MINING INDUSTRY
OCCUPATIONAL
SAFETY & HEALTH

MINERALS COUNCIL
SOUTH AFRICA

PERMANENT WORKFACE AREAL MESH

Source mine report and adoption guide

Prepared by the MOSH falls of ground (FOG) team:

Obakeng Rakumakoe
Christopher Legodi

CONTENTS

1 INTRODUCTION

Over the years the South African mining industry has experienced a continuation of fall of ground (FOG) related incidents, (i.e. high potential incidents (HPIs)) and accidents.

The analysis of the FOG SAMRASS data by the MOSH FOG team in 2021 showed that 52 of the 64 (81%) assessed accidents occurred at the workface of the excavations (Figure 1). There are several factors that contribute to these incidents and accidents occurring on the workface. These factors include (but are not limited) to inherent rock mass conditions, the sequence of work activities, the nature in which the activities are conducted, and the type of support installed. There is an industry consensus that the introduction of a permanent workface areal coverage support will significantly influence the three above-mentioned factors. If this view is true, then permanent workface areal coverage support may enable the industry to see a further reduction in FOG-related HPIs and accidents. This report presents the MOSH FOG findings on investigating the practices and the potential benefits the practice can bring in reducing FOG-related accidents in the industry.

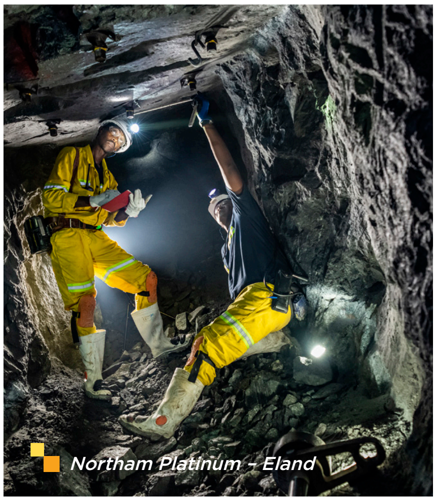
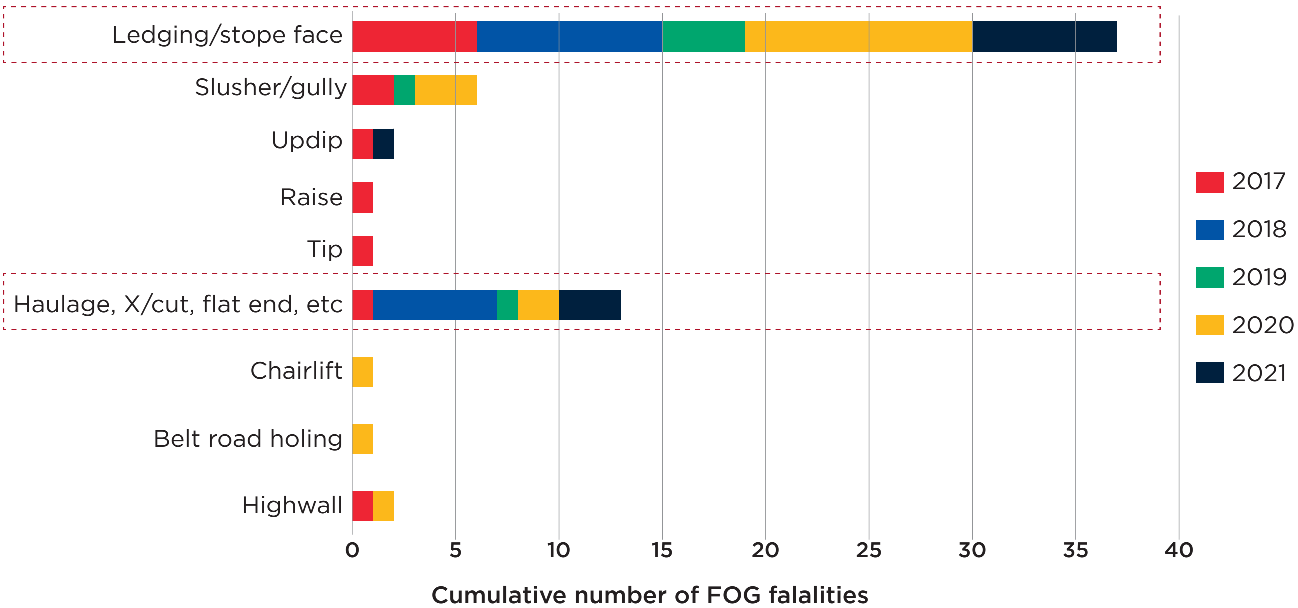

Northam Platinum – Eland

Figure 1: Location of FOG-related fatalities in underground mines




Anglo American Platinum – Tumela

2 BACKGROUND AND IDENTIFICATION OF PERMANENT WORKFACE AREAL MESH

2.1. SOUTH AFRICAN MINING INDUSTRY FOG-RELATED SAFETY PERFORMANCE

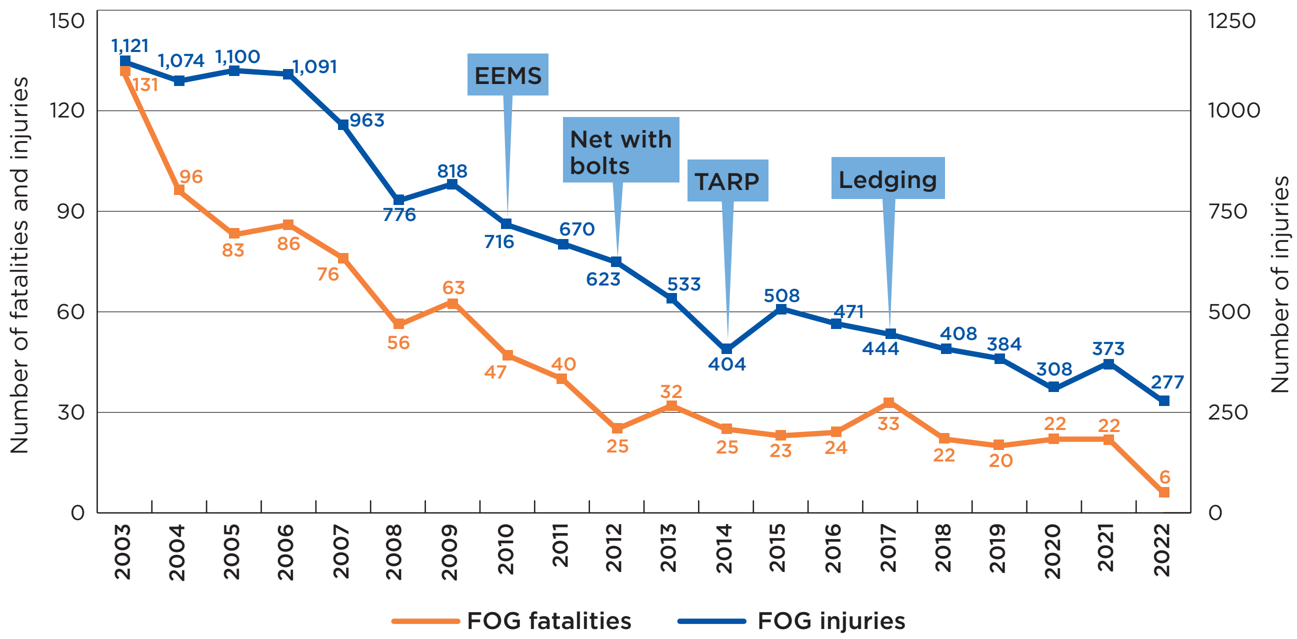
Figure 2 indicates that between 2012 and 2022, the South African mining industry experienced a decline in the number of FOG-related reportable injuries and fatalities (Figure 2). This decline comes as a result of continued efforts made by the government, the mining companies and employee representatives to improve the safety and sustainability of the industry.

The Minerals Council South Africa has collaborated with several stakeholders in devising strategies and initiatives to reduce FOG fatalities. One such initiative was the inception of Mining Industry Occupation Safety and Health (MOSH) Learning Hub in 2003 which was tasked with a mandate to focus on the adoption of leading practices to improve safety and health. One of the four risk areas that the MOSH Learning hub focuses on is FOG safety, which is led by the MOSH FOG team.

Under the MOSH FOG risk area, several leading practices have achieved widespread adoption in the mining industry. As a result of these leading practices (Figure 2) and other company specific initiatives, the industry has managed to a reduction in FOG-related fatalities. In 2021 the mining industry recorded 373 reportable (serious) FOG-related injuries and 22 fatalities compared to 308 injuries and 22 fatalities in 2020. This difference can be observed as a significant regression in safety. However, this observation comes without considering the lower production of the underground mines in 2020 due to the COVID-19 pandemic (this lower production period is shown in Figure 3). If these numbers are normalised against production, there is a possibility that the observed regression might not be so significant.

The severity of the serious injuries reported in the SAMRASS data varies from deep lacerations to amputations. Reportable FOG-related injuries are directly proportional to fatal injuries, with an average ratio of 17:1 between 2012 and 2022 (i.e. over the past 10-year period).

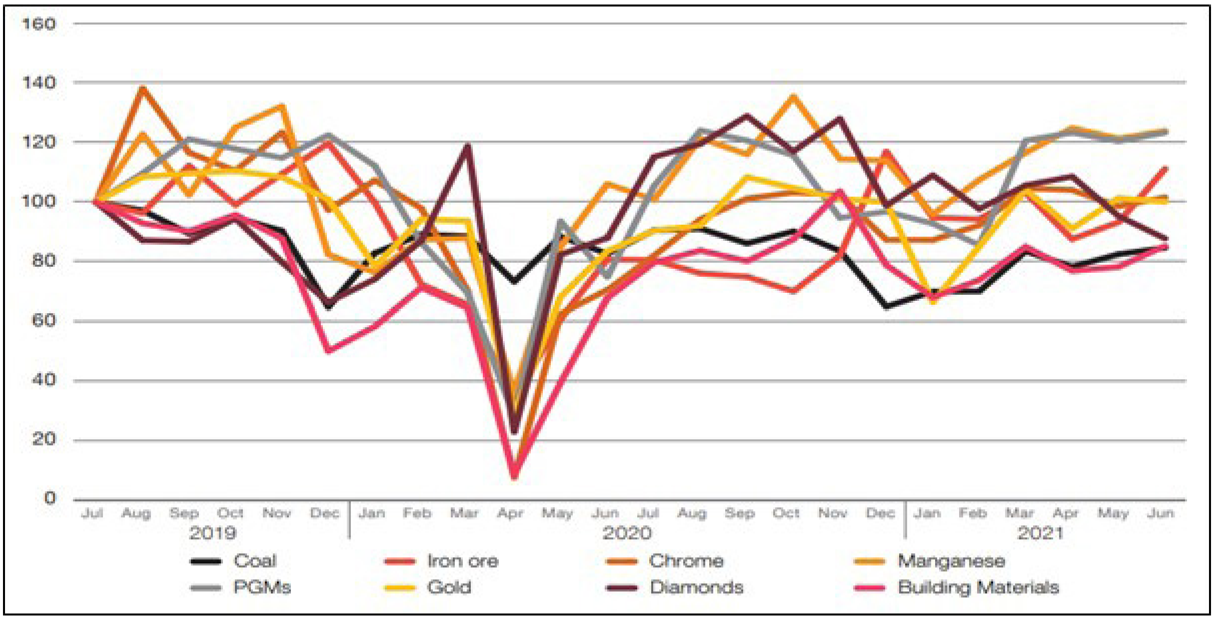
Figure 2: FOG-related reportable injuries and fatal accidents



BACKGROUND AND IDENTIFICATION OF PERMANENT WORKFACE AREAL MESH CONTINUED

2.1. SOUTH AFRICAN MINING INDUSTRY FOG-RELATED SAFETY PERFORMANCE CONTINUED

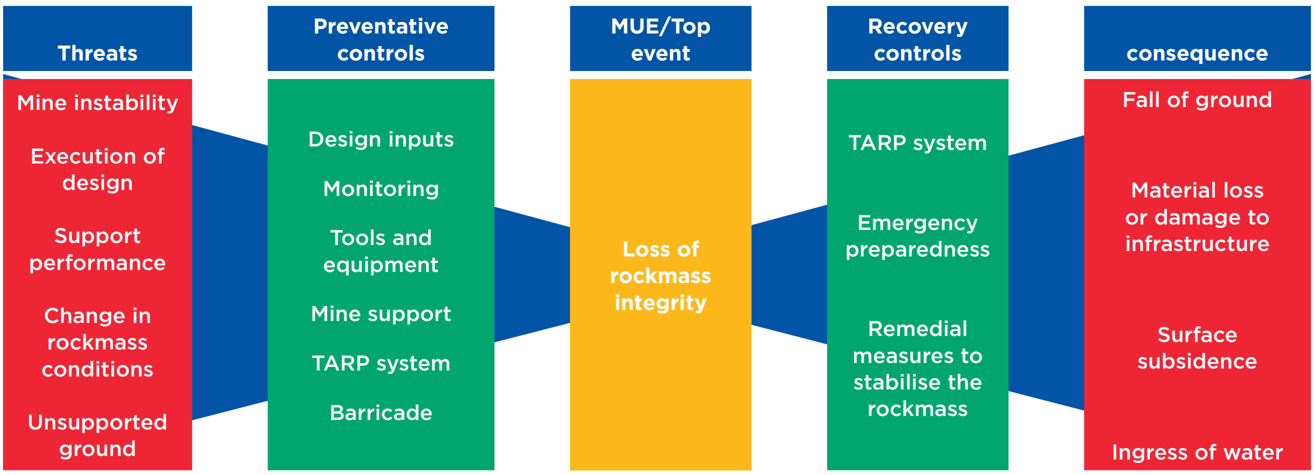
Figure 3: The industry production over a two-year period showing the reduction in production during the COVID-19 pandemic lockdown period



2.2. FOG HAZARD IN THE SOUTH AFRICAN MINING INDUSTRY

In an effort to prevent FOG related fatalities and injuries it is important to turn the attention to the FOG hazard in the industry. Recently the MOSH FOG team together with the industry, developed a FOG risk bowtie to identify the contributing factors (threats) to FOG and the controls (critical controls) to prevent FOG incidents. Figure 4 shows the summary of the FOG industry parent bowtie with the material unwanted event (MUE) identified as loss of rock mass integrity. Loss of rock mass integrity leads to rock mass failure which can result in a FOG. The FOGs come in different forms and are triggered by different factors. Understanding the trends of the FOG accidents, such as the type of FOG, the contributing factors including mining environment and method, assists in identifying the solutions to preventing FOG accidents.

Figure 4: Summarised FOG industry parent risk bowtie for the industry

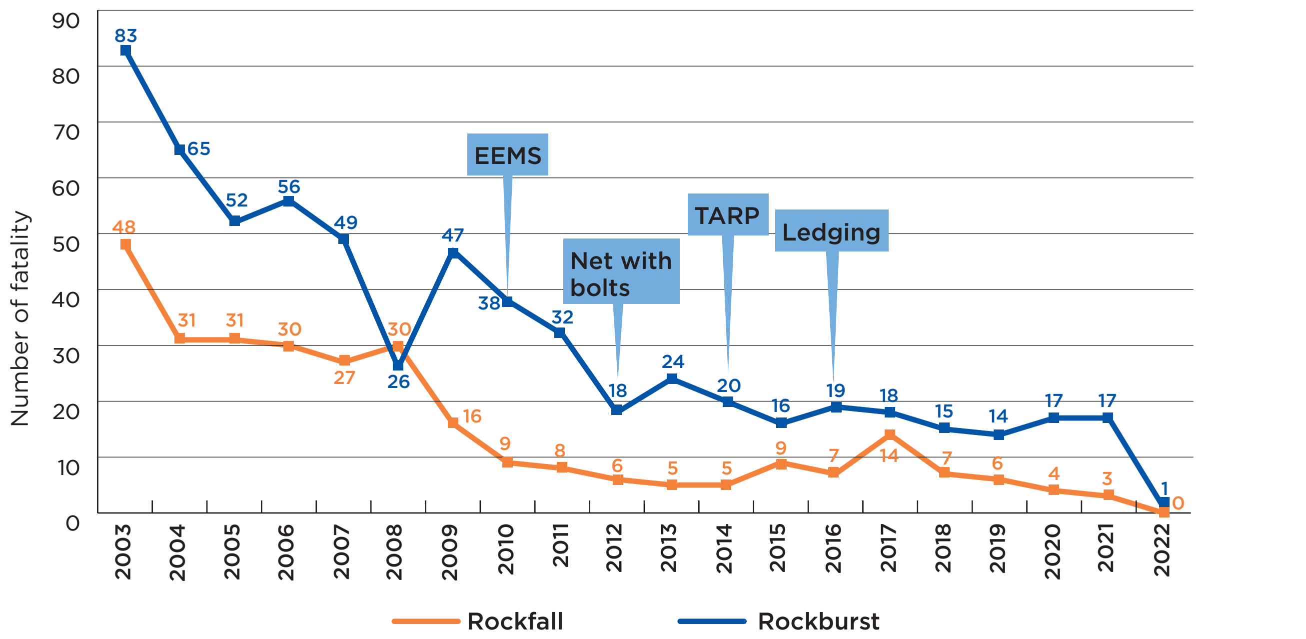


2.2. FOG HAZARD IN THE SOUTH AFRICAN MINING INDUSTRY CONTINUED

2.2.1. Types of falls of ground

Although the description of FOG-related accidents is said to be either gravity or seismic (as shown in Figure 5) in reference to the rock mass failure mode, there are many different failure mechanisms within the two simplified descriptions. Failure mechanisms are influenced by several factors, for example, inherent rock mass conditions and mining induced stresses. Commodity classifications are a good indication of the host rock and the stress due to mining depth.

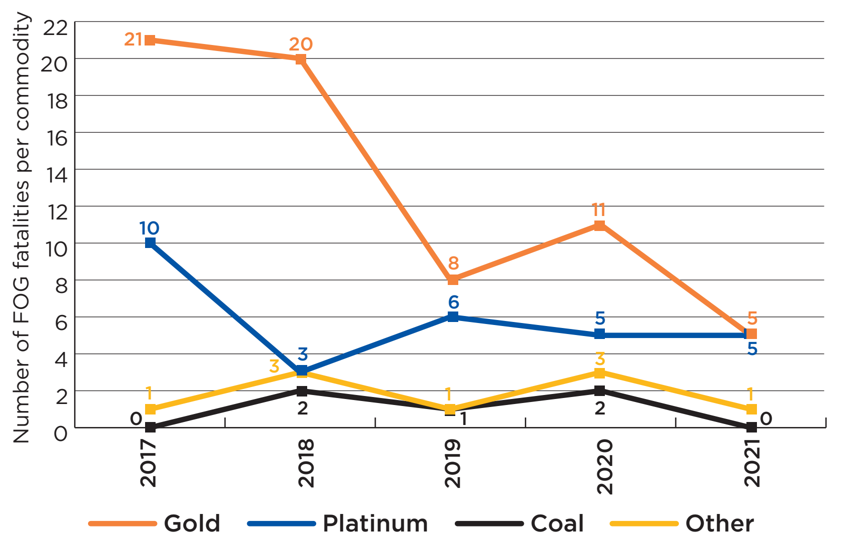
Figure 5: FOG related fatalities from 2003 to June 2022 in correlation with MOSH FOG Leading Practices



2.2.2. Commodity influence on FOG fatalities in the industry

In the year 2020, at least 76% of all FOG-related fatalities were from the gold and platinum commodities, with the former (gold sector) contributing to 52% of the fatalities (as shown in Figure 6). In 2019, the gold and platinum sectors contributed towards 20% and 39% of the total industry employment respectively. Considering that gold employs only half the number of people compared to the PGM sector, it can be concluded that the gold sector has a higher number of FOG-related injuries per employee. Since the gold sector is synonymous with ultra-deep mining, it is associated with mining-induced seismicity.

Figure 6: FOG-related fatalities per commodity

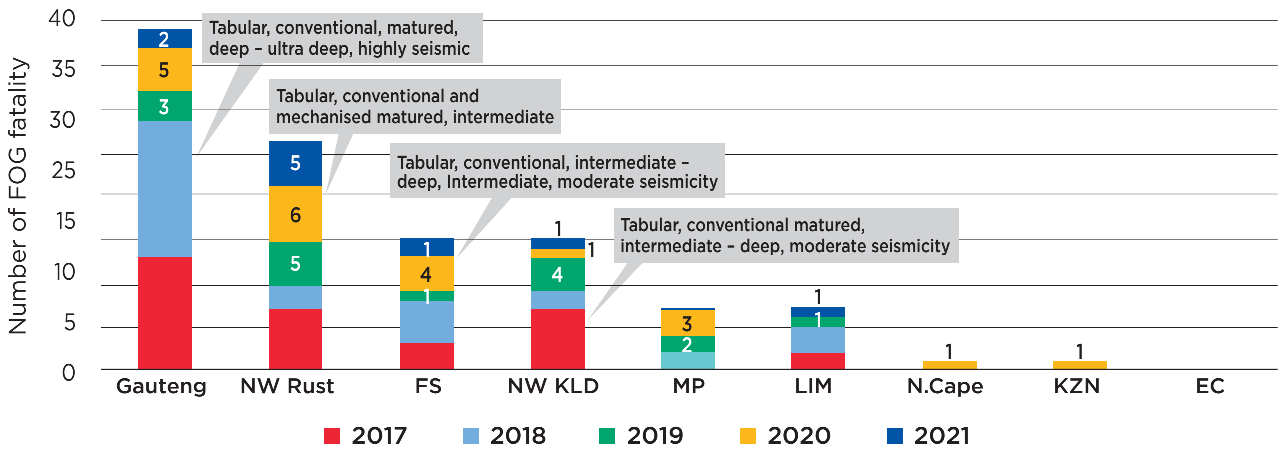


2.2. FOG HAZARD IN THE SOUTH AFRICAN MINING INDUSTRY CONTINUED

2.2.3. Influence of mining region on FOG fatalities in the industry

The FOG fatality data of the various mining regions shows that the higher FOG risk is in the gold mining areas which predominantly lie in the Gauteng, Free State and North West (Klerksdorp) regions (as shown in Figure 7). Understanding which commodities and regions present a substantial risk of FOG helps in the analysis of contributors of FOGs within these areas.

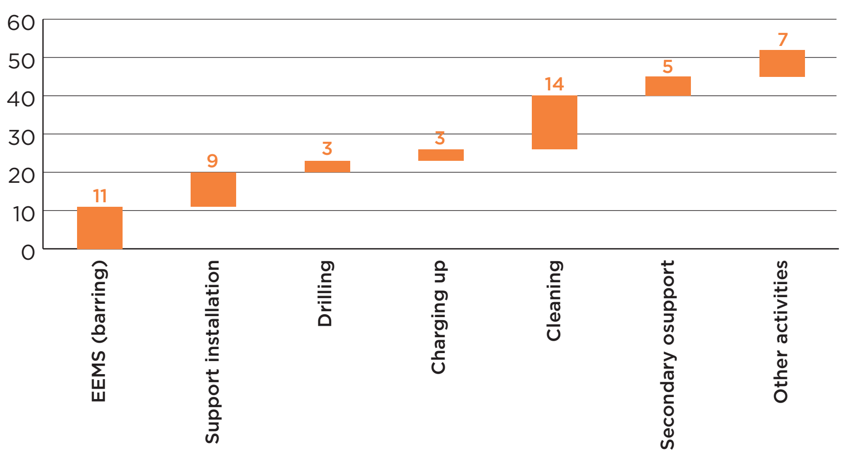
Figure 7: FOG fatal accidents by region and the correlating mining environment



2.2.4. Mining practices and their relationship to FOGs

It has been established in the previous section that gold and platinum sectors have been the major contributors to FOG accidents (and therefore the FOG risk). The risk is mainly due to the mining method used to extract the ore body. The tabular nature of most PGM and gold deposits in South Africa make breast mining and board and pillar mining the most practical and feasible mining methods. These mining methods involve advancing mining faces with every blast and exposing fresh rock mass daily. The methods used in narrow tabular mining are different from those in massive mining (which required extensive development in the beginning, and production conducted remotely or from supported and safe excavations). Breast mining and board and pillar on the other hand require the daily inspection of freshly exposed rock mass and making the mining faces safe for the commencement of daily activities. In this process, the employees are in close proximity to an unknown and unsupported rock mass.

Figure 8: Activities associated with FOG fatalities: 2017-2012



In 2022, the MOSH Learning Hub identified permanent workface areal mesh support as a potential leading practice. It has been shown that the FOG risk cuts across all commodities, with regions of higher risk (i.e. those associated with gold and PGM mining). The making safe process (inspection and support) and cleaning activities presents high FOG risk and these activities take place on the working face. These activities also take place in areas that do not have adequate FOG prevention controls. It is for this reason that the permanent workface areal mesh was identified as one of the critical solutions to aid in the prevention of FOG accidents in the workface.

3 LITERATURE REVIEW

3.1. CAUSES AND CONTRIBUTORS OF ROCK MASS INSTABILITY IN THE INDUSTRY

Fall of ground incidents occur as a result of the rock mass losing integrity during the creation of excavations. The loss of integrity is due to factors that differ according to commodities and regions. These different rock mass and environmental factors can be managed by different rock engineering strategies such as mining layouts and mine support systems. There is no doubt that the most significant contributor to the loss of rock mass integrity is the induced stresses on the excavations. The inhomogeneity of the rock mass results in different rock behaviours when the rock is exposed to induced stress. Understanding these two aspects enables the anticipation of the following: resultant rock mass behaviour, instability mechanisms and the required controls. Table 1 and Table 2 show the generalised mining environments/conditions, and the degree to which these factors influence stability for various commodities. These tables use a scale ranging from 0 to 5, where 0 means that the mining environment or condition has no influence on the stability, and 5 which means the mining environment/condition has a very high influence on the stability. The book on tabular hard rock mining (Ryder & Jager, 2002) gives an overview of the geotechnical environment and challenges presented by the gold and PGM/chrome mining areas. Table 1 represents the described conditions and their influence. The other column includes many different commodities such as base metal and diamonds that conduct underground mining. The Rock Engineering of Underground Coal Mining book (van der Merwe & Madden, 2010) describes the South African coal mining environment as shallow soft rock, characterised by stratified or layered geological units.

Table 1: Geotechnical factors (mining environment) contributing to rock mass integrity

	Geotechnical factors	Gold	Platinum / chrome	Coal	Other
1	High stress level (depth)	5	3	0	0
2	Intensive fracturing	5	2	0	0
3	Large discontinuities	1	5	3	3
4	Seismicity	5	1	0	0
5	Geological features	3	4	2	4
6	Weak strata	3	3	4	3

(Stacey & Swart, 2001) indicated in their book that the instability is a result of the interaction of inherent rock mass structures and induced stresses around the excavation. The combinations in the Table 1 make it possible to derive the possible instability and failure mechanisms in the rock mass as presented in Table 2.

Table 2: Likelihood of rock mass failure mechanism by commodity

	Failure mechanism	Gold	Platinum / chrome	Coal	Other
1	Slabbing / scaling / beam	4	3	5	3
2	Unravelling / shakedown	5	3	1	1
3	Seismic – rock burst	5	2	0	0
4	Face burst (strain)	4	1	0	0
5	Back breaks	2	4	1	1
6	Wedge and block failure	2	5	3	3

3.2. CAUSES AND CONTRIBUTORS OF FOG ACCIDENTS

Accidents occur when people are exposed to the identified hazards. In the absence of people, the occurrence of these hazards is merely referred to as incidents, and some go unreported or undocumented.

Mining has evolved over time from an activity that was conducted with picks and shovels to one that is more advanced using autonomous machinery (i.e. modern mining). The nature of the orebody and type of commodity within the orebody are some of the major deciding factors in determining the mining method(s) to be used. The majority of orebodies mined in South Africa are tabular in nature (near-horizontal deposition). However, they vary in inclination and thickness. Most of the gold deposits mined in South Africa are found in narrow tabular reefs ranging from a few millimetres to a couple of metres. The majority of the currently mined reefs such as the Basal Reef (Welkom), Vaal Reef (Klerksdorp) and Carbon Leader and VCR (West Wits) hardly exceed 2m in width with dips ranging between 15° to 30° inclination ((Ryder & Jager, 2002). The efforts to mechanise the mining of these orebodies across the industry have not been successful to date, and as a result, most orebodies are mined conventionally with handheld drilling machines and manually loaded explosives.

The platinum and chrome orebodies have a varying dip, ranging from 10° in Rustenburg to 26° in the north-western lobe (Lomberg & Rupprecht, 2010). They also have varying stoping widths due to weak formations in the hanging wall. The flatter inclination and thicker stoping width allows for mechanised mining methods in some of the platinum and chrome deposits. However, there remains a high number of conventional mining similar to that described for the gold mines being applied in the platinum and chrome mines.

The conventional mining method activities such as visual and sounding inspection, barring, manually supporting the freshly exposed hanging wall, handheld drilling and manual loading of explosive depend on the abilities and consistency of the workers. This is taken on the backdrop that the process and procedures have sufficiently covered all possible scenarios and they have been addressed with all the necessary control. Figure 8 suggests that even though these activities have been risk assessed, they still contribute towards fatal accidents. (Bonsu, van Dyk, Franzidis, Petersen, & Isafiade, 2017) suggested that owing to the nature of the mining environment in South Africa, the largest contributor to accidents is non-compliance to standards. In their analysis they also identified lack of hazard identification as the highest contributor to accidents.

Considering the mining practices and contributors to rock mass instability, Table 3 summarises the factors that contribute to the occurrences of FOG accidents. The factors are also presented in a scale of influence according to the commodity. Where 5 is high influence and 0 is no influence.

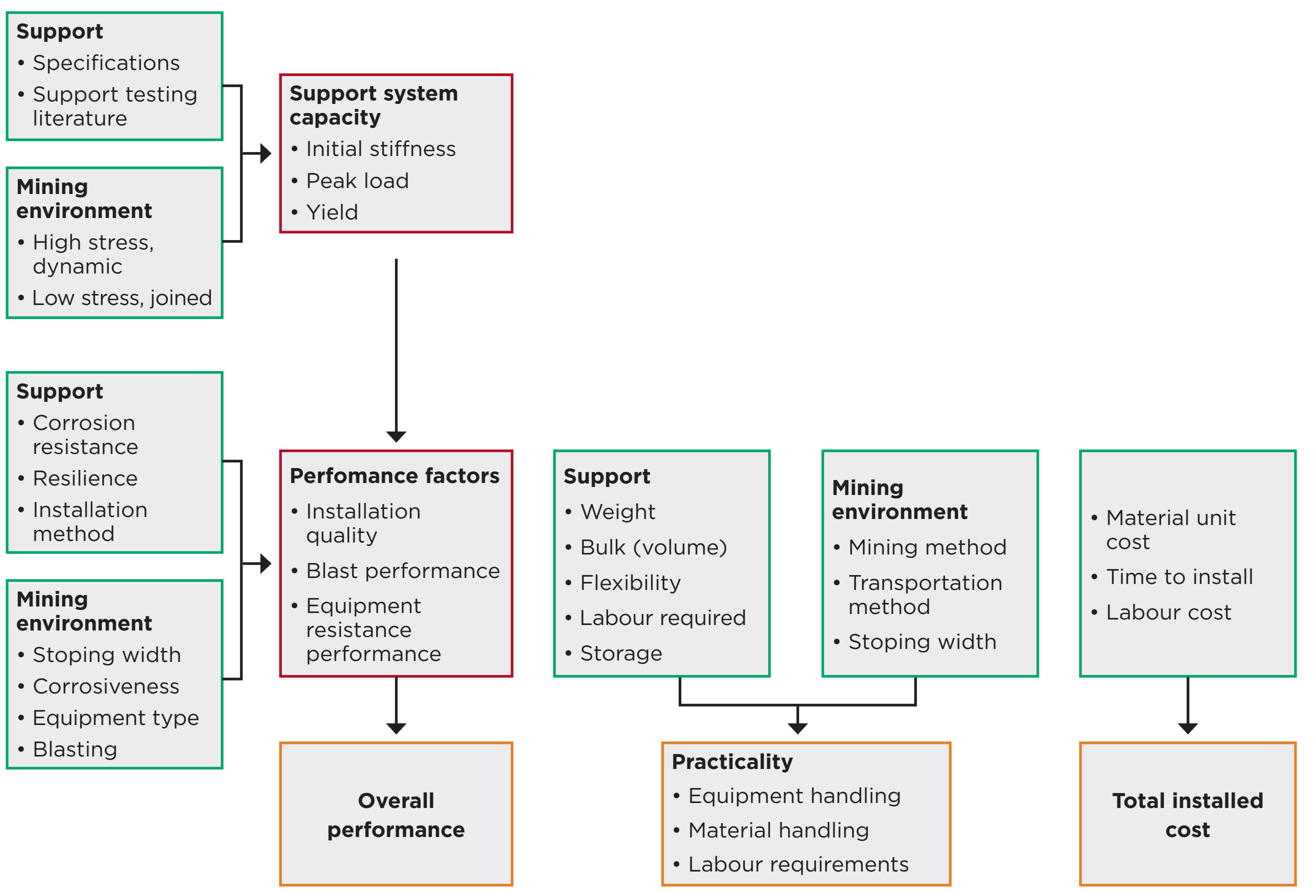
Table 3: Mining method factors contributing to FOG risk

	Gold	Platinum / chrome	Coal	Other (massive)
Conventional mining (exposure)	5	5	0	3
Blasting damage	5	4	0	2
Hazard identification	4	4	4	2
Barring tools	5	5	2	2
Compliance to mining layouts	4	4	3	2
Compliance to support standards	4	4	4	2
Manual installation and removal of support	5	5	2	0

3.3. PERMANENT WORKFACE AREAL MESH AS A SUPPORT SYSTEM

Support systems of tabular orebodies in South Africa have gradually evolved over the years with the focus of improving the performance and application of the different support units and systems. The completed support system may comprise of one or more different support units with a predetermined pattern to achieve the designed rock mass stability. Several factors determine the type of support systems used. In a Mine Health and Safety Council (MHSC) SIM 150202 report, Mulenga et.al, 2016 covered some of the key factors in support design and selection. The four key elements covered are support performance, mining environment, support robustness and mining method (as shown in Figure 9).

Figure 9: Overview of the methodology for the selection of permanent areal support



Achieving rock mass stability for a predetermined period is the key objective of using support in excavations. There are a variety of support types to cater for the requirements, and these are based on the key input factors. Support types can be classified into three main categories which are based on the following:

- Installation / application method
- Function / mechanism interacting with the rock (support)
- Strain / yielding / failure behaviour

Table 4: Rock mass support classifications

Support classification (application)	Functions	Strain behaviour
In-situ support	Re-enforce	Non-yielding
Stand-up support	Support	Stiff – non-yielding / soft yielding
Areal support	Confine / contain	Stiff yielding
Surface / liner support	Confine	Stiff / non-yielding

3.3. PERMANENT WORKFACE AREAL MESH AS A SUPPORT SYSTEM CONTINUED

Different support units with distinct functions can be combined to form a support system that meets the mining method and mining environment's requirements to maintain rock mass stability. The in-stope permanent support system is made up of either in-situ (tendons/bolt) support or stand-up support (i.e. elongates/sets). Areal support units (mesh and nets) cannot be installed on their own, and they are always attached or secured to the hanging wall using tendons or elongates hence they are referred to as passive surface support (Jjuuko & Kalumba, 2014). There are also active surface supports which are referred to as liner support types which are made up of cement / chemical-based components (shotcrete and thin sprayed liner). These types of surface support attach to the rock surface and offer confinement.

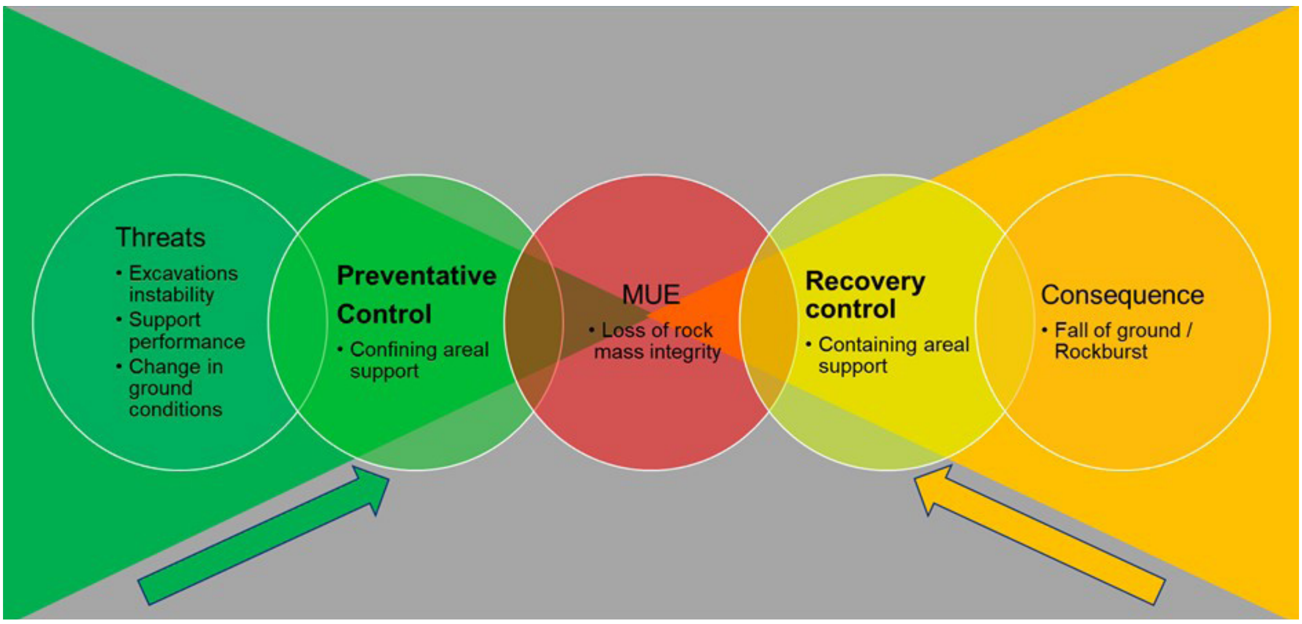
Differentiating between the areal support and liner support is important, as these two variations offer completely different functions. Surface liner support offers confinement at the surface of the rock, preventing the movement in jointed rock. Surface support does not interact with other support units (such as tendons and elongates) in the excavations, and it is therefore an independent system. One can argue that the interaction in surface support is as large as the largest grain size in the applied support system. This characteristic of the surface support limits it in recovery capabilities (Stacey & Ortlepp, 2001). Table 5 presents a comparison between the surface liner support and areal support.

The areal support system is characterised by the interaction and interlocking of the material forming the mesh system. The mesh systems differ in characteristics, from very soft (chain-link mesh and nylon and steel nets) to very stiff (welded mesh). Depending on the stiffness, some units (such as welded mesh) can offer some confinement to the rock surface. When there is sufficient confinement, the mesh can function as a preventative control. Where the mesh is made up of ropes, steel cables or threads, the mesh will only function as a net and become a recovery control. Figure 10 shows the characteristics of mesh as a control in a risk bowtie.

Table 5: Comparison of characteristics of areal support and liner support

	Confine (offers resistance)	Contain (hold post failure)	Rock adhesive	Support interaction and interconnection	Effective immediately
Areal support	✗ (flexible) ✓ (stiff mesh)	✓	✗	✓	✓
Surface liner support	✓	✗	✓	✗	✗

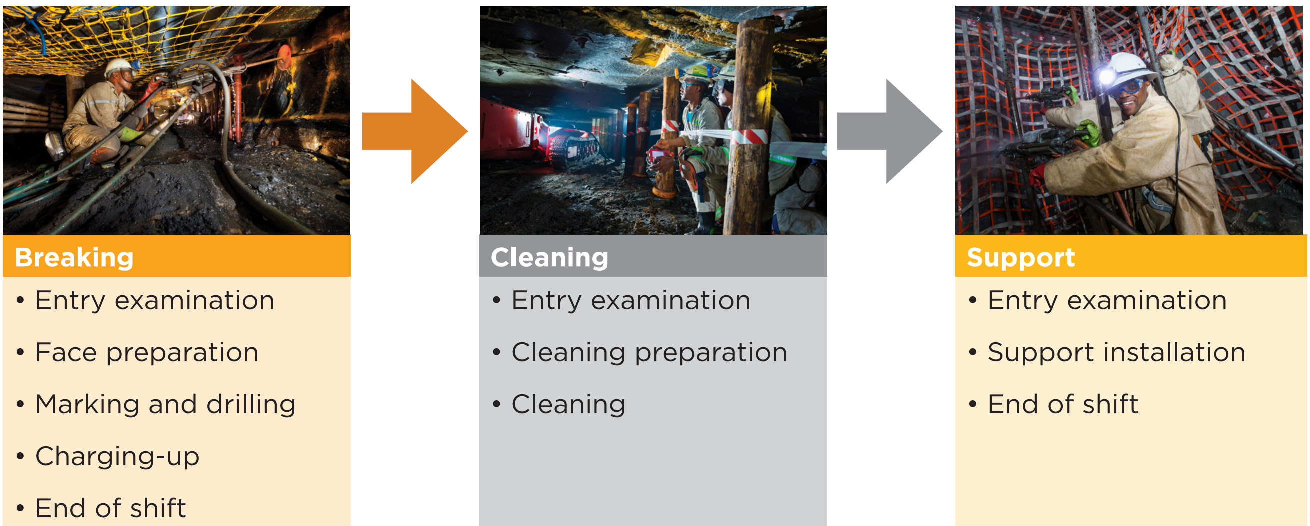
Figure 10: Bowtie representation of a permanent mesh support as a control



3.4. PERMANENT WORKFACE AREAL MESH IN THE MAKING SAFE AND SUPPORTING ACTIVITIES

The graph shown in Figure 8 shows that most FOG fatal accidents (between 2017 and 2021) occurred during the entry examination and making safe process (i.e. during barring, installation temporary and/or permanent support). It is therefore critical to appreciate the mining process, mining cycles and activities as it is during the execution of these tasks that employees are exposed to FOG hazards. Most underground mining methods follow the cycle as shown in Figure 11. The activities might differ depending on the mining method and level of mechanisation. The use of areal support in conventional stoping has always featured in the support cycle and the breaking cycle, since the launch of the MOSH leading practice on net with bolts in 2012.

Figure 11: Illustration of the mining cycles and the activities in each cycle



Areal support in the form of temporary nylon nets has become the industry standard practice. In this process, the temporary net is installed during the entry examination and making safe process and is removed when all work in the stope has been completed (at the end of a shift). Although the temporary areal support offers a reduced FOG risk, it must be noted that once the net is removed at the end of a shift, there is no areal support in the stope. The comparison between temporary areal support and permanent areal support are presented in Table 6 below.

Table 6: Comparison of the permanent workface areal mesh and temporary stope net / mesh

	Weight	Area to examined and barred	Entry examination time	End of shift time	Back area coverage	Night shift coverage	Cost
Temporary areal support	✓	✗	✗	✗	✗	✗	✓
Permanent areal support	✗	✓	✓	✓	✓	✓	✗

4 CURRENT USE OF PERMANENT NETS / MESH IN UNDERGROUND MINES (CASE STUDIES)

To have a good representation of the underground mining environment in South Africa, four case study mines were identified for documentation. The mines had to represent key areas that determine support selection and applications of permanent workface areal mesh. Table 7 gives the summary of the case study mines against the five key selection criteria. The key outcomes and findings from each case study are presented in summary table format from Table 8 to Table 12.

Table 7: Description of the case study mines for the permanent workface areal mesh

	Case study 1	Case study 2	Case study 3	Case study 4
	Masimong Mine (Harmony Gold)	**Mponeng Mine (Harmony Gold)**	**Saffy Shaft (Sibanye-Stillwater)**	**K6 Shaft (Sibanye-Stillwater)**
Mining environment (stress and geotech)	• Depth: 1,700m • Rock mass: fracture • Seismicity: low	• Depth: 3,700m • Rock mass: very fracture • Seismicity: high	• Depth: 700m • Rock mass: jointed • Seismicity: none	• Depth: 500m • Rock mass: jointed • Seismicity: none
Mining method (layout)	• Breast mining	• Breast mining	• Breast mining	• Board and pillar
Mining equipment (mechanisation)	• Conventional drill and blast	• Conventional drill and blast	• Conventional drill and blast	• Mechanised and semi-mechanised
Stoping width (mining height)	• <1.2m – 1.4m	• <1.5m	• <1.5m	• >1.8m
Support systems (support application)	• Elongates, steel mesh and bolts	• Elongates, steel mesh and bolts	• Elongates, steel mesh and bolts	• Steel mesh and bolts

4.1. MASIMONG MINE (HARMONY GOLD)

Table 8: A summary of the use of permanent workface areal mesh at Masimong Mine

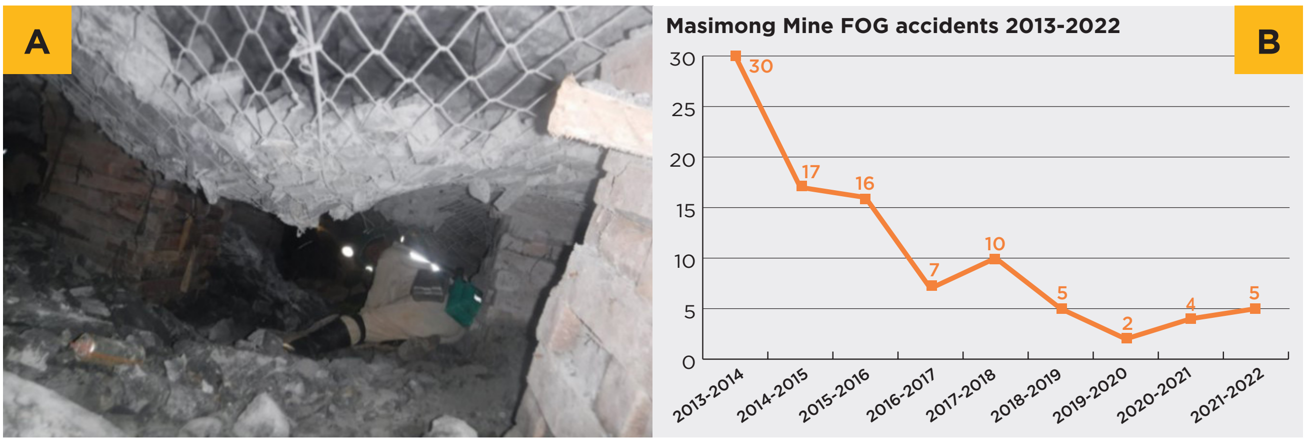
1. Mine background			
Name of mine	**Masimong**	**Location**	**Welkom**
Commodity	Gold	**Mining method**	Conventional breast
Description of mining method	• Masimong Mine utilises the conventional scattered mining method • Conventional barring and making safe • Support, drill and blast in one panel (1 on 1)		
Number of employees	2,024	**Number of people affected**	874 (stoping and vamping)
Stoping width	1.2m – 1.4m	**Average monthly production (m^2)**	10,800
2. FOG risk description		• FOG between permanent (active) support	
3. Objective of permanent net		• Stope netting to assist with areal coverage when drilling the face • Fall of ground incidents / accidents were also occurring on nightshift	
4. Permanent mesh specification		• High load-capacity • Corrosion resistant • Resistant to mechanical damage (blasting and cleaning activities) • Minimum sag	
5. SOP and standard		• Primary installation with stope tendons	
6. Change management		• Management support to investigate the use of permanent mesh • Stakeholder consultation • Timeous and continuous communication to the stakeholders • Scraper corners modified (Figure 12) • Washer sizes on tendons was increased (Figure 13) • Hooks removed from support washers	
7. Labour requirements		• No labour changes	
8. Logistics requirements		• Increased material transporting and handling	
9. Cost		• Increase in support cost	
10. Quality of mesh usage		• Very good	
11. Safety performance		• 30% reduction in accident (Figure 14)	

4.1. MASIMONG MINE (HARMONY GOLD) CONTINUED

Figure 12: Changes made to the scraper and drilling machine enable the installation of netting in low stoping widths

Figure 13: In-stope permanent netting installed with rock-studs and bigger washers and temporary mechanical jacks in a panel at Masimong Mine

Figure 14: A. Permanent in-stope steel net arresting a seismic induced FOG following a magnitude 2.4 event at 1810 S12 E17 UD3 on 24 May 2022.
B. FOG related accidents statistics over a nine-year period.



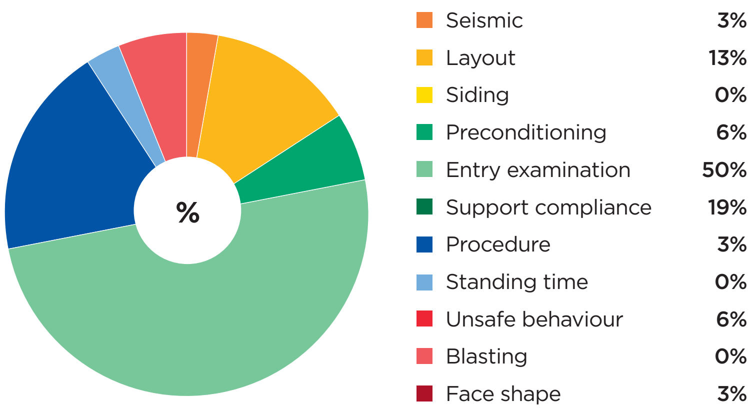
4.2. MPONENG MINE (HARMONY GOLD)

Table 9: A summary of the use of permanent workface areal mesh at Mponeng Mine

1. Mine background			
Name of mine	**Mponeng**	**Location**	**Carletonville**
Commodity	Gold	**Mining method**	Conventional breast
Mining depth	3,780	**Mining environment**	Ultra-deep – seismic and highly fractured
Description of mining method	Ultra-deep narrow tabular mining up to 3,700m below surface conducted using conventional breast mining. Three cycles are used to mine the panel using three smaller dedicated crews specialising in each activity of the cycle (support, drill and clean). Support is composed of timber elongates, in-stope bolting, timber packs and backfill. Entry examination and making safe consists of barring and temporary support installation in the form of temporary steel elongates and temporary nylon nets.		
Number of employees	4,540	**Number of people affected**	4,360
Stoping width	150cm (VCR) 121cm (CLR)	**Ave monthly production (m^2)**	12,500 – 14,000
2. FOG risk description		• Shake down FOG and loose rocks (63%) (Table 10) • Entry examination and making safe (Figure 15)	
3. Objective of permanent net		• A real support to catch shake down during seismic events and loose rock • Reduce area to be barred during entry examination • Fall of ground incidents / accidents were also occurring on night shift • Poor compliance to temporary net	
4. Permanent mesh specification		• High energy absorption • Easy to handle and install in stopes • Resistant to mechanical damage (blasting and cleaning activities) • Minimum sag • Connect easily with other mesh installed	
5. SOP and standard		• Primary installation with stope elongates • Secured with tendons	
6. Change management		• Management support on investigation of the use of permanent mesh • Stakeholder consultation • Elongates moved closure to the face (Figure 16) • Zone three supported for every mesh unit • Bolts changed to tensioned bolts with washers larger than the mesh aperture	
7. Labour requirements		• No labour changes	
8. Logistics requirements		• Increased material transporting and handling	
9. Cost		• R3.86 to R266.40 per square metre	
10. Quality of mesh usage		• Bottom of panels still a challenge due to mining constraints (cleaning and face shapes)	
11. Safety performance		• Year 1: 20% reduction in FOG accidents • Year 2: 18% reduction in FOG reportable accidents • Accident / incident rate reduced from five-year average of 1.4 to 1.0 in 2022	

4.2. MPONENG MINE (HARMONY GOLD) CONTINUED

Figure 15: FOG incidents contributing factors at Mponeng Mine



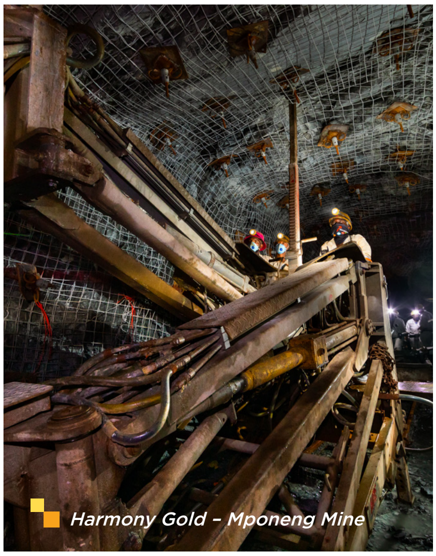


Table 10: Distribution of FOG incident mechanism at Mponeng Mine

Hazards	Controls	Sub-control (focus area)
Rock burst (16%)	Mine design and mining strategies	• Stope profiles
Shake down FOG and loose rocks (63%)	Entry examination, support installation	• Barring • Temporary and permanent support sequencing • In-stope bolt type and installation • Areal coverage support
Face ejections (21%)	Preconditioning	• Drilling practices • Explosives

Figure 16: Permanent workface areal mesh installation at Mponeng Mine with elongate support installed close to the face

4.3. SAFFY SHAFT (SIBANYE-STILLWATER PGM)

Table 11: A summary of the use of permanent workface areal mesh at Saffy mine

1. Mine background			
Name of mine	**Saffy Shaft**	**Location**	**Marikana**
Commodity	Platinum	Mining method	Scattered breast
Mining depth	Shallow	Mining environment	Low stress – blocky
Description of mining method	Conventional scattered breast mining using handheld rock drills for drilling shot holes and in-stope bolts. Cleaning is conducted using winches and scrapers. Stopes are supported with timber bolts / elongates / packs as primary support. The mining cycle follows that of support and blast (day shift) in single panel and cleaning on night shift.		
Number of employees	3,992	**Number of people affected**	224
Stoping width	140cm	**Ave monthly production (m²)**	N/A
2. FOG risk description		• TARP 3 brows, faults and shears dipping at less than 60°, dykes, flat dipping features, domes that create complex and blocky ground conditions (Figure 17)	
3. Objective of permanent net		• The blast resistant mesh will be installed as additional permanent support, anchored and suspended from the roof bolts in TARP 3 areas	
4. Permanent mesh specification		• Resistant to mechanical damage (blasting and cleaning activities) • Corrosion resistant	
5. SOP and standard		• Secured with tendons	
6. Change management		• Support by senior management • Risk assessment • Stakeholder engagement • Communication and training plans	
7. Labour requirements		• No labour changes	
8. Logistics requirements		• Increase for limited period	
9. Cost		• Special areas / no additional cost	
10. Quality of mesh usage		• Good and improved support spacing	
11. Safety performance		• The correlation to FOG safety has not been clearly defined. KPI to be put in place.	

Figure 17: Permanent workface areal mesh installation at Saffy Shaft while negotiating TARP 3 conditions

CURRENT USE OF PERMANENT NETS / MESH IN UNDERGROUND MINES (CASE STUDIES) CONTINUED

4.4. KROONDAL K6 SHAFT (SIBANYE-STILLWATER PGM)

Table 12: A summary of the use of permanent workface areal mesh at Kroondal K6 Shaft

1. Mine background			
Name of mine	**Kroondal K6 Shaft**	**Location**	**Rustenburg**
Commodity	Platinum	Mining method	Board and pillar
Mining depth	Shallow	Mining environment	Low stress blocky
Description of mining method	The board and pillar mining is conducted using two different types of mining equipment, one being fully mechanised while the other being conventional support and drilling and blasting using hand-held rock drill machines.		
Number of employees	1,335	**Number of people affected**	1,204
Stoping width	220cm	**Ave monthly production (m^2)**	N/A
2. FOG risk description		• Rocks falling in between installed support units • As recommend by Rock Engineering Department or TARP response	
3. Objective of permanent net		• Where the tendon spacing of 1m x 1m is insufficient • Areal coverage support particularly in the back areas	
4. Permanent mesh specification		• Load carrying capacity of 2 tonnes • Aperture of 102mm x 177mm • Resistant to mechanical damage (blasting and cleaning activities) • Corrosion resistant • Handle with hands and mechanised	
5. SOP and standard		• Secured with tendons • Handling and installation of mechanised rig (no temporary support) (Figure 18)	
6. Change management		• Support by senior management (Figure 19) • Risk assessment • Stakeholder engagement • Communication and training plans	
7. Labour requirements		• No labour changes	
8. Logistics requirements		• Increase for limited period	
9. Cost		• Special areas / no additional cost	
10. Quality of mesh usage		• Good	
11. Safety performance		• Not fully implemented to correlate to FOG safety	

Figure 18: Permanent workface areal mesh installation at Kroondal 6 (K6) Shaft using a bolter rig

CURRENT USE OF PERMANENT NETS / MESH IN UNDERGROUND MINES (CASE STUDIES) CONTINUED

4.4. KROONDAL K6 SHAFT (SIBANYE-STILLWATER PGM) CONTINUED

Figure 19: Implementation followed by Sibanye Stillwater showing ownership by the senior management on the operation

Appointee and senior management

- The employer shall be responsible for the implementation of this document
- The Adoption Page template shall be completed, signed off by the responsible MHSA 3.1(a) appointee and management team

Supervisors (MID management)

- Sign the Governance Acknowledgement
- Communicate to all relevant employees

HR and training department

- It is the responsibility of the Human Resource – Tarining Centre Manager to ensure the contents of this document are conveyed and included in training material

Affected workers

- Sign the Governance Compliance Acknowlegement following communication and understanding

Sibanye-Stillwater – SA PGM operations

5 ANALYSIS OF CASE STUDIES AND KEY CONSIDERATIONS FOR ADOPTION

The case studies shown in Table 8 to Table 12 represent different applications of permanent mesh to manage the fall of ground risk. The case studies shown in Table 8 to Table 12 represent different applications of permanent mesh to manage the fall of ground risk. Each case study has key findings that made the implementation and application of permanent mesh successful. In analysing the case studies, we also identified the key elements from each case study to develop an adoption guide that can be applied in any underground mine. The adoption guide will cover the technical aspects, leadership behaviour requirements and behaviour communication elements. These are the three legs of the mosh adoption process which holistically covers the critical components of management of change and change management process to ensure the successful adoption of new solutions.

5.1. CONSOLIDATION OF CASE STUDY FINDINGS

Table 13 provides a consolidated summary of the key elements from the case studies that should be considered when adopting permanent workface areal mesh.

Table 13: Case study analysis and summary on permanent workface areal mesh application

Assessed factors	Consolidated case studies finding
FOG risk description	• Rock mass unravelling between primary and/or temporary support due to: – Weak rock, increased discontinuities, increased fractures and seismicity – Time-dependent deterioration and increased barring
Objectives of permanent net	• To provide areal coverage on the workface • To reduce area to be barred during entry examination • To improve on the short comings of the temporary net (quality control) • To prevent unravelling of rock mass in weak rock mass • To provide areal coverage support particularly in the back areas
Permanent mesh specification	• Permanent workface areal mesh is defined as a mesh system that is installed as primary support as close to the working face as possible and remains in place for the life of the excavation. Some of the key technical features of such a system are: – High load-capacity mesh system (1 tonne – 2 tonnes) – Minimum sag and/or deflection under load (not greater than 300mm) – Resistant to mechanical damage (blasting and cleaning activities) – Corrosion resistant – Portable and easy to handle
Standard operating procedure (SOP) and mine standard	• Temporary installation with jacks • Primary installation with stope tendons and/or elongates
Change management	• Support from senior management • Risk assessment • Stakeholder engagement • Communication and training plans (timely and continuous communication to the stakeholders) • Tendon washers size vs mesh aperture • Scraper shapes not to hook the mesh • Entry examination and making safe procedure review • Review of support installation sequence and procedure
Labour requirements	• No labour changes. Same labour as when using temporary nets • Consider workload and additional labour if not already using temporary mesh
Time requirements	• Reduced barring in zones 1 and 2 (access ways into the stope (gullies) and the face area before the last line of support) • Reduced end of shift procedure • Longer time to install
Logistics requirements	• Increased material transporting and handling
Cost	• Review support cost to incorporate permanent mesh
Quality of mesh usage	• Determine mesh KPI to monitor performance
Monitoring	• Mponeng Mine recorded: – A 20% reduction in FOG-related accidents in the first year of implementing the permanent mesh – An 18% reduction in reportable injuries due to FOG

5.1. CONSOLIDATION OF CASE STUDY FINDINGS CONTINUED

From the case studies what remains clear is the type of FOG risk required to be addressed and the common objectives of how the mesh is to be used, as illustrated in the graphs in Figure 20. What also stands out is the reduced area to be barred which was seen to provide the following two benefits: firstly the reduced risk associated with barring, and secondly, reduced time in the entry examination and making safe process (as shown in Figure 21). Although the latter was not well documented in the case studies, there is a general observation that the barring time was reduced. This is one of the benefits/opportunities that is still to be explored and measured.

In all the four case studies, there was already temporary mesh adopted before the implementation of permanent mesh. Hence there was no need to change the labour complement of the crews. It is important to note that this will not necessarily be the case for mines that will be introducing permanent mesh where temporary mesh is not currently in use.

Figure 20:
The need for permanent mesh from the case studies | **Objectives of the permanent mesh from the case studies**

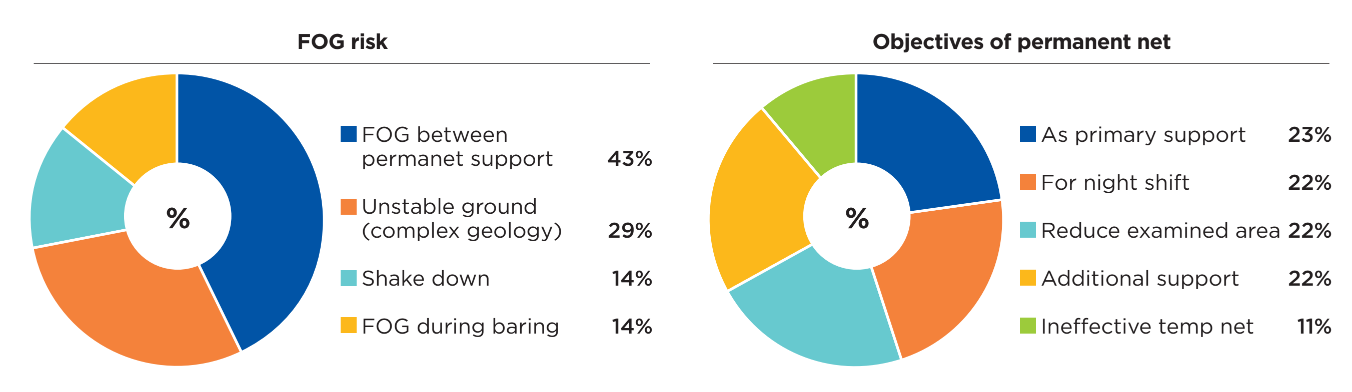
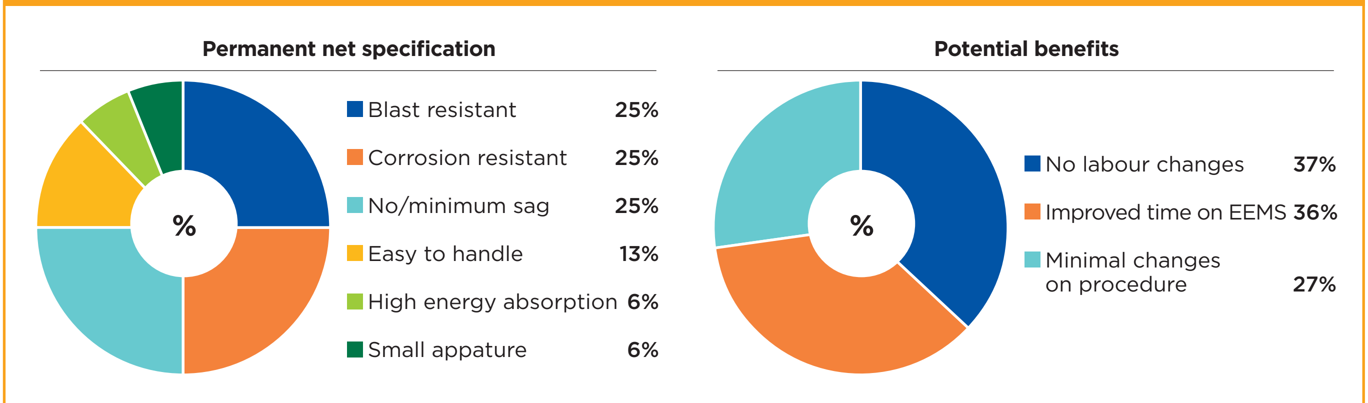


Figure 21:
Key mesh specification from the case studies | **Main benefits from the case studies**



5.2. IMPLEMENTATION PROCESS AND GAP ANALYSIS FROM THE CASE STUDIES

What makes the introduction of any technology successful is how the change is managed (i.e. the change from the old to the new). In all the case studies the fundamentals of good change management were appreciated and well managed. The following key elements of good change management stood out from the case studies: support from senior management, consultation with stakeholders and well-planned communication to employees. Figure 22 shows a typical change management process that was followed in the Mponeng Mine case study.

Figure 22: Example of the process followed in the Mponeng Mine case study for the successful adoption of permanent mesh

Project initiation
- RGM and GM of Mponeng commissioned the investigation of permanent mesh in September 2020

Investigation of the permanent mesh
- The investigation of permanent mesh wa held by REM
- Potential safety improvements
- 21% increase in support costs

Risk assessment and proposal to test
- 17 November 2020, to identify all risk associated with the installation of the permanent mesh

Engagement with stakeholder
- 11 December 2020 presented the proposal to test the mine's MHSC of the mine
- Endorsed by stakeholders

Trials and testing
- Completed in 25 March 2021
- Approved by SNR management and the mine's MHSC

Operating procedure
- 25 March 2021 the installation procedure was drafted

Support standard review
- Relevant standards updated together with training and awareness materials
- New material added to standard stock

Roll out and training
- Training on new standard given to shift bosses by rock engineering
- Training is the responsibility of the section mine overseer
- Supplier instructor conducted PTO

One of the shortcomings in the change management process used in the case studies was the lack of a well-planned consultation process with employees across all levels. This consultation process should have taken place in the form of focus group discussions. As part of the documentation of this practice the MOSH FOG team conducted focus group discussions at Mponeng Mine. Table 14 highlights and addresses the key gaps identified from the Mponeng Mine focus group discussion. The lack of adequate consultation with employees was identified as one of the major gaps in the change management process. A second key finding from the focus group discussion was the need for good role clarification and accountability in the introduction of innovative solutions. This would help to ensure good and consistent communication throughout the transition period.

Harmony Gold – Mponeng Mine

5.2. IMPLEMENTATION PROCESS AND GAP ANALYSIS FROM THE CASE STUDIES CONTINUED

Table 14: A summary of the feedback from the MOSH focus group discussions

	Themes	Lower management (crew)	Middle management	Senior management
1	**To understand the perception of fall of ground risk at the operation**	• There needs to be a common understanding on what is the hazard (what, where, when and how) and what are the controls (which, for what and how)	• There needs to be a common understanding on what is the hazard (what, where, when and how) and what are the controls (which, for what and how) • There must be good communication across all discipline regarding the hazards and controls (not only productions)	• Good understanding of the hazards and controls must be supported by a monitoring system focusing on control performance (leading indicators) against the hazard (lagging indicators)
2	**To understand the perception of falls of ground management at the operations**	• Individuals need to understand their role towards control effectiveness and performance (control ownership and management)	• Individuals need to understand their role towards control effectiveness and performance (control ownership and management)	• Risk management systems to focus, highlight and track crew compliance and behaviour. (crew and supervisor control ownership) • Investigation to establish the causes of non-compliance
3	**To understand the perception of the use and installation of permanent stope mesh support**	• There needs to be: – Consultation and input from users in developing the standard and procedure – Timely communication of the proposed changes – Quality training and instructors	• Supervisors and service departments to be empowered as change agents • Training and communication to middle management to be prioritised • Technical understanding to measure the impact of mesh	• Properly define the mesh system and the changes to work process, equipment and change on workload • Identify factors that impact load on crews such as level of absenteeism
4	**To establish the behaviours required for adoption of mesh**	• Poor communication of real issues within the crews and management e.g. absenteeism impacting workload (honesty) • Reporting and communication systems (system that empowers the crew to communicate freely)	• Role appreciation as the key change agents • Knowledgeable and effective communication on the practice	• Decision to adopt must be supported in mine's systems "incentives" • Clear rules on the use of the mesh "willingness to lose production" • Continuous communication on the impact of the new practice (positive stories and challenges that are resolved)
5	**To establish the perception on the effectiveness of permanent stope mesh on FOG**	• There needs to be a common understanding on what is the hazard (what, where, when and how) and what are the controls (which, for what and how)	• Communication to be on actual KPI to empower	• Clear value proposition supported with clear KPI for monitoring

5.3. THE HUMAN BEHAVIOUR AND LEADERSHIP ASPECTS

The MOSH FOG team examined information from the case study analysis and the focus group discussions and developed behavioural communication and leadership behaviour models that can assist in the successful and sustainable adoption of permanent workface mesh. Table 15 and Table 16 provide summaries of the key behavioural communication and leadership behaviour elements that will make the adoption of permanent workface mesh successful. This section also provides information about management of change consideration (Table 17) and change management considerations (Table 18) for the adoption of permanent workface areal mesh. Having looked at the two there is little added by splitting it into two different sections. It could all be in one section and cause less confusion.

Table 15: Required leadership behaviours

Requirements	Description
Rationale and objectives (setting the context)	• It is important that the reason for the adoption of permanent workface areal mesh be understood. This requires: – The type of FOG hazards (mechanism) being targeted to be well defined as well as the extent of the FOG risk across the operation also be well defined – This will translate into the value of the mesh to the operations and a clear direction on the monitoring and evaluation of the effectiveness of the mesh
Support for adoption	• The MOSH adoption process requires precise execution of each of the seven steps to ensure seamless and sustainable change. This means that adequate resources need to be made available and roles and accountabilities should be well defined. • The adoption process must be escalated to monthly senior management meetings (MANCO / EXCO / OPSCO) to ensure timely interventions and support. • The Mine Health and Safety Committee structures need to be consulted to obtain buy-in and support.
Communication	• It is important for all the relevant disciplines (rock engineering, safety, geology, mining, ventilation, survey, Mine Health and Safety Structures and labour representative i.e. all persons entering the workface) on the operations to be made aware of the permanent workface areal mesh and have the same appreciation of the adoption of the leading practice. This ensures a consistent message across the operations. • The communication needs be timely with clear messages. • The communication must always be in an official format such as but not limited to: – GM/Mine Manger Briefs and/or circulars and/or other official forms used by the operations for GM/ Mine Manager to communicate • Identify the misconceptions about the leading practice and develop a communication plan to address the misconception e.g. the permanent mesh does not replace good barring practices, people won't be rescued in time if mesh is used, etc.
Management of change	• A detailed management of change plan will ensure that all technical issues that need to be addressed are identified and managed accordingly. • The management of change plan must detail the following: – The testing and/or trial process of the permanent workface areal mesh – The processes and activities involving the permanent workface mesh – The equipment and accessories that are required in the use of permanent workface mesh (handling and installation)
Systems review and update	• It is important to ensure that management systems are in place to support and inform decisions made by management. • When adopting the permanent workface areal mesh, the monitoring and evaluation systems must be revised and updated to incorporate the use of mesh. • Some of the key element to be considered are: – Procurement systems: The correct usage of mesh through the consumption and cost – Correct installation (compliance to the standards) – Quality assurance and quality control (QA/QC)
Training	• It is important to note that training for the use of this mesh is relevant to all employment levels across the operations and not only the lower-level employees. • Awareness training on the adoption of permanent workface areal mesh must be conducted for all disciplines involved in and affected by the adoption. This includes senior management and all service departments. • Application training must be conducted for all users, and the training package must be developed following trial and testing of the permanent workface a real mesh.

5.3. THE HUMAN BEHAVIOUR AND LEADERSHIP ASPECTS CONTINUED

Table 16: Role and responsibilities

Role	Responsibility in the adoption of permanent workface areal mesh
Mine manager	• Take the decision to investigate the adoption of permanent workface areal mesh • Appoint a champion to lead the adoption team. A champion is ideally a person in a position of influence (HOD). Preferably the section manager (mining manager) or the 3.1a appointee • Appoint a multidisciplinary adoption team • Provide support by making the adoption of permanent workface areal mesh a discussion item in the monthly MANCO meeting
Rock engineer	• Investigate and recommend the use of permanent workface areal mesh (specification, support standard) • Monitoring the mesh installation and performance during routine visit • QA/QC of the permanent workface areal mesh
Mine overseer	• Schedule the roll out and crew training in area of responsibility
Shift overseer	• Facilitate the adoption process through communication • Monitor and report finding on the use of permanent mesh to the rock engineer • Conduct planed task observation (PTO) on the installation of the mesh and provide continuous couching to improved quality of installation
Miner and crew	• Monitor and report finding on the installation of permanent mesh to the supervisor and rock engineering department
Safety department	• Facilitate the management of change by ensuring the following: – Procedures are updated – Monitoring and measurement systems are updated (compliance, control performance and risk)
Full time health and safety representative	• Must be well informed about the leading practice adoption and key requirements to communicate to front line workers • Must record and promptly report any findings (positive and/or negative) to the safety department and/or rock engineering department
Human resources / training	• Together with the OEM develop and update training manuals • Ensure sufficient training personnel are available to cover the mine as per the determined adoption plan. Consider the following: – Collaboration with the OEM to have an instructor on the mine • Provide and record all training and refreshers
Resourcing and logistics	• Review and plan for the additional material handing brought about by the introduction of permanent mesh • Consider some of the following aspects for review: – Number of material cars – Storage both underground and surface

5.3. THE HUMAN BEHAVIOUR AND LEADERSHIP ASPECTS CONTINUED

Table 17: Management of change considerations

Consideration	Description
Mesh and equipment testing	• The testing phase is most critical, as this is when the concept and methods (SOP and Standard) are refined. • The test must end when a practical and sustainable solution on the use of permanent workface areal mesh is found. i.e.: – Correct mesh – Correct equipment and accessories – Installation procedure
Issue based risk assessment	• A multidisciplinary issue-based risk assessment (IBRA) must be conducted before and after the testing. • All potential hazards introduced when using permanent workface areal mesh must be identified and remedial actions developed. • This includes but is not limited to damaged mesh and falls of ground on mesh
Standard operating procedure (SOP)	• The remedial actions from the Issue Based Risk Assessment "IBRA" must be incorporated into the SOP to ensure the solutions
Mining standard	• A practical mining standard must be developed, and it should consider the following: – Face advance, support spacing, entry examination and making safe process
Training	• The training that is conducted must cover all key elements of the standard operating procedure and the mining standard
Procurement	• It is important to ensure the selected mesh can be procured and is made available to meet the needs of the operations in a timely manner
Monitoring	• Monitoring systems must be updated in line with the new processes and equipment i.e.: – Rock engineering and safety monitoring systems – Put in place KPIs to measure the performance of the permanent mesh. Consider: o FOG frequency o accident severity o lost blast due to FOG o lost reserves due to unstable ground o support consumption due to unstable ground

Table 18: Change management considerations

Considerations	Description
Stakeholder consultation	• Share the strategic vision and where the leading practice fits • Build coalition with stakeholders (tripartite)
Worker / crew consultation	• Employees to have input into the functional detail of the leading practice aligned to the strategic vision (ownership) • Conduct focus group discussion to solicit input
Communication	• Establish communication channel that removes barriers and reduces misunderstanding • Management of worker engagement during the transitions (face to face) • Constant feedback and update on the progress towards agreed goals

6 BUSINESS / VALUE CASE

The objective of documenting and evaluating a practice is to ultimately determine if there is value that can be gained by the industry through wide-spread adoption of such a practice. In determining the value of the practice, we evaluate the potential benefits offered against the challenges it presents and what other opportunities may arise. The business case and the value of the practice is best summarised using the SWOT analysis presented in Table 19. The analysis shows that the strengths and the opportunities outweigh the challenges. The threats identified can be addressed by applying the adoption guide developed for the permanent workface areal mesh.

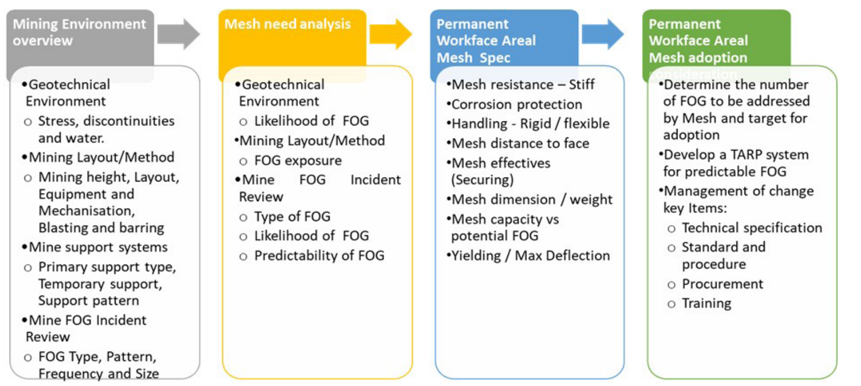
Table 19: SWOT analysis

Strengths	Weaknesses
• Improvement from temporary nets with bolts which have been very successful • Ensuring the continued success of the temporary nets across the whole stope and not only the face • Minimal change management when already using temporary nets with bolts • Reduces area that needs to be barred daily • No additional labour requirements for mines that currently utilise temporary nets with bolts • Improved FOG safety performance in areas where the permanent mesh is well installed	• Increased direct support cost • Increase support material handling and transporting • Steel mesh / nets are heavier than temporary nylon nets • Additional time and labour requirements for mines that do not currently use temporary nets with bolts
Opportunities	**Threats**
• Reduced overall entry examination and making safe time (reduced barring) • Revision of support systems with improved support interaction between primary support units (not reducing support spacing when using net) • Revision of the TARP systems (triggers) with the use of permanent mesh, reducing TARP stoppages • Reduced number of FOG accidents associated with FOG between support • Overall reduced number of stoppages associated with FOG incidents and accidents • Increased time to focus on production activities	• Not clearly defining the objectives of the use of the permanent mesh / net on the operation • Failure to consult stakeholders in the decision to adopt permanent mesh / net • Not clearly communicating the objectives and intention for the use of permanent mesh • Failure to monitor the performance of the mesh against the set objectives and KPIs • Failure to monitor FOG safety performance before versus after the mesh installation • Failure to develop a business case and/or value proposition for the use of permanent mesh on the operation • Limited number of suppliers of blast resistant mesh

6.1. ADOPTION EVALUATION GUIDE TOOL

The documentation of the case studies showed that there are specific needs (conditions and hazards) for the use of permanent workface areal mesh and it's when these conditions exist that the practice needs to be considered. To better draw the value from the practice for the different types of underground mining operations a high-level adoption guide is presented to evaluate the needs of the mine and how best to adopt the use of permanent workface areal mesh. Figure 23 illustrates the adoption guide tool process flow and the key elements to be considered.

Figure 23: MOSH FOG permanent workface areal mesh adoption guide tool



7 CONCLUSIONS

Permanent workface areal mesh is an evolution from one of the most successful leading practices to be introduced into the industry by the MOSH learning hub being the nets with bolts leading practice. Building on such success, the permanent workface areal mesh can only bring about the much-needed step change in reducing the FOG related accidents in the industry. There are clearer benefits to some operations than others but with widespread adoption and use, the identified opportunities can be realised. Widespread adoption will enable knowledge sharing and increased innovation on the technology, making it much more accessible and easier to adopt. The adoption evaluation guide tool developed by the MOSH FOG team is comprehensive:

- To enable easy adoption for various mining environments
- To ensure that the practice is successful and sustainable
- To add value to the industry

Sibanye-Stillwater – Northwest Platinum Operation

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