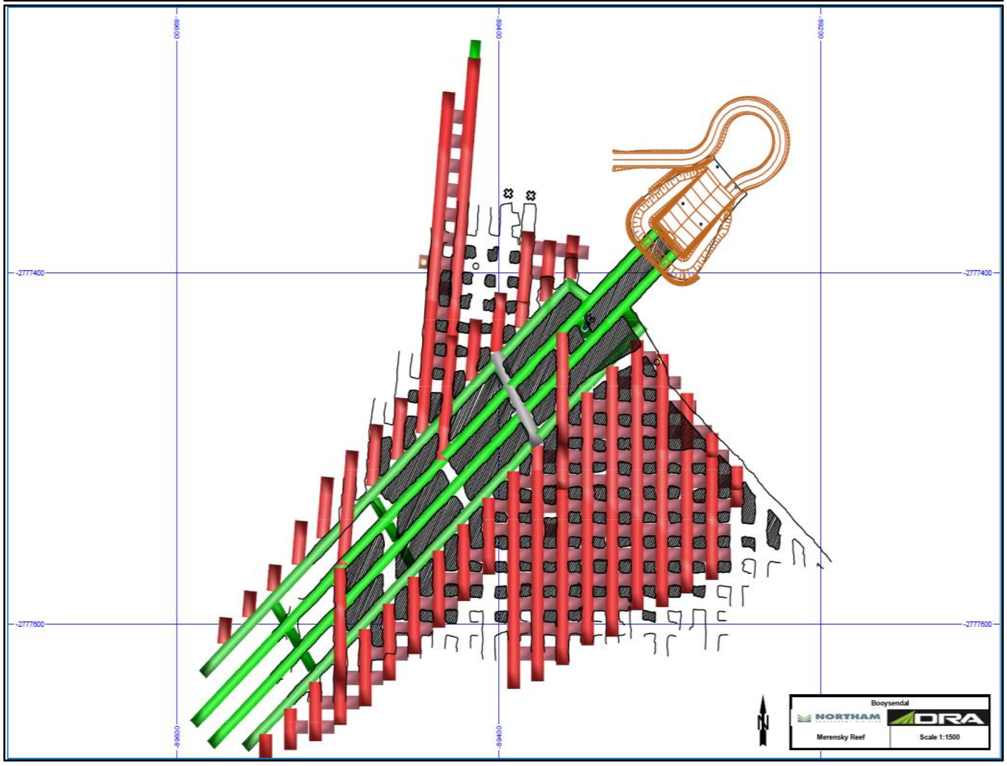


Figure 5 (i): Capital spent and the work in progress of the Merensky Shaft (Source: Northam Platinum Limited)