OPTIMISATION OF THE SHAFT CALL FACTOR THROUGH IMPROVING THE ADVANCE STRIKE GULLY GEOMETRY AND ITS CONDITIONS AT DOORNKOP SHAFT

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A research 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 of Masters of Science in Engineering.

Johannesburg 2018

DECLARATION

M Nelwamondo 467148

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

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(Signature of Candidate)

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ABSTRACT

Doornkop Shaft had a regression in the Shaft Call Factor (SCF) from the year 2012 to 2017 of about 26%. This regression continued to a SCF of 59% in February 2017, against the plan of 81% of the year 2017 budget. The SCF is the ratio, expressed as a percentage, which the specific product accounted for on the belt as dry tonnage is compared to the corresponding product called for by a survey measurement from underground sources. These underground sources include amongst others a blasted stope, which requires an Advanced Strike Gully (ASG), orepass, haulage and skip to transport the blasted ore from the stope to the belt. This research study seeks to optimise the SCF through the improvement of ASG geometry and conditions. This improvement is done through the prevention of any loss of ore likely to occur during the cleaning process due to the geometry and conditions of the ASG.

The research study was carried out using quantitative methods in data collection through underground visits, grade reports, Radio Frequency Identification (RFID) tags report (Appendix B) and sampling sheets. Thereafter analysis was conducted. The correlogram was conducted to analyse the correlation between the SCF to the gully depth, width and length. The research study findings indicate that the geometry and condition of the ASG encourages the loss of ore during the cleaning process. This loss occurs mainly through accumulations, which negatively impact the SCF on a month-to-month basis. The study further, found that a 14 % gain to the SCF can be achieved if these accumulations are cleaned to surface. In addition, it is recommended that ASG's geometry must be developed to the required mine standard, as that will ensure ore capacity and easy flow of ore to the ore pass.

DEDICATION

I dedicate this report to my wife Priscilla Nelwamondo and my children Thando and Pfano Nelwamondo for giving me enough time for my research more especially when they needed me most. I dedicate this research study in memory of my father Mr. Ratshilumela Alfred Nelwamondo.

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1 INTRODUCTION

1.1 Research Background

Ore flow is the process of calculating survey call from planned figures through blasted ore from the stope, face grade, tonnage from on reef developments, ore trammed from ore passes, ore hoisted to the surface, discrepancy between the hoisted ore, available for hoisting, milling process and calculation of factors. There are different factors in the ore flow (Appendix E) such as Shaft Call Factor (SCF), Mine Call Factor (MCF), Plant Call Factor (PLC), Plant Recovery Factor (PRF) and Mine Recovery Factor (MRF). The research study focuses on the optimisation of the SCF.

The difference between the SCF and MCF is the Plant Call Factor (PCF). PCF is the ratio expressed as a percentage at which the gold recovered plus residues are compared with the shaft tonnage. Optimisation is the action of making the best or most effective use of a resource and it is done to improve the production and productivity of the operation. This research study focuses on improving the shaft call factor (SCF). Shaft Call Factor is defined as the ratio, expressed as a percentage, which the specific product accounted for on the belt as dry tonnage compared to the corresponding product called for by survey measurements, vamping and mud available for hoisting (Harmony Gold Mining Company Limited, 2016). Mine Call Factor is defined as the ratio of the gold accounted for over the gold called for, expressed as a percentage.

The SCF can be affected by several elements within the real and apparent losses categories; however, the research study will focus more on the impact of ASGs conditions. The real losses take place during the flow of ore process from underground sources to the plant. Flow of ore is defined as the movement of ore from the blasted face through sweepings, scraping into the advance strike gullies, ore passes, haul through locomotives, skips and then conveyed to the plant. All elements along the flow of ore chain have a potential of a negative impact on the SCF, however, the research study focuses on ore in the advanced strike gullies as one of the important aspect during the flow of ore. As mining advances and especially when the mining depth increases, stope advance strike gully (ASG) scrapers were necessary and were first introduced at the Modderfontein B Gold mine in 1984 (Naidoo, *et al*., 2002). The gully is an excavation cut in the immediate footwall of the reef for the purpose of enabling the removal of the rock blasted from the stope face or providing access to the face for miners and materials.

The advance strike gully serves as the dedicated route for cleaning the blasted ore and each operation has the standardised geometry in terms of the length, depth and width in order to recover ore more efficiently. In 2002, 100% of the advance strike gullies were confirmed to be not cleaned at Tautuna mine leading to damages to gully hanging wall, difficulty of examining the hanging wall and revenue losses since the broken ore is stagnant in the gully instead of being treated (Thompson, 2002). Thompson (2002) indicated that 82% of the gullies were deteriorated barely 30m from the gully face due to the convergence rate and this can results in ore not easily recovered because of the reduction of gully height. The term gully was not adopted in 1932, but ore cleaning used to be done through on-reef drives, exploration drives and tramming routes. Most documented cases show that advance strike gully problems have been recognized for over 70 years (Naidoo & Handley, 2002).

The standard gully geometry standard mostly used is a width between 1.6m and 1.8m in order to have adequate capacity for the blasted ore, people and material access (Figure 1.1). The ASG is designed and mined 2m ahead of the mining face with a siding being 3m behind the face. There is a clear distinctive link between the SCF, face blasting practice and ore cleaning. This distinctive link exists because mineral content cannot be liberated if the ASG depth, width, length and direction does not adhere to the required mine standard.

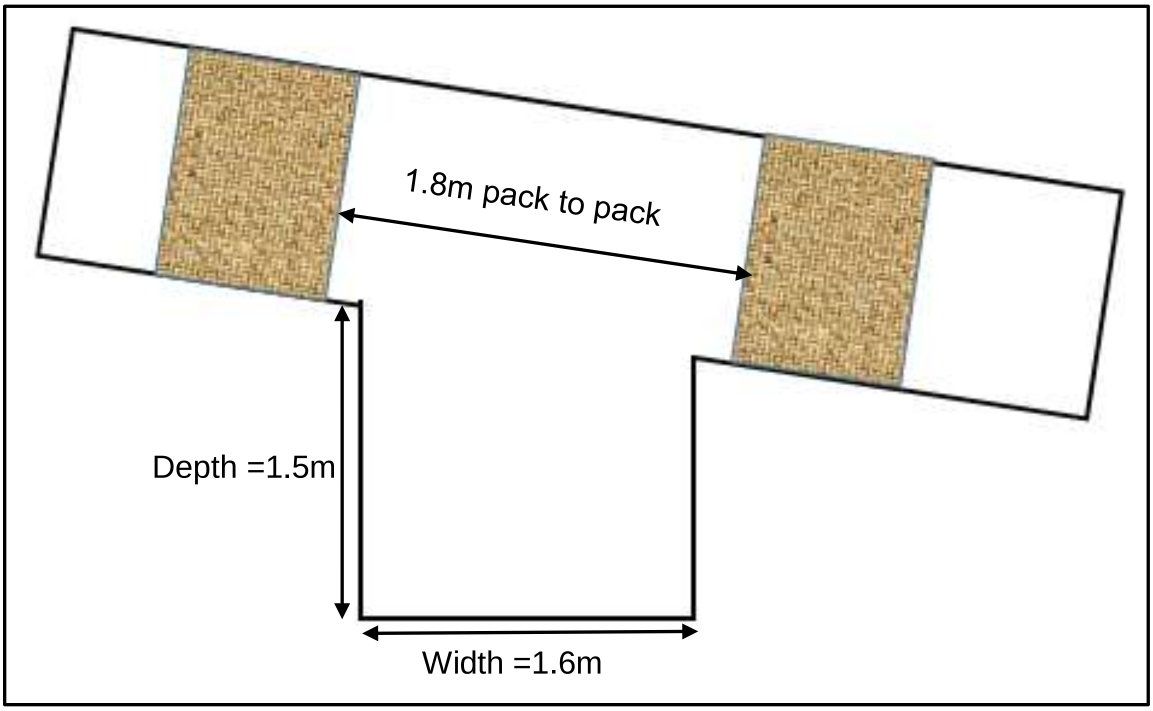


Figure 1.1 Gully geometry (Gaula, 2015)

Figure 1.2 shows the total ore from stopes in relation to ore available for hoisting to the plant through the surface belt. The ore tonnage available for hoisting are a combination of total trammed tonnes, which include vamping tonnage, development reef tonnage to mill and mud. About 90% of the tonnages passing through the surface belt are from the stope sections as per survey measurements. The research study focused on the stope sections advance strike gully in order to improve the SCF conditions through enhancing its geometry and conditions.

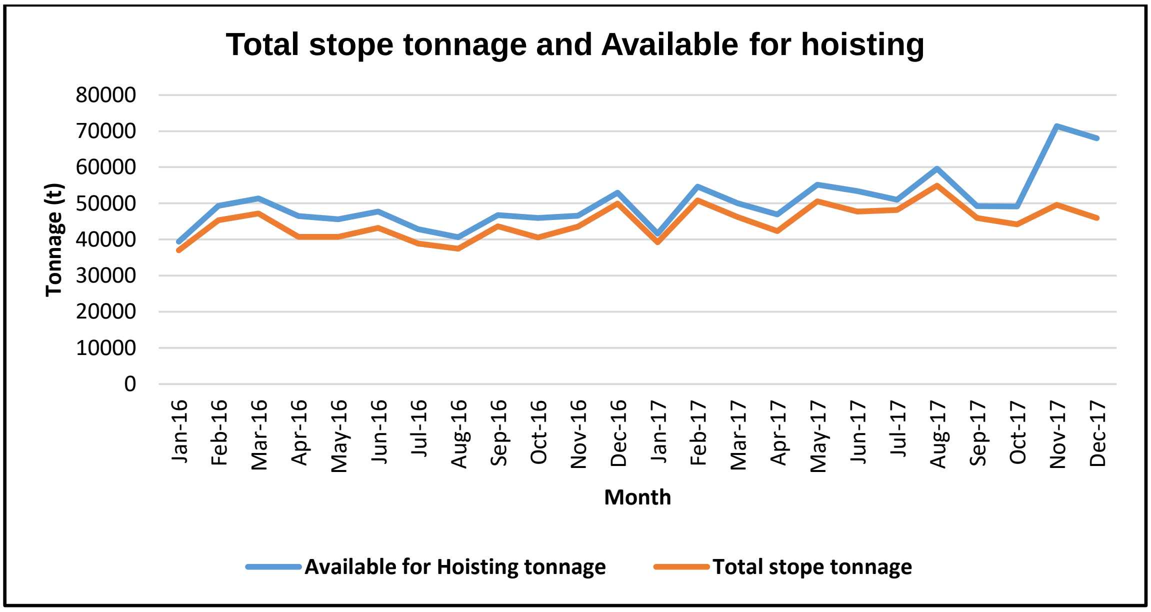


Figure 1.2 Stope tonnage and available for hoisting tonnage

The difference between available for hoisting tonnage and hoisted tonnage is called discrepancy tonnage. Tonnage discrepancy can be negative or positive and it is important to investigate the source. It is necessary to investigate the tonnage discrepancy as it can increase the gold in the residue due to additional tonnage. The negative discrepancy tonnage has a negative impact on the SCF for that specific measuring month, because ore called for is not recovered. Negative tonnage called for can probably be removed by vamping at an additional cost. If the discrepancy is positive, there are additional tonnage unaccounted for and can come from either waste or ore tonnage which can have an impact on the ore grade, thus, increasing the processing cost. From October to December 2017 there was an average of 29, 451 positive discrepancies and average SCF of 74% which is far below the budget of 81%.

Figure 1.3 shows the discrepancy in tonnage from January 2016 to December 2017; where more or less 59, 406 tonnes were unaccounted for as per survey measurements from underground sources. Discrepancy tonnage are above the planned 8% tonnage in several months in a two year period from 2016 to 2017, see Figure 1.3. This occur when tonnage blasted in previous months are cleaned during the current month without being quantified, over or under measuring and even fall of grounds not recorded during the month.

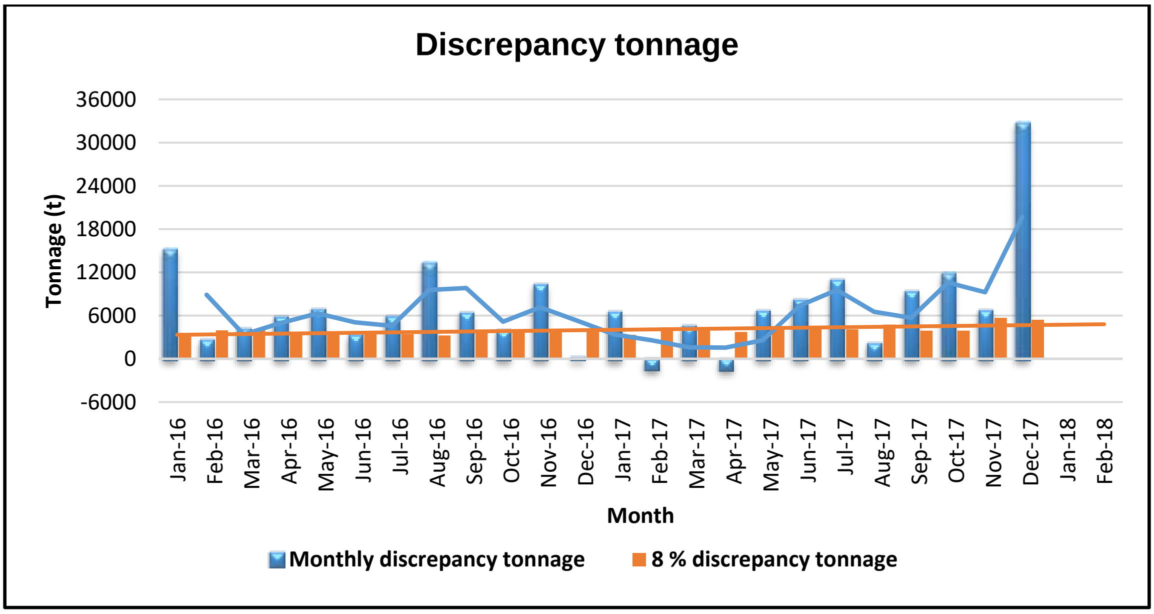


Figure 1.3 Discrepancy tonnage from year 2016 to 2017

The mine standard states that sweepings must be kept at a maximum distance of 9m from the face, therefore, when sweepings measured are 9m or less away from the face, the working place is said to have passed the sweepings and this includes the strike gully area of the 9m advance from the face. When the tonnage achieved from blasting the panel for the month is equal to the swept tonnage for the month, the panel has achieved 100% sweepings for the month.

The sweeping concept does not take into account tonnage accumulated in the advance strike gully. Therefore, a panel can achieve 100% for sweepings while the ASG is full of blasted ore. This has a negative effect on the SCF, since the SCF is based on the survey measurements and the ore hoisted from working areas. The SCF at Doornkop Shaft from 2012 to 2017 (Figure 1.4) showed a continuous regression and there is a need to further investigate. This is mathematically expressed as in Equation 1 (Harmony Gold Mining Company Limited, 2016):

$$SCF = \frac{Grams\ of\ gold\ delivered\ on\ the\ belt\ (dry\ tonnes)}{Grams\ of\ gold\ available\ for\ hoisting\ (survey)}\ x\ 100\% \qquad (1)$$

Figure 1.4 shows the SCF for Doornkop Shaft from 2012 to early 2017 as per ore flow. The SCF shows a continuous regression and there is a need for further investigation on the tonnage blasted, ore cleaning, tramming and any or flow of ore system pertaining to low SCF. The research study is focusing on phase A and B whereby the SCF showed a significant drop.

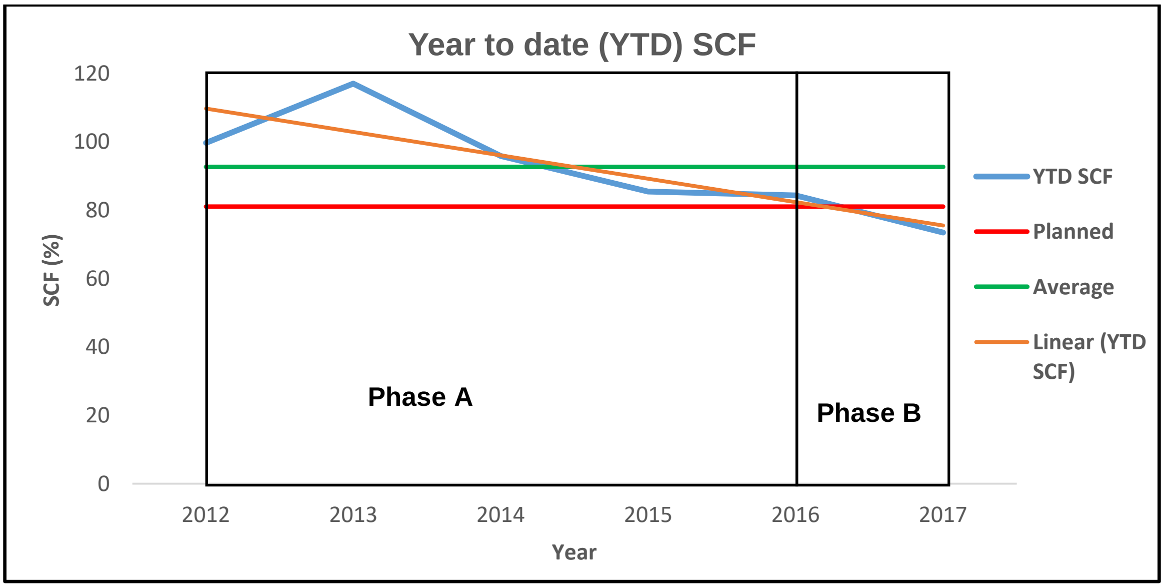


Figure 1.4 Shaft Call Factor

Figure 1.5 shows the grade comparison between the face grade, belt grade and recovery grade from the year 2012 to 2017. Thereafter, as years progress there is a downward trend from year 2012 to 2014 and flattens to 2017 in terms of the belt grade. In year 2012 to 2013 the face grade had a downward trend and there is gradual increase on the face grade from 2013 to 2016. This gradual increase from 2014 to 2016 shows focus in mining blocks of ground above the 680cmg/t cut-off grade and a possible improvement on the stoping width. In year 2016 to 2017 both the face grade and the gold recovered grade dropped, but the belt value slightly increased, however, the belt grade has shown similar trend with the gold recovered grade and face grade over the years.

If flow of ore systems are not monitored to ensure that blasted ore is cleaned efficiently in advance strike gully, cross tramming of waste to reef belt, liberation of metal during sweeping and loss of metal during tramming and hoisting can have a negative impact on the SCF and the belt grade. Poor grade control systems have a negative impact on the belt grade as a result affecting the recovery grade and profitability of the operation.

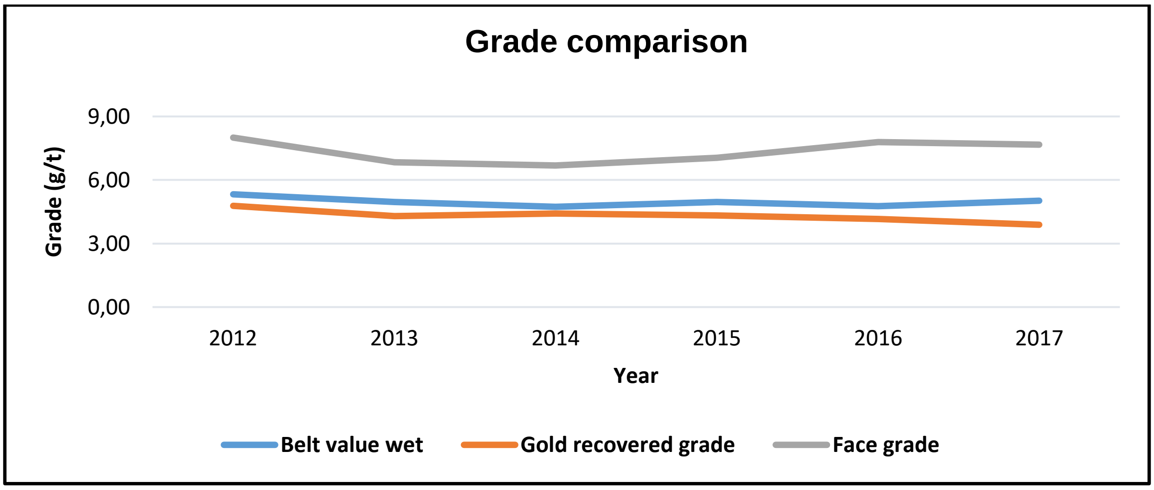
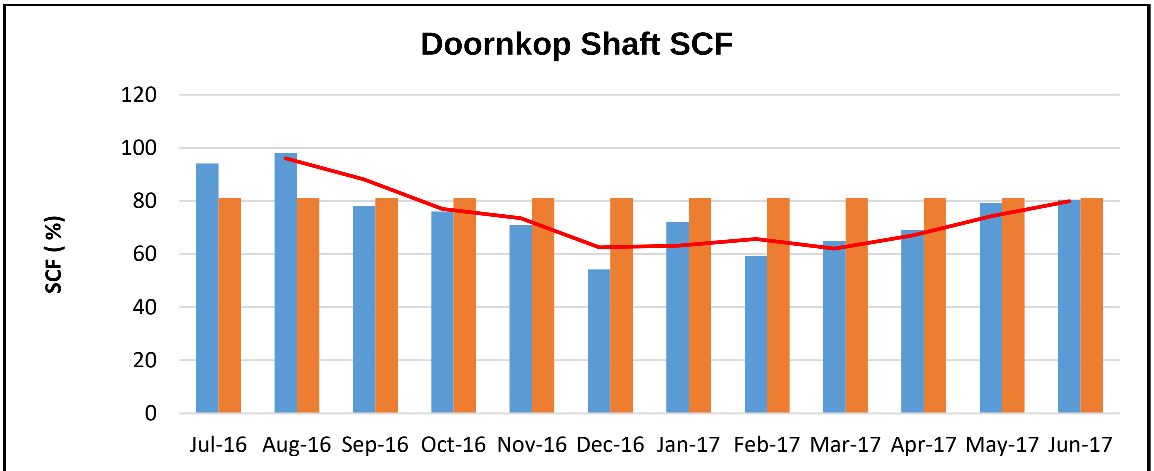


Figure 1.5 Grade comparison

Figure 1.6 indicates the Doornkop Shaft SCF from July 2016 to June 2017. The SCF plan for the year 2017 was 81% and only two months out of 12 months reached the planned target. In April 2017, the SCF gradually increased after the implementation and follow up on the flow of ore tracking systems such as RFID tags.



	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17
Actual(%)	94	98	78	76	71	54	72	59	65	69	79	80
Planned(%)	81	81	81	81	81	81	81	81	81	81	81	81

Figure 1.6 Shaft Call Factor for 2016 to 2017

The SCF percentages indicate that the product accounted for on the surface belt does not correlates to the product called for by survey measurements resulting to SCF regression. This regression of the SCF from October 2016 to March 2017 calls for further investigation in order to solve the problem in the operation. In March 2017, flow of ore tracking tool systems such as the radio frequency identification, radio frequency identification (RFID) tags, PTO's (planned task observation) on gully depth measurements were implemented. During the continuous regression of the SCF, analysis of RFID tags is used to understand the entire flow of ore. RFID tags consist of a small chip and an antenna and have a frequency machine that detects the antenna and it is linked to a computer, which populate a report. RFID tags are populated to different underground sources by geologists, samplers and surveyors. The RFID tags from advance strike gully should pass through the surface belts normally after 3 to 5 days instead of 15 to 25 days. This transit of RFID tags between 3 to 5 days will give an impression that there is no accumulation of ore from underground sources. The assumption of receiving RFID tags after so many days is that advance strike gully are not cleaned sufficiently, and this calls for investigation on the advance strike gully conditions.

Figure 1.7 shows the RFID tag report for April 2017, whereby an average of two tags passed through the surface belt monitor between 6 days and 156 days and all these RFID tags were from advance strike gully. The RFID tag report brought attention towards the advance strike gully and there is a need to further investigate its condition especially against the flow of ore, because most of the tags reflecting after 10 days plus are coming from the strike gullies.

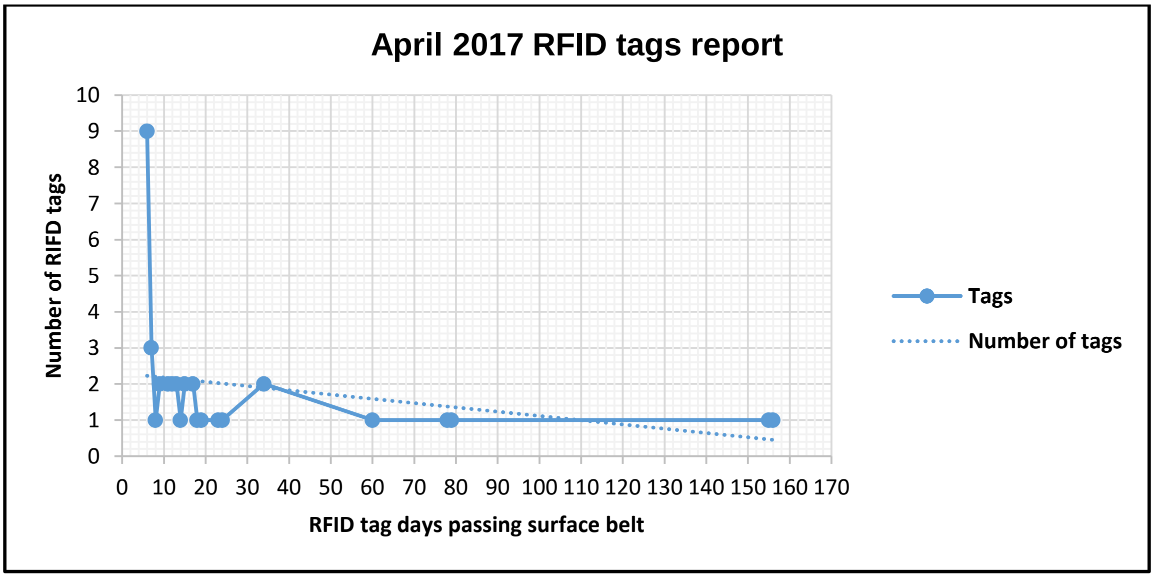


Figure 1.7 RFID tag report

Different systems were introduced in order to manage the ore discrepancy as it can lead to low profitability. The systems used to monitor and audit flow of ore from underground to the surface is through grade control, the ore tag tracking system, sweeping audits in the panel faces and ASG, mapping report for checking off-reef panels and grade quality reports.

The gold mines generally follow the system of strike to center gully mining. A raise is developed on-reef along the true dip and it becomes the center gully of the stope during stoping. Every stope panel has an advance strike gully (ASG) carried above the strike of the reef and advance away from the center gully along the strike of the reef (O' beirne & Cantab, 1979).

The tonnage accumulation in the ASG consists of current sweepings ore that is called for by mine measuring methods but was not removed during the time of the metal accounting as a result the ore gets compacted if not properly cleaned. When this broken ore is cleaned it is categorised as old gold during the vamping stage of mining. Advance strike gully cleaning can be seen as a barrier that may limit face advance because if not cleaned during night shift, day shift employees must first clean the panel before drilling (Van der Merwe, *et al.*, 2001).

Ore loss refers to any unrecoverable economic ore left inside a stope (broken) or to any valuable ore not recovered by the mineral processing system and the unfortunate part is that these broken tonnages have been called for and paid for during that measuring month. This creates bottlenecks in terms of daily stope face cleaning. Thus, the crew may lose a blast.

1.2 Doornkop Shaft location

Doornkop Shaft is located in the Gauteng Province of South Africa, about 30km west of Johannesburg, on the northern rim of the Witwatersrand basin. The operation is currently mining the South Reef conglomerate using convectional breast mining method. The ore is being processed at Doornkop Plant, which is about 100m from the shaft. The mine focuses on mining only areas above cut off of 680cmg/t on the South Reef in order to increase the profitability rate especially during the higher gold price seasons, although the traditional norm is that of mining marginal blocks of ground when the gold price is at its peak. The mine achieved about 87 772 oz of gold during the year 2016.

Figure 1.8 shows the location of Doornkop Shaft in South Africa and surrounded by Durban Rooderpoort, Rand Uranium, which is now Sibanye Gold (Cooke operations) and Luipaardsvlei towards the north.

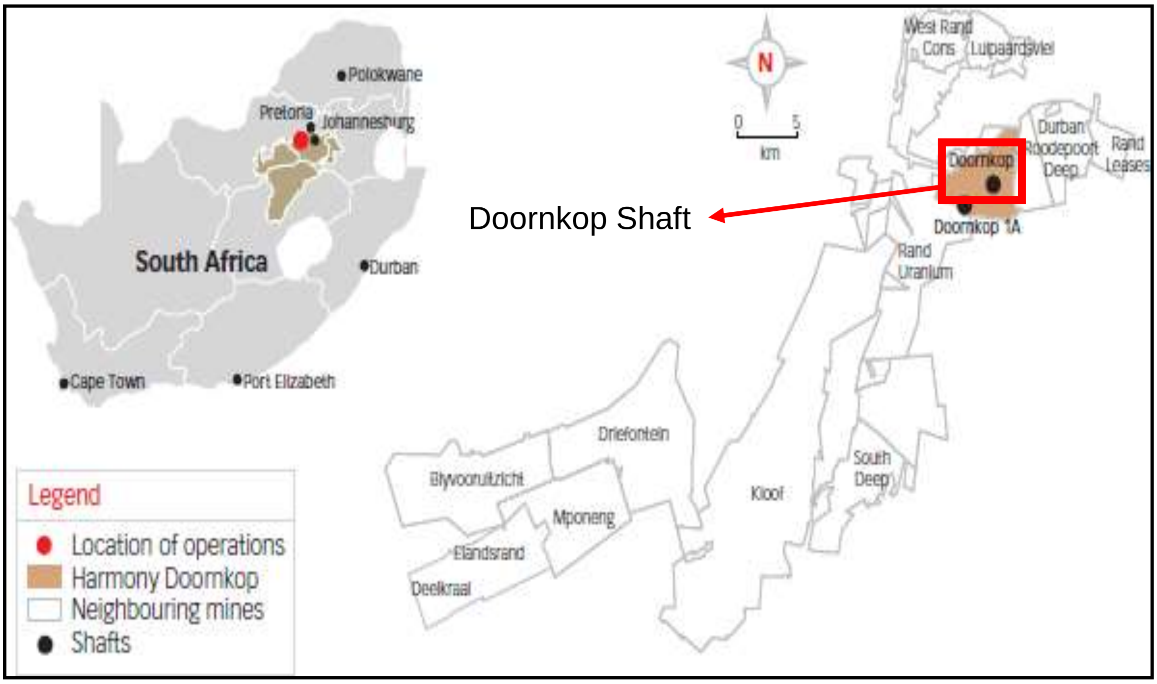


Figure 1.8 Doornkop Shaft location (Harmony Gold Mining Company Limited, 2009)

1.3 South Reef sedimentology

The South Reef channel consists of several conglomerates with the thickness ranging from 3cm to 10cm with blue and white gritty pebbles on the footwall and within the conglomerate matrix.

Figure 1.9 shows the Witwatersrand super group stratigraphy and the research project focuses on the South Reef situated within the Randfontein formation. The South Reef was deposited about 60m above the Main Reef.

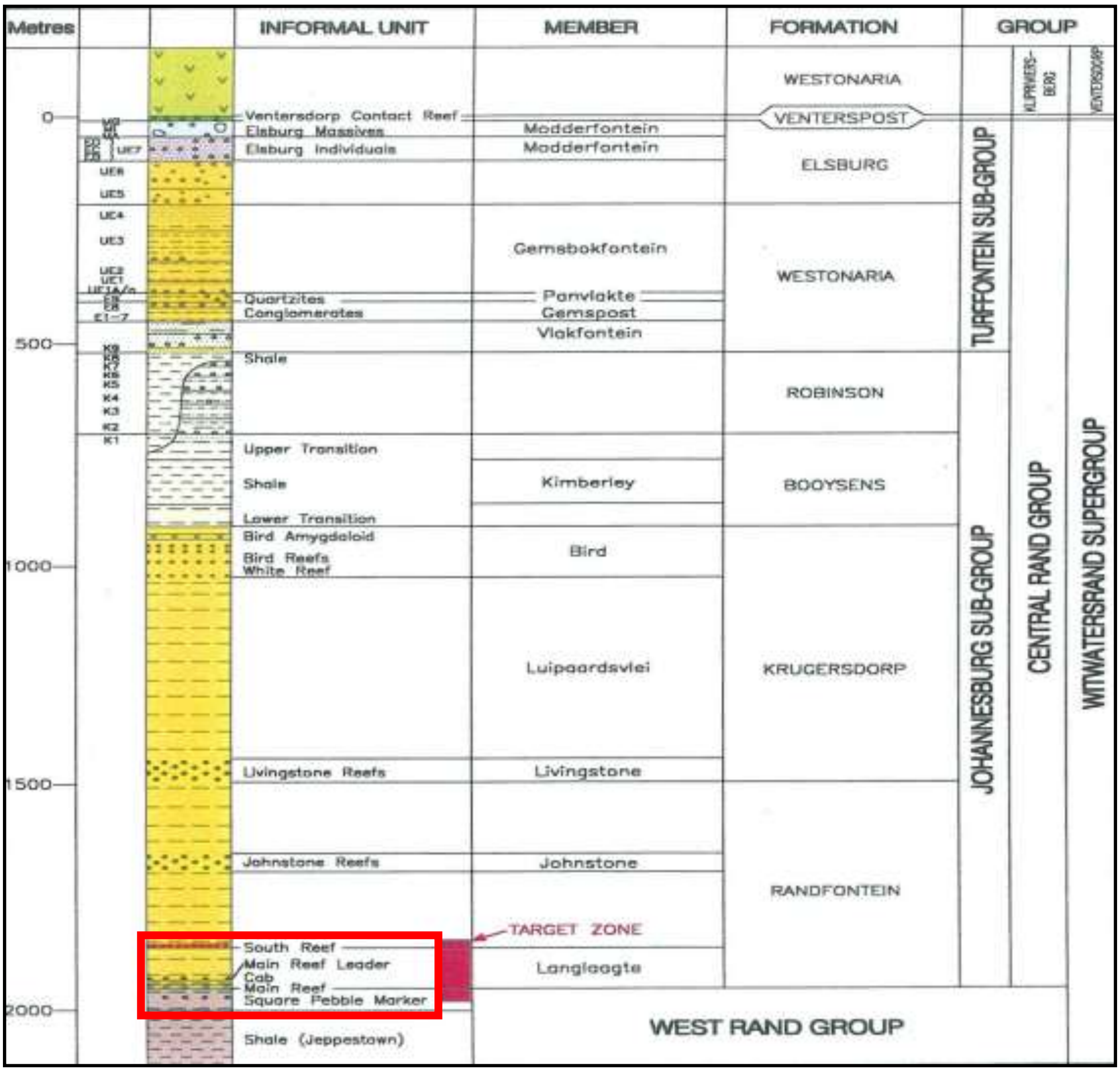


Figure 1.9 The South Reef stratigraphy (Harmony Gold Mining Company Limited, 2013)

The South Reef has light-coloured vitreous quartzite usually predominates above the South Reef. Blue – shot grit, thin khaki shale partings and dun – coloured quartzite are present. The hanging wall of the South Reef contains a number of leader bands that contain less sporadic gold values than the lower-most band. The pebble intervals are matrix to clast supported with carbon spikes in between the matrix and sometimes seam carbon stringers on the bottom contact. Grade increases from the leader bands towards the first bottom conglomerate which is the South Reef.

The conglomerate that Doornkop Shaft is currently extracting is called South Reef and all the other conglomerates above are defined as South Reef leader bands. The conglomerate has more or less round to sub-round smoky to milky quartz pebbles and splits easily from the rock strata due to carbon around the matrix. In the South Reef conglomerate, there are accessories of chloritoid specks, muscovite, and sometimes zircon. These chloritoid speck constituents are also present in the barren quartzite, which separates the conglomerate and they have been cemented in the conglomerate by the same silica cement through metamorphic action (Delaunay, 2003).

The depositional channel represents a high energy inflow where sufficient reworking occurred to concentrate gold as is postulated for the South Reef in general. The South Reef band carries most of the gold but the leader bands are payable in some localities. In numerous localities, the South Reef is poorly developed and may be represented by a narrow stringer of carbon on a scour surface where some gold values may be present and gold is often visible in these thin conglomerates.

Figure 1.10 shows South Reef sample having the carbon around the matrix including smokey quartz pebbles where the conglomerates in a channel are between 3cm to 5cm in thickness.

The carbon surrounding the matrix can be removed during the sampling and overcharging up of the stope face resulting to gold liberation.

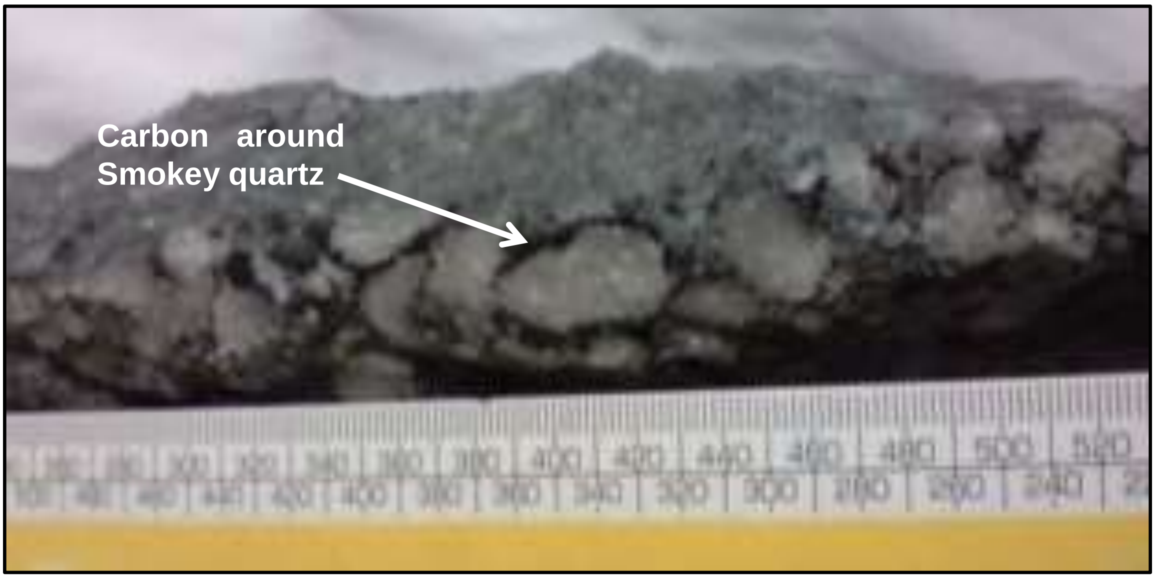


Figure 1.10 South Reef sample (Doornkop Shaft, 2017)

1.4 Problem definition

In 2016, Doornkop Shaft planned to achieve a SCF of 81%, however, the actual SCF achieved was 59%. Thereafter, further statistics were derived from grade reports and RFID tags. Statistics through grade report and RFID tags report (see Figure 1.7) shows that there is an increase in locked up tonnes in gullies as most of the RFID tags buried in advance strike gully were retrieved after more than 10 days. Although the monthly impression after measuring is that when sweepings have passed on the face, ore tonnage is at the plant and in most cases opposite is the case. Sweepings on the face do pass, however, every measuring month end strike gullies are full of tonnage and if not cleaned efficiently between the 14 days to milling month then tonnage gets locked up influencing the SCF for that specific month. Doornkop Shaft is mining a carbonaceous reef and when over blasted it creates fines and if there is a delay on cleaning such tonnage it gets compacted when mixed with drilling water and this can influence the SCF for that month due to ore left compacted on the strike gully footwall. There is a need to efficiently clean the stope working places during the measuring month in order to reduce the vamping percentage and increase the current sweepings, thereafter, increasing the SCF for that month.

There is a discrepancy of about 2.5g/t between the face grade and the belt grade, increase in lock up tonnage and poor conditions of the strike gullies and this has led to a question: *How can the shaft call factor of the measuring month be improved through ASGs geometry?* It is common knowledge that there are several factors that affects the SCF in the mining environment, however, the research study focuses on strike gully conditions and when addressed can influence efficient transit of ore from the face to the ore pass for the measuring month, thus improving the SCF for that measuring month.

The research study focuses on the gully conditions in the operation in relation to ore cleaning, which have been one of the major concerns in the shaft such as:

- Long ASG resulting in long pull affecting the cleaning rate of the face and gully for year 2017;
- Shallow ASG leading to overflow of ore to the sides and contamination of back areas;
- Off-line ASG resulting to accumulation of ore and water around the curves causing losses of gold metal content;

- Compaction of ore in ASG due to failure to expose the footwall during scraping resulting to locked up tonnage. The locked up tonnage can possible be removed during vamping process at additional cost and possible convergence, therefore, the research study aim to improve the transit of ore during the measuring month, thus, influencing the SCF for that month; and
- Footwall lifting of strike gullies close to the life span of the strike gully to the centre gully.

Figure 1.11 shows the flow of blasted ore from stope face through the gully to the ore pass. When the ore is blasted from the stope face, face cleaning commences and the ore blasted can be cleaned by scraping and sweeping process. During the scraping and sweeping of ore from the stope face, the ore is scraped into the advance strike gully and thereafter, through the center gully into the orepass.

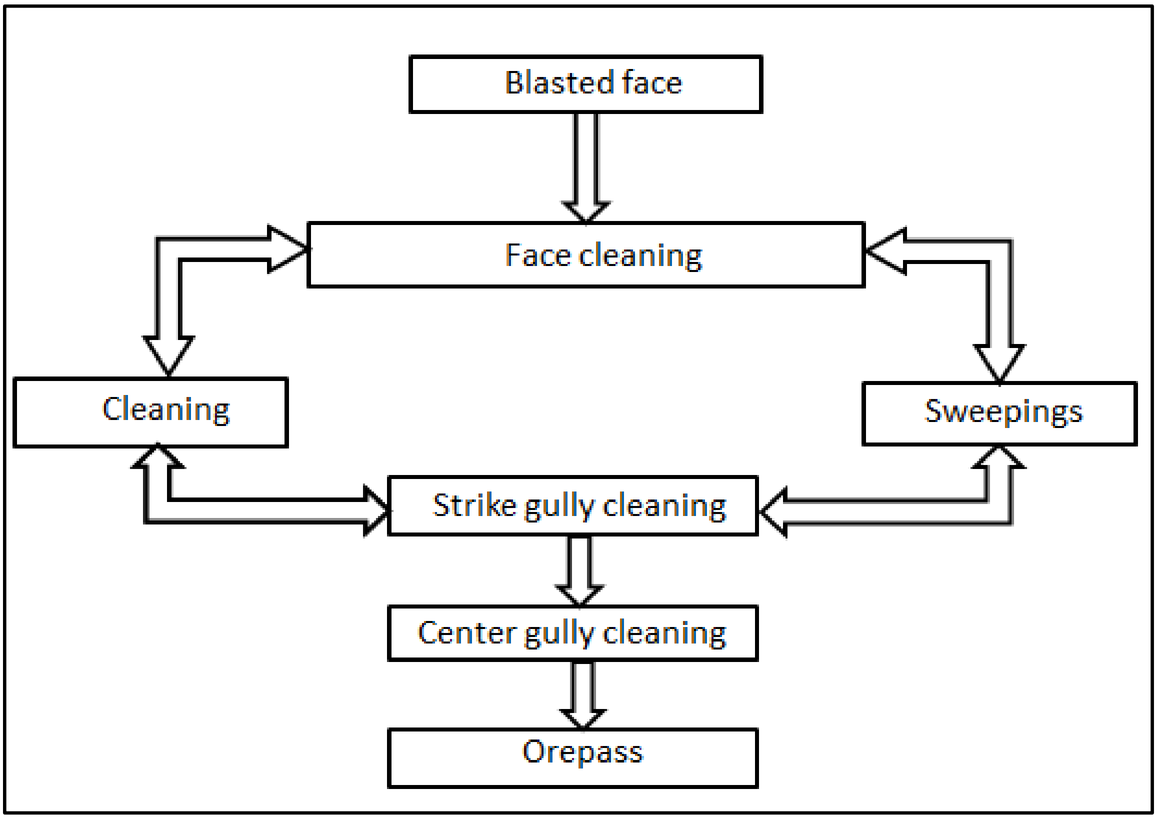


Figure 1.11 Flow of ore from the stope face to the Orepass

1.5 Research objectives

The objectives of the research study are:

- To evaluate the cleaning rate in advance strike gullies;
- Determine the grade and mine locked up tonnes in the ASG as per grade reports;
- Evaluate the current gully mine standards in relation to actual gully conditions; and
- To emphasise the importance of developing advance strike gully depth, width and length to standard for a positive impact to the SCF.

1.6 Relevance of the research

When exploiting gold using conventional breast mining method, the blasted ore is scraped from the face into the ASG and from the ASG, the ore is scraped into the orepass or into the center gully. From which, it will be scraped into the orepass. If advance strike gully conditions are good there should be minimum ore losses during cleaning of the measuring month, thus, having minimal negative impact on the SCF for that month, if any. Ore losses for that measuring month will be any unrecoverable economic ore left inside a stope for that month, when paid for and called for. It is known that blasted ore can also be recovered at a later stage as old gold during vamping stage, however, it is important to increase the current sweepings and reduce the vamping percentage due to argillite partings at Doornkop Shaft influence an increase in convergence rate and high convergence rate can lead to fall of ground and small gap between the hanging wall and the footwall affecting scraping during vamping stage. However, in most cases, the ASG conditions are not good (not developed to standard), thus, resulting in ore losses during cleaning.

1.7 Research expected outcome

The shaft call factor at Doornkop Shaft is mostly below plan and the research study focuses on the advance strike gully conditions to ensure that there is full compliance to the mine standard and better area for ore transit. The improvement of the SCF will have positive impact on the mine call factor (MCF) and improving the Plant Call Factor (PCF).

1.8 Report outline

Chapter 1 focused on introduction and discussed the research background and provides the definition of the problem. Chapter 2 focuses on the literature review on the historical experience on gully geometry and the preferred standard in the gold mining industry. Chapter 3 discusses the methodology employed when collecting and analysing the data. Chapter 4 presents on the analysis of the data from reports, systems and underground visits. Chapter 5 provides the conclusions and recommendations of the research study.

2 THE THEORY OF THE SHAFT CALL FACTOR

2.1 Introduction

De Jager (1997) defined MCF as the ratio, expressed as a percentage, of the gold called for from all underground sources, to the gold recovered plus residues in the metallurgical plant. SCF deals with the shaft measurements and MCF focuses on the end product of gold processing in relation to the shaft survey measurements. During the accounting and extraction of ore gold can be lost and this can affect the SCF and MCF. Therefore, the literature of the MCF components is similar to that of the SCF. If sampling and tonnage measurements from underground workings are perfect and there is no gold loss, theoretical the SCF must be 100%.

In ore flow, discrepancy is the more or less tonnes delivered to the plant from the accounted ore as per survey measurements. When the surveyed tonnage is greater than tonnage accounted for at the belt, there is a reasonable gold loss from underground sources. Whereas, when the tonnage accounted for on the belt is higher than the surveyed tonnage, there is additional tonnage unaccounted for in the system. Both the discrepancies need to be investigated as they can influence a low belt grade resulting to a low or high SCF. The discrepancy of ore between the underground stope face and the surface belt is normally due to metal content loss and this is as a result of apparent and real gold losses. Apparent gold loss is the difference between the calculated gold loss and the real gold loss. This is gold that was not there in the first instance. Real Gold Loss is that portion of the total gold loss that can actually be found in the underground situation. All these gold losses can impact the SCF in the flow of ore process; however, the research study focuses on the impact of ASGs on the

SCF. ASG geometry should ensure that there is efficient stope cleaning during the production phases, however, the conditions must be as per required mine standard in terms of the depth, width, length and directions.

2.2 Ore flow

Ore flow is the movement of the broken rocks from underground sources to the ore passes, locos, skip, belt, bin, stockpile and tailing dams. When stope face is blasted, ore is swept into the gullies to the ore passes and in areas where ore blasted is not sufficiently cleaned, thereafter, sweeping fails. Each movement is an opportunity to take spatially relevant measurements, to engage in routine tracking of rock movements, and to quantify location, tonnage, and content. Various other technologies for monitoring weight or density may also contribute usefully to required reconciliations. And we do not need to wait for end-of-period measurements, as both weight and volume can be measured at will (Woodhall, 2014). Reconciliation is merging all the rock flow network measurements with the plant recovered product and residue with ore body content. Underground survey measurement gives an indication of blasted ore and excavations from underground sources and which is the reconciled from the belt and the plant. The main reason to reconcile the blasted ore from underground is for internal and external purposes in the mining industry.

2.3 Gold losses

The ore movement from an underground stope face is through blasting; face cleaning, ASG cleaning, center gully and ore scraping into the ore passes. Rupprecht (2003) indicated that the failure to remove the ore from stope face and ASG can causes bottlenecks, resulting in low SCF and MCF. Futhermore, ore losses were also classified as arising when ore is misclassified as waste and sent to the waste dumps, this is also called cross-tramming (Engmann, *et al*., 2013).

Tonnage accumulation in underground sources is catergorised into two types, namely: current ore and vamping ore (gold left in old workings). Current ore accumulation is the ore accumulated during the current month blasting and must be removed before the end of a survey measuring month, however, if not removed, ore accumulates and is removed during vamping mining stage.

Andersen (1999) defined vamping as removal of gold accumulations left during the previous months blasting, this is known as old gold and can be measured and called for together with the current ore accumulations at a specific percentage. Gold losses are either classified as apparent and real losses.These losses have negative impact to the SCF and MCF (Tetteh & Cawood, 1981).

Figure 2.1 shows the apparent and real gold losses common in the gold mining industry. De Jager (1997) further categorised the causes of apparent and real gold losses as shown in Figure 2.1.

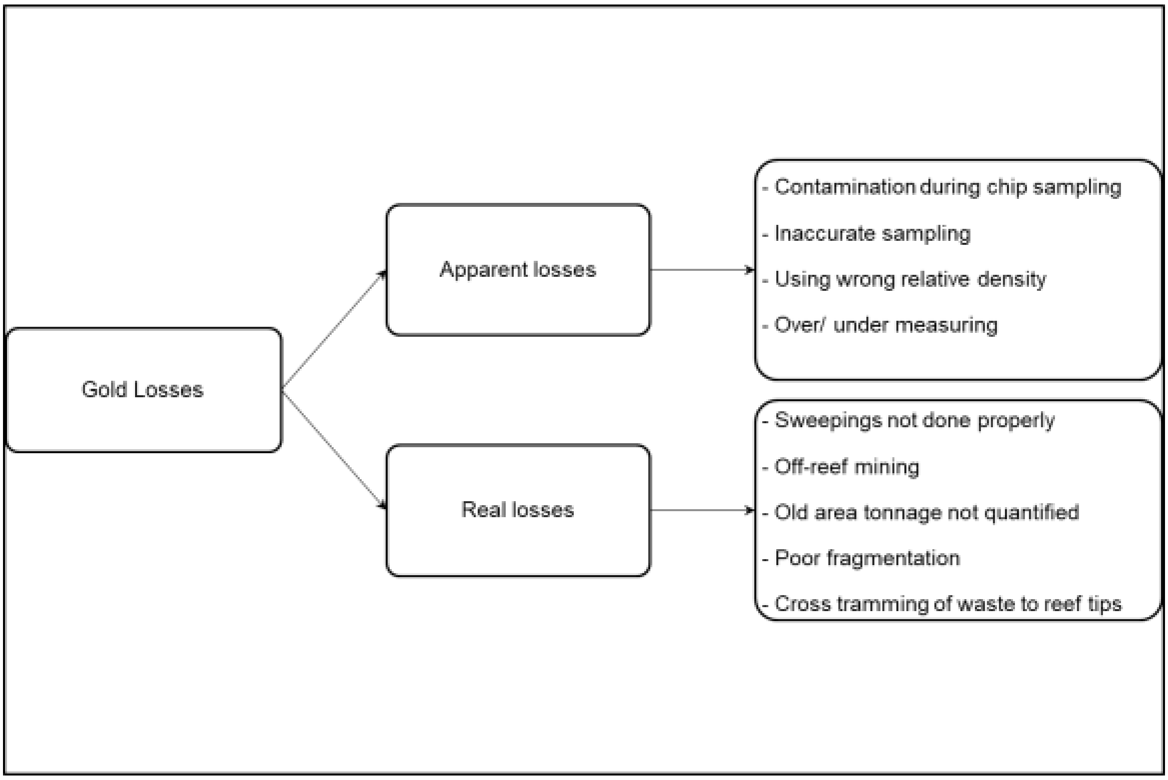


Figure 2.1 The theoretical gold loss (De Jager, 1997)

2.3.1 Apparent losses in stope face

These apparent losses are the ore loss that occurs during the extraction of the ore body and it gets measured by comparing the grade on the stope face and on the belt. The gold loss results through the poor quality of chip sampling, the wrong relative density and under or over measuring of the stope face.

2.2.1.1 Reef sampling procedure

The reef sampling procedure normally used in the gold industry is chip sampling. This is the sampling procedure where rock samples are taken from the stope face using chisel and hammer. The chipping procedure starts from footwall of the stope face to the hanging wall in order to avoid contamination to the sections. Samples are immediately put into sampling bags with ticket numbers attached to it for identification. Chip sampling has its pros and cons especially when chipping carbonaceous conglomerates which result in losses of gold and contamination.

Carbonaceous conglomerates were normally called soft-reef (Fourie & Minnitt, 2015). Chip sampling of carbonaceous reef is bias and has errors. These bias and errors result when chipping carbon particles falls off to the footwall and there can be possible contamination during chipping of the footwall sections. The bias in sampling results is over or under estimation of the in-situ grade and this has an impact on the SCF and MCF (Fourie & Minnitt, 2015).

Figure 2.2 indicates the stope face marking when conducting chip sampling, where the image (a) is before chipping and (b) is after chipping. Due to the carbonaceous conglomerate there are occasions where the chipped sample can be smaller or bigger than the markings of the sections, therefore, sample sections marks must be at least 5cm below and above the conglomerate.

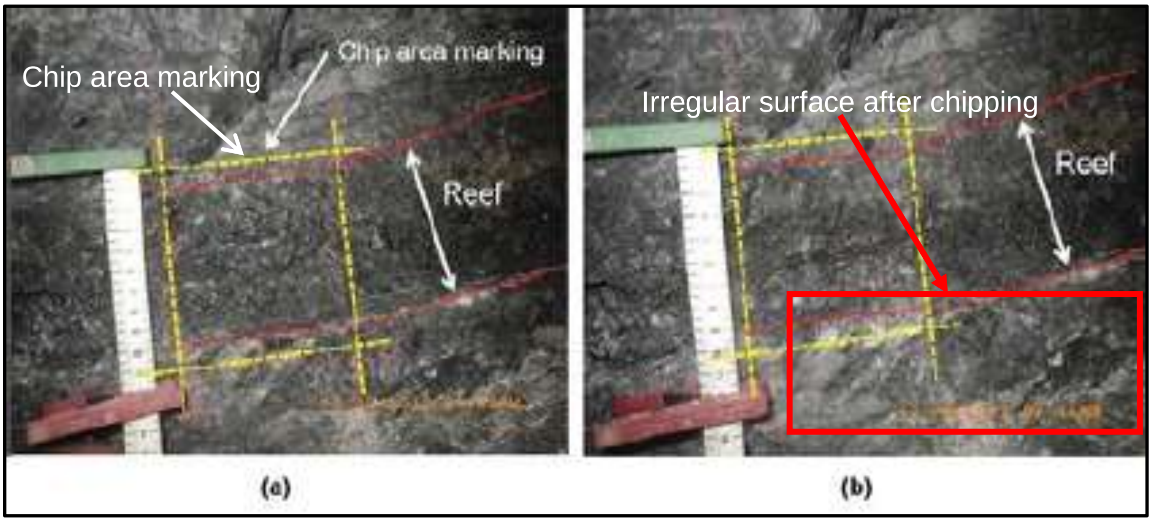


Figure 2.2 Stope face marking when doing chip sampling (Freeze *et al*., 2013)

Over extraction and poor estimation of the reef width of the soft reef can result in as much as 26% overestimation (Fourie & Minnitt, 2015), however, AngloGold Ashanti stated that the bias from chip sampling of soft-reef is not sufficient enough to cause the deterioration of the SCF and MCF (Freeze, *et al*., 2013). Chipping soft reef can create difficulties during due to possible contamination and losses of ore metal particles.

2.2.1.2 Survey measuring in stoping areas

Survey measuring is the survey off-setting and recording of excavations blasted underground with the quantification of the tonnage accumulated. Tonnage measured from underground sources is compared to the tonnage received on the belt. If the underground measuring results are accurate, they result to positive or negative discrepancies of tonnage. Negative discrepancy is when the tonnage measured during survey measuring/available for hoisting is higher than tonnage received on the belt. While positive discrepancy results when the belt tonnes are more than ore available for hoisting as per survey measuring. In all panels where temporary or permanent stoppages occur, stop panel procedures must be performed in order to ensure sweepings are conducted. This serves as a controlling tool for avoiding a negative or positive discrepancy between the called for tonnage as per survey underground measuring and accounted on the surface belt to the plant.

Figure 2.3 indicates the electric weight meter for tonnage mass on the belt. This instrument measures the tonnage conveyed from underground and it is positioned close to the conveyor belt before the plant. The total tonnage hoisted during the month is then compared to the tonnage available for hoisting from underground workings according to the survey measurements.

Figure 2.3 Electric weightometer for tonnage (Doornkop Shaft, 2017)

2.2.1.3 Belt sampling

On the surface the ore is fed onto the conveyor belt, sampled using a cross-belt hammer sampler. The go-belt sampler is the first point where both grade and tonnage are estimated in the reduction of gold ores. Studies indicate that a composite sample collected at the go-belt should be 200t to 500t (Minnitt, 2014). Go- belt samples gives an estimation of the overall gold produced per each reef for the month. At some operations go-belt samplers are activated on a mass basis by a weightometer, such that a single 200t increment is collected over a 24 hour period from 10 increments of about 20kg each (Minnitt, 2014).

2.3.2 Real losses in stope face

There are gold losses occurring during the extraction, face cleaning, ASG cleaning, ore tramming, hoisting and processing. However, ore processing cannot be a factor on the SCF. There is clear indication that from the investment perspective, 40% of the ore is left behind as support and clamping pillars to geological structures. This percentage normally increase with the depth of the mine and of the remaining 60%, 20% to 30% of the gold bearing rocks are lost during the extraction, cleaning, tramming, hoisting and processing (Candy, 2014).

The research study focuses on the ASG conditions as the major component affecting the SCF. The negative impact is due to gold liberation on the advance strike gully sides and compaction of ore on the footwall. Poor fragmentation can be caused by poor blasting techniques and long scraping distances. Poor blasting techniques produce fines, which may result in gold being lost through cracks. Whereas, long scraping distances may cause fines to be lost through cracks and in the back areas. Poor sweepings, inefficient blasting barricade and uncontrolled water usage can cause low SCF and MCF.

2.2.2.1 Ore fragmentation in stope mining

Fragmentation is defined as the size distribution of the rock fragments (Cho & Keneko, 2004). It depends on the rock type and blast design. Xingwana (2016) stipulated that the fragment size decreases as it moves away from the source and this can be in a situation where advance strike gully are very long, resulting in a long pull scrapping resulting in “free gold”. Free gold is defined as the amount of gold content lost to the back areas, packs, the blasting barricade, ASG sides, and footwall cracks and as mud in cross-cuts. Excessive hole burden, small or large burden and small or large spacing of drilled holes on the stope face has a direct impact on the rock fragmentation. If excessive energy per blast hole is used in carbonaceous conglomerate, the fragments size will decrease exponentially. The decrease in fragmentation of carbonaceous conglomerate is also explained through the Kuznetsov Equation (Equation 2), which relates the mean fragment size to the quantity of explosives needed to blast a given volume of rock (Kuznetsov, 1973):

$$k^{50} = A\left(\frac{V}{Q}\right)^{0.8} Q_{\frac{1}{6}} \qquad (2)$$

Where:

k^{50} is the average fragment in cm;

A is a rock factor;

V is the rock volume in cubic meters broken per hole; and

Q is the mass in kg.

Shaft call factor can be improved by selecting the right type of explosive that suites the rock type. Figure 2.4 indicates ore fragments on a surface belt at Doornkop Shaft. These fine fragments get compacted on the ASG footwall when in contact with drilling water. Therefore, it is important that the ore be scraped such that the footwall is exposed in the ASG.

Figure 2.4 Fragments distribution in underground workings (Doornkop Shaft, 2017)

2.2.2.2 Ore dilution

Dilution is defined as the waste material that is not separated from the ore during the extraction and sometimes mixed with ore during cross tramming. Extra dilution during stoping increases the operating cost and affects the grade because there is an increase in tonnage at a low grade resulting to low belt grade and less projected grams of metal per tonne. The ore dilution differs from mine to mine and it is mostly generated through extra waste due to excessive stoping width, off-reef mining and cross tramming of waste blasted from waste development ends. Dilution may also occur as the results of mining low grade block of ground below cut-off grade and can reduce the value of the ore per tonne (Chieregati & Pitard, 2009).

2.2.2.3 Other real losses

During the extraction of the ore from the stope face, other factors can contribute to a low SCF such as:

- Inefficient blasting barricade can be the contributor of gold loss when not fully installed from footwall to hanging wall and when there are spaces. Gold particles can easily liberate to the back areas resulting to contamination if not swept;
- Sweeping tools such as water jets is believed to cause gold loss as it has a high pressure, water assist in depressing the small particles through footwall cracks;
- Extensive water usage when drilling without pump installation in ASG result in water seeping through the ore passes. These conditions result in mud accumulations in the cross-cuts and metal content gets liberated through the flow of water; and
- Spillages of ore during tramming and hoisting can result to gold losses. Spillages during tramming may occur when hoppers are overloaded. While spillage during hoisting may occur when skips are overfilled.

2.4 Stope cleaning

Blasted ore from the stope face is cleaned by using scraper-winch system of the face and ASG in order to have successful cycle of mining in the operation. Stope cleaning occurs during the blasting month and vamping during the removal of old gold metal content. If stope cleaning is not done properly, it has an impact on the mining cycle. The packs support must be installed on the footwall free of ore accumulation thus, during cleaning in the face area, the footwall must be exposed. Face preparation without properly cleaning the face can result to improper face marking, subsequently, leading to off-reef mining.

2.4.1 Face cleaning

After blasting the panel face during day shift, the ore must be cleaned during night shift using the scraper-winch system.

Figure 2.5 indicates the winch rigging process, whereby two 1-tonne scraper scoops are in tandem. Where two scrapers are in tandem, weighing one tonne each, this system is used to increase the fill factor of the scrapers and tonnage of the cleaning system. The tailing scraper ensures that the leading scraper is pulled down into the muck pile, increasing fill ability. Cleaning rate is the rate at which the scraper winch takes to clean the face and the advance strike gully taking into consideration the winch capacity, face length, rope speed, availability on utilization and the ASG length.

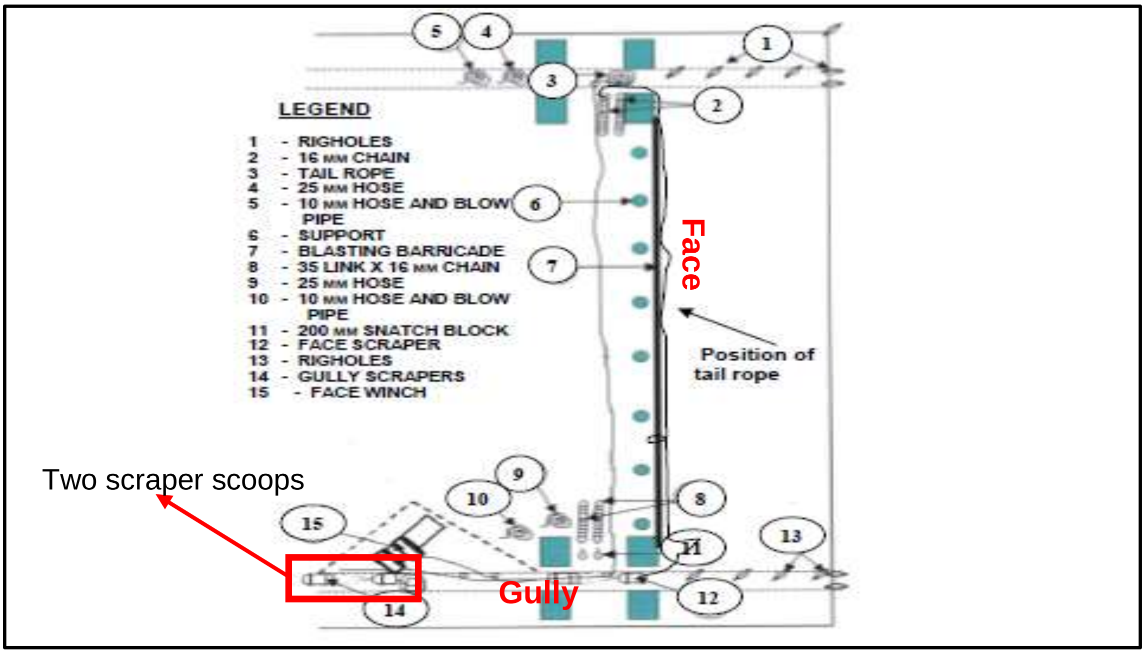


Figure 2.5 Face winch rigging standard (Doornkop Shaft, 2015)

2.4.2 Gully cleaning

ASG drilling using the short hole of 0.9m in length was accepted as a standard at Blyvooruitzicht Gold Company Limited. In most cases, there is no problem in cleaning the stope face, however, ASG cleaning hinders the cycle of mining more especially, when the gully exceeds 90m in length and is mined off-line (Diering, 1975). The ASG contains two scrapers in tandem (Z34) with a 16mm chain of 3m length for efficient cleaning. These scrapers have blades or runners installed for effective cleaning. As mining progresses, worn out blades are replaced because they interfere with the effectiveness of the cleaning process.

Figure 2.6 indicates the gully rigging standard. When the rigging is substandard, the cleaning process will not be effective, thus, resulting in delays in the cleaning process. When rigging the scraper winch is substandard, the scraper cannot clean the broken ore efficiently and can remove the pack support. The substandard rigging can increase the width of the ASG by continuous colliding with the gully sides and can result to overflow of the ore onto the gully sides.

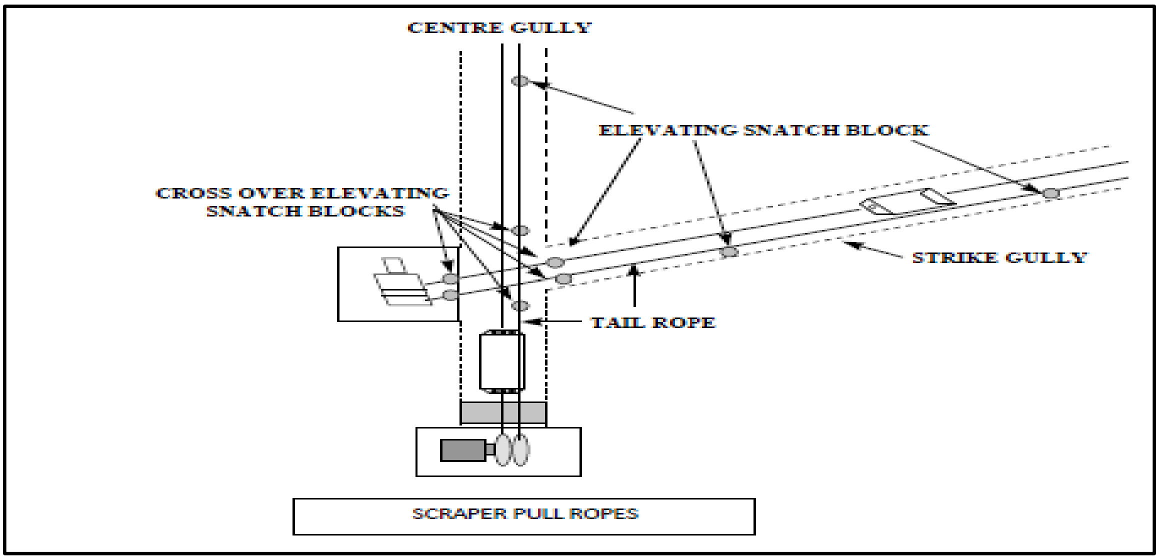


Figure 2.6 Advance strike gully winch rigging standard (Doornkop Shaft, 2015)

2.4.3 Sweepings

Sweepings are referred to as the removal of blasted ore from the stope face, siding and the advance strike gully for that measuring month advance. The sweepings task is performed using the brushes and minimum amount of water in order to reduce the dust level. It is believed that these fines are the carriers of the richest potion of gold metal. According to De Jager (1997), good SCF and MCF is achieved when sweepings targets are met. In most cases, sweepings are not carried out as per the monthly blasting schedule, thereafter, done one or two shifts before measuring and this delay in sweeping process has a negative impact on the SCF as ore blasted is not going to reflect on the conveyor belts on time. This ore delay creates locked up tonnage in stope face, siding and gully because ore blasted on the face is accounted for as per survey measuring can lead to low SCF.

2.5 Gully geometry and conditions

The research study focuses on the advance strike gully geometry in terms of the depth, width, direction and length. However, aspects such as gully siding are briefly discussed as it is an important component for reducing gully fracture. Advance strike gully not developed to the correct depth result in spillages of ore on the sides. Therefore, discussion of the advance strike gully geometry and condition gives an overview to the required mine standard and the impact of not adhering to the mine standard.

2.5.1 ASG layout

Each mining company has a different ASG standard and procedure depending on the type of the ore body being mined. The cross-cuts are supposed to be developed perpendicular to the reef strike direction in order to avoid having skewed face shapes to the ASG. ASGs developed at apparent dips of 2º to 5º are free of stresses. At Doornkop Shaft, ASG are designed at about 7º to 15º, due to the crosscut layouts being not perpendicular to the reef strike, thus, create a safety risk towards the advance strike gully when the face is not perpendicular to the gully.

Figure 2.7 indicates the underground workings, reef contours and geological structures. Most of the advance strike gully lengths are mostly affected due to the distance between raise lines and the geological structure strike directions in relation to the raise line.

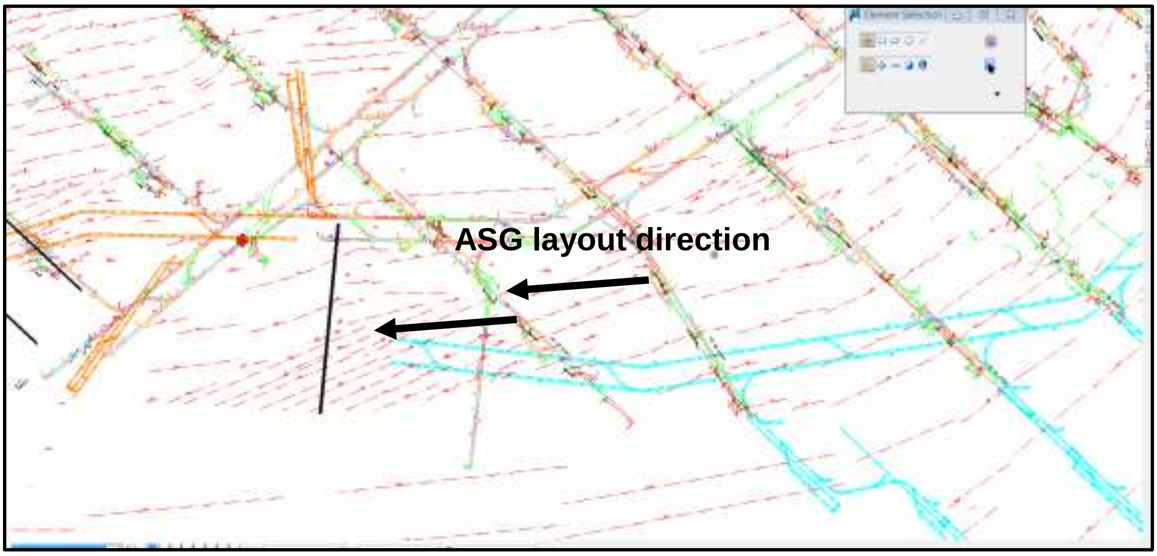


Figure 2.7 Cross-cut design at Doornkop Shaft (Doornkop Shaft, 2017)

The favoured gully layout in deep gold mines is 1.6m width by 1.8m depth in the deeper mines (Naidoo & Handley, 2002). However, at Doornkop Shaft the gully dimensions as per standard must be 1.5m depth and 1.5m width. The advance strike gully standard length at the operation is 90m because cross-cuts are planned at an interval of 180m.

Figure 2.8 indicates the scoop size and the advance strike gully width. The scoop width used at Doornkop Shaft is 1m and if ever the advance strike gully width increases to be more than the standard of 1.5m, the effeciency of cleaning becomes a challenge because blasted ore cannot be removed close to the ASG sidewall during that measuring month, thereafter gold content is left on the sides of the advance strike gully and when mixed with drilling water it gets compacted.The loss of the gold content affects the SCF because the tonnes blasted during the month will end up being removed during vamping several month later.

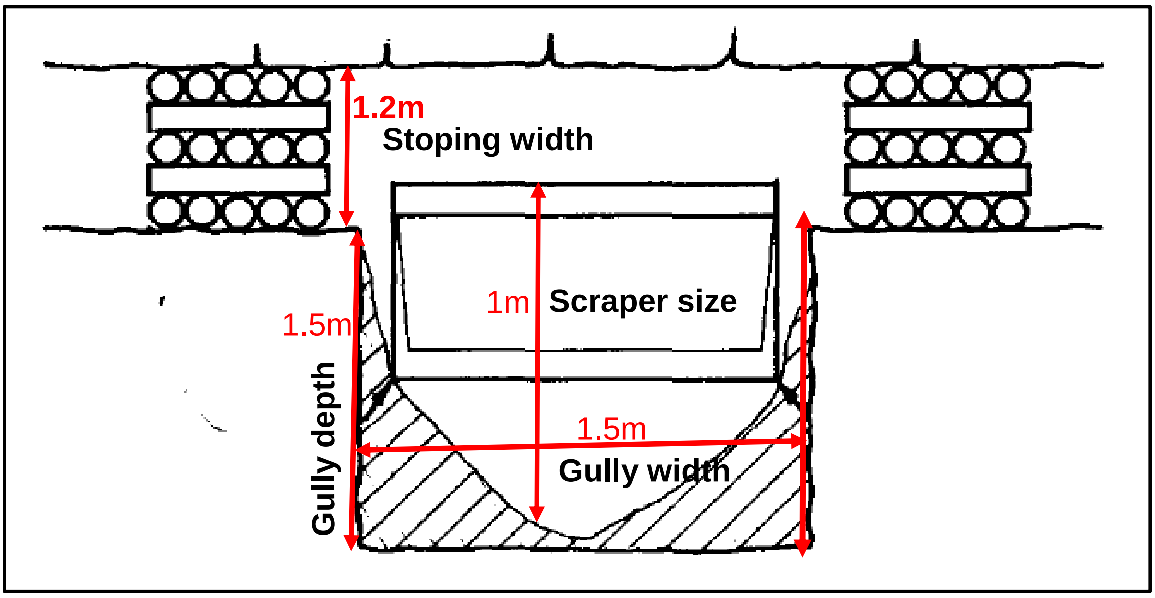


Figure 2.8 Scraper width in the ASG *(Solomon & Van Niekerk, 1978)*

The optimum lead of the ASG is about 2m lead from the stope face to provide free face during blasting and for cleaning purposes. The ASG is blasted on the dip side of the panel to allow efficient cleaning from the stope panel and it is blasted with the siding on the bottom side of the panel as a safety procedure/standard in order to reduce the stress-induced when blasting the stope face and the gully. The proper marking of the gully is still essential to avoid off-line advance strike gully as it remain more important when cleaning commences.

Figure 2.9 indicates the ASG geometry of the stope panel and the best fit for mining the reef at Doornkop Shaft. The gullies dimensions are such that it can act as temporary ore storage before ore is scraped into the center gully and consequently into the ore pass. The gully dimensions are 1.5m in depth, 1.5m wide on the panel footwall horizon and 1.2m on the bottom of the gully to allow adequate cleaning of ore because the scraper scoop is 1m wide. If the ASG bottom is wider than 1.2m, broken ore on the corners cannot be cleaned resulting to compaction and negative impact on the SCF.

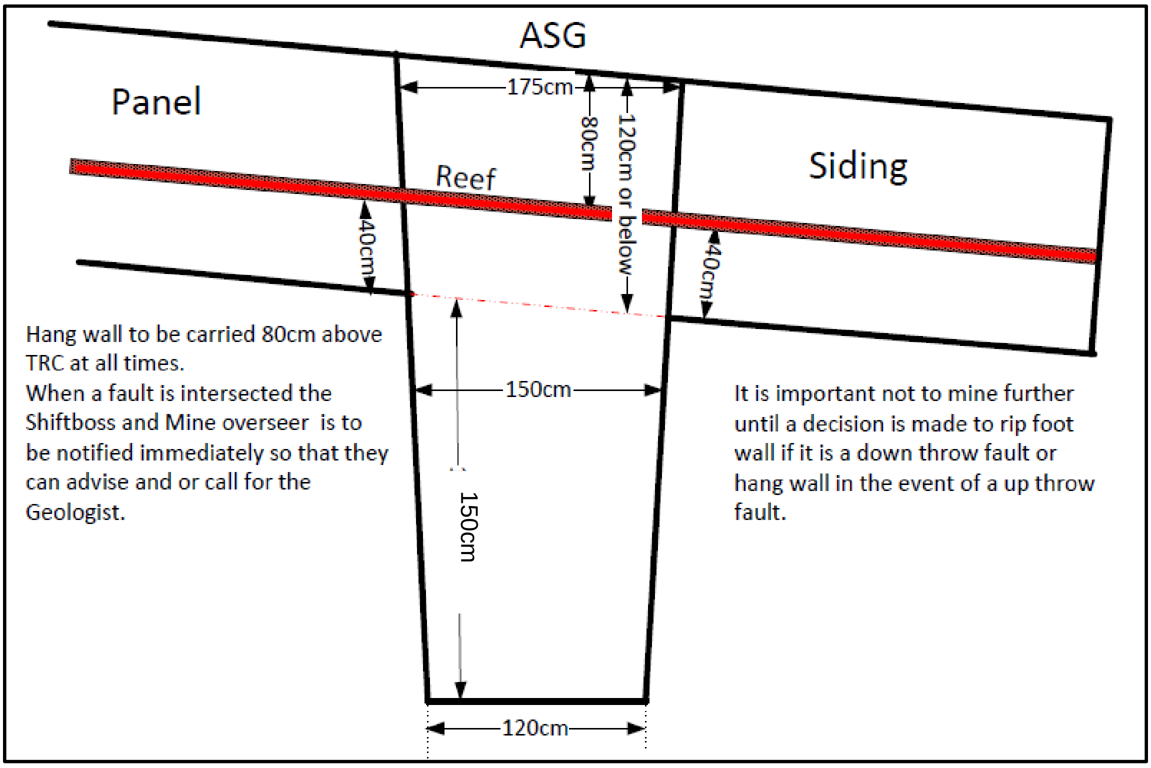


Figure 2.9 ASG geometry (Doornkop Shaft, 2015)

The dangerous area in the ASG can be the space within the 5m from the face and there is a generation of adverse fracture patterns. These fractures are always associated with a low convergence and combined with cleaning constraints, creating difficulty in support design. ASG geometry that is not to standard in terms of depth of 1.5m, width of 1.5m and longer than 90m creates constraints onto the pack support close to the gully because scrapers normally remove the support, resulting to support re-installation. It should be noted that re-installation increases the cost of mining.

2.5.2 Gully stability

In deep gold mines, advance strike gullies are always taken for granted in terms of its standard and this has a direct effect on the stability (Thompson, 2002). Most of the gully conditions and the friable hanging wall are as a result of large lead-lag, lack of barring, poor blasting practice, excessive unsupported span (Thompson, 2002). The orientation of the gully should be safe along the entire length and Thompson (2002) revealed that in most cases, the advance strike gully deteriorate within the first 30m distance from the center gully because blasting fragments and advance strike gully distance has an impact on the stope mining.

2.5.3 ASG not cleaned

In the mining industry, 100% of the advance strike gullies are referred to as being not cleaned if the workers are not able to walk upright in the gully (Thompson, 2002). The life circle of the stope section can depend on the raise line length, block width to the opposite raise line, number of crews mining and the efficiency of each crew. This can be more than a year period and that’s when vamping is done. Keeping advance strike gully not cleaned is a significant problem that must be investigated and analysed as it is a contributing factor to issues such as:

- Inadequate space for the scraper, resulting to the damage of support packs, gully sidewall thus increasing the gully span;

- Difficulty for employees to examine the hanging wall during the re-entry examination, resulting to poor hazard identification;
- Negative impact on the SCF as most of the blasted ore will be stagnant and this result to compaction of ore. In most cases, the compacted ore is not removed leading to a reduced gully depth;
- Accidents in advance strike gully as employees will not be walking upright; and
- Revenue is lost since the broken ore is stagnant in the gully instead of being treated for gold extraction.

2.5.4 Off-line gully development

Surveyors play a major role in the mining industry in terms of measuring, off-setting of working places and also elevating the working places using pegs. Miners rely on survey pegs in order to direct their working places. In most cases, when advance strike gullies are off-line as a results of lack of surveyors, falls of ground removing pegs in the advance strike gully, negligence from the miners for not following the installed peg directions. The off-line gully has a negative effect to the operation resulting to:

- Removal of pack support by the scraper;
- Accumulations of blasted ore on the bends, resulting to blasted ore not being removed for processing; and
- Accumulation of water on the bends of the advance strike gully.

2.6 Convergence rate

The elastic deformation of the rock in underground mines depends on the in-situ modulus of the rock and on the mining depth, geometry and span. In the mining environment where the energy release rate (ERR) is 30 MJ/m^2, the convergence rate at a position that is 10m from the face is 10mm/m (Jager & Ryder, 1999). The closure rate in underground operations is measured using the telescopic closure meter at which the data is recorded in Microsoft Excel format. The closure rate is typically recorded into the logger at 5 minutes intervals (Malan & Piper, 2009). The convergence can affect sweepings if the strike gullies are developed at a smaller depth. This is because the strike gully height will reduce and scrapers will not be able to clean efficiently and break downs of scrapers can be a night mare when trying to fix them due to the strike gully height.

Figure 2.10 shows the telescopic closure rate meter installed in between the timber permanent support units in an underground stope panel. The data from the closure rate meter is analysed every 30 days in order to get an understanding of the rock behaviour over a month period.

Figure 2.10 Telescopic closure rate tool (Malan & Piper, 2009)

2.7 Gully accidents

The advance strike gully at Doornkop Shaft is used for access to stope materials, people and blasted ore. During the life of the stope panel, it is highly recommended that advance strike gully conditions be good as it can be a hazard to employees. In mining industry, scraper rope accidents remain a major concern as workers continue to be fatally injured. In 2003, at least 12 fatalities were scraper winch related (Rupprecht, 2011).

Figure 2.11 indicates the 2016/17 accident categories and the main highlight is scraper winch fatality of 17% and 4% double-drum winch. This accident rate reported in 2016/17 creates awareness on the importance of ensuring that gully standards are implemented.

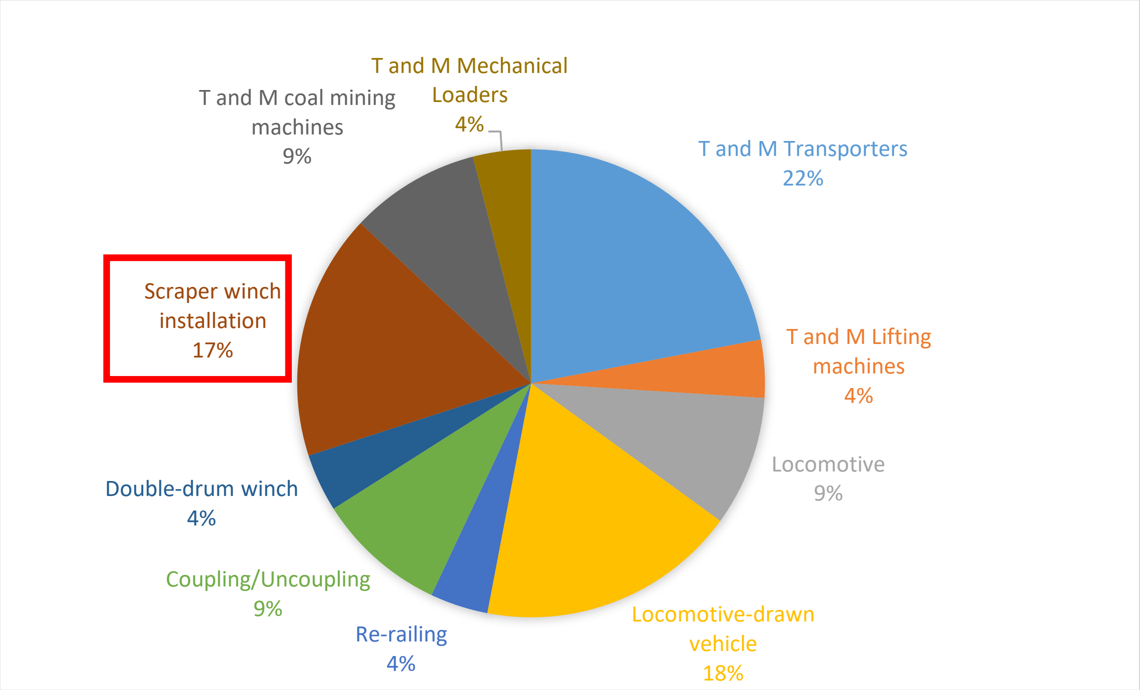


Figure 2.11 Causes of accidents in underground mines for 2016/2017 (Department of Mineral Resources, 2017).

2.8 Chapter summary

SCF that is below 100% is influenced by apparent and real losses. Sweepings percentages are derived from the extracted tonnes from the stope face as per square meter mined and swept tonnes. Sweepings percentage in the stope below or above 100% can be as a result of improper measurements, panels having sweepings above the required standard of 9m, accumulations of stope tonnes in the advance strike gully.

When the tonnage recorded on the surface belt is greater than the measured tonnage from underground or vice-versa, there will be tonnage discrepancy. The advance strike gully conditions and geometry not kept to mine standard in terms of width, depth and length can have an impact on daily stope cleaning resulting to bottlenecks. Poor fragmentation can be as a result of overcharging resulting in over blasting of the rock. This result to ore fines accumulated on the advance strike gully footwall. The next chapter focuses on the methodology used in order to achieve the objectives of the research study.

3 RESEARCH METHODOLOGY

3.1 Introduction

Departmental quality report is done every Monday analysing the face advance, sweepings, gully depth, gully tonnes, stoping width, vamping and off-reef mining (Appendix C) in stopes. There is a continuous challenge during the vamping stage as most of the old stope areas are converging and causing fall of ground. The convergence of the hanging wall can cause vamping crews not vamping the area due to safety reasons and this lead to loss or ore and can affect the SCF. This serve as a grade control system to ensure quality mining during the month and analysis of the report is done to understand the ore flow during the month. Ore blasted from the stope face is scrapped, trammed and hoisted from underground, thereafter, Radio Frequency Identification (RFID) tags are used to track the blasted ore in terms of the time factor and quality. Analysis gives an overview of the flow of ore from the advance strike gully to the surface belt.

Belt sampling report analysis to be done in order to track the grade challenges in relation to underground face grades. Grab sampling has been done to have an estimation of the gold accumulated in ASG. Although grab sampling has an error, however, it gives an indication of the grade condition in the advance strike gully. The error from grab sampling cannot be easily quantified in terms of percentage and that is why this is not a preferable way of sampling.

3.1.1 Underground grade audit reports

Every Monday, Geologists, Samplers and Grade Officers conduct underground visits for grade control using a template in (Appendix A). This is done in order to quantify the sweepings in stope panels, gully condition measurements, gully tonnes, position and condition of blasting barricades, stoping width and use of pumps in gullies. The data collected is analysed and communicated to the management of Doornkop Shaft. Other data that is communicated to the management is the convergence rate findings from the logger installed in underground stopes. The convergence rate readings from logger tool to be analysed. Further explanations and discussion of the logger findings from the rock engineer at the operation is essential. The higher the convergence rate the lower the strike gully and the higher potential of falls of ground. if the strike gully height is lower due to convergence, ore recovery from stopes can be compromised because the scrapper will hit the hanging wall and it can be difficult to fix whenever there are break downs leaving ore accumulations in the gully.These findings from the logger assist with obtaining the optimum advance strike gully length as convergence rate is related to the advance strike gully length during each blast and the worst the convergence rate the impact on the SCF.

3.2 Data collection

3.2.1 RFID tags report

RFID tag is a tool used to track the source of the blasted ore and it uses a chip with an antenna installed in a black hard protective plastic shell. RFID tags number is recorded before being buried in the ASG underground. In order to easily track the blasted ore from the advance strike gully, on daily basis, Geologists, Surveyors, Grade Officers and Samplers bury RFID tags in gullies. At surface, the responsible person records the working place and the RFID tag number in the computer. The RFID tags are then tracked on the surface conveyor belt. Once the RFID tag is recovered on surface, the date and time of recovery is recorded and checked against the date of issuing in order to ascertain the flow of ore process. About 95% of the RFID tags are recovered on the conveyor belt but different days of recovery. Figure 3.1 shows RFID tags being buried beneath the compacted blasted ore and this will assist in terms of giving an indication if tonnage compacted in the advance strike gully are removed or not.

Table 3.1 indicates the RFID tags report; this gives an indication of the tagged area from underground, responsible person, tag number, a read date and retrieve days. For instance, tag A6180 took 27 days to be recovered while tag A6661 was retrieved on five days. This shows the discrepancy or shortcomings in advance strike gully cleaning. It can be concluded that panel 197 S8 S4 was either not cleaned to footwall or the ore from the orepass was not loaded until the 27th day.

Figure 3.1 Burying of RFID tags in the advance strike gully (Doornkop Shaft, 2017)

Table 3.1 Oretrak read tag listing Adopted from (Oretrak tag reader, 2017)

Reader	Reader Date	Tag	Surveyor	Panel	Tagged area	Development end	Issue date	Days
Plant^ [Reef^^]	2017/06/07 11:04	A6661	Vusi	192 S6 S1C	Gully		2017/06/02	5
Plant^ [Reef^^]	2017/06/10 11:13	A6572	Tebogo	197 S7 S3	Gully		2017/05/30	11
Reef^^	2017/06/11 15:26	A6573	Tebogo	197 S7 S3	Gully		2017/05/30	12
Plant^ [Reef^^]	2017/06/11 23:26	A6573	Tebogo	197 S7 S3	Gully		2017/05/30	12
Plant^ [Reef^^]	2017/06/11 07:47	A6732	Joyce	197 S8 S3	Gully		2017/06/07	4
Reef^^	2017/06/09 05:19	A6732	Joyce	197 S8 S3	Gully		2017/06/07	2
Plant^ [Reef^^]	2017/06/12 02:47	A6733	Joyce	197 S8 S3	Gully		2017/06/07	5
Plant^ [Reef^^]	2017/06/07 14:16	A6180	Marvin	197 S8 S4	Gully		2017/05/11	27
Reef^^	2017/06/07 13:47	A6180	Marvin	197 S8 S4	Gully		2017/05/11	27

Figure 3.2 shows the antenna for retrieving the RFID tags on the surface belt, the equipment is linked to a computer and on daily basis the report is sent out showing the RFID tag number, working place, responsible person and the return day. The Antenna detects the RFID tags when they are being conveyed on the surface belt and has a link to a computer.

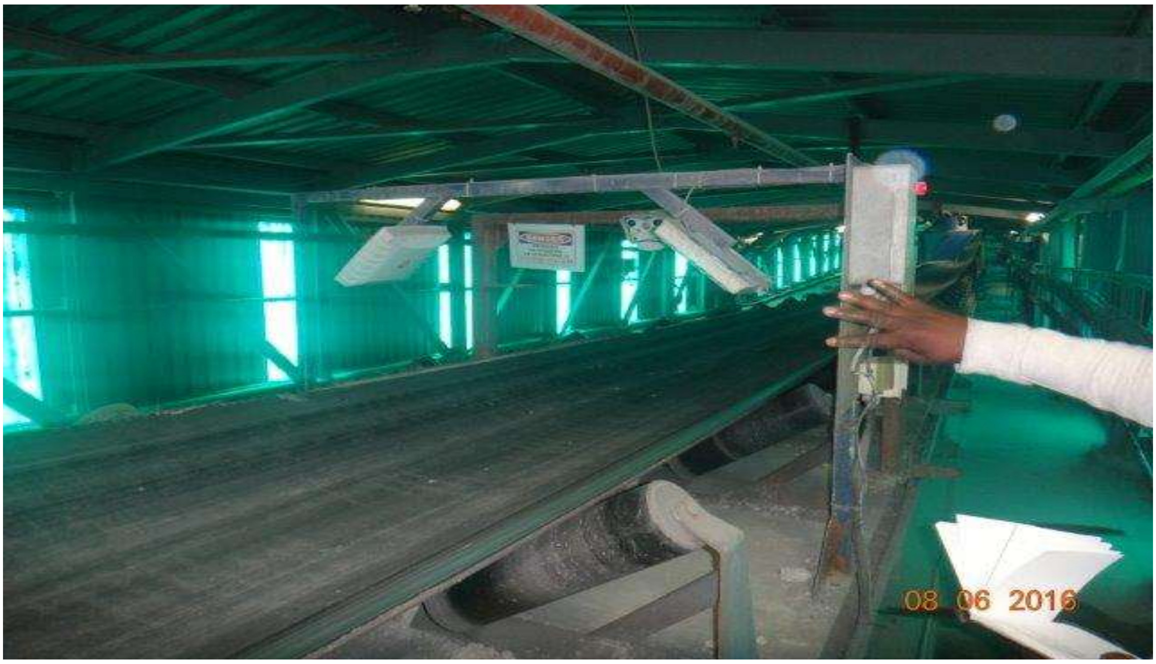
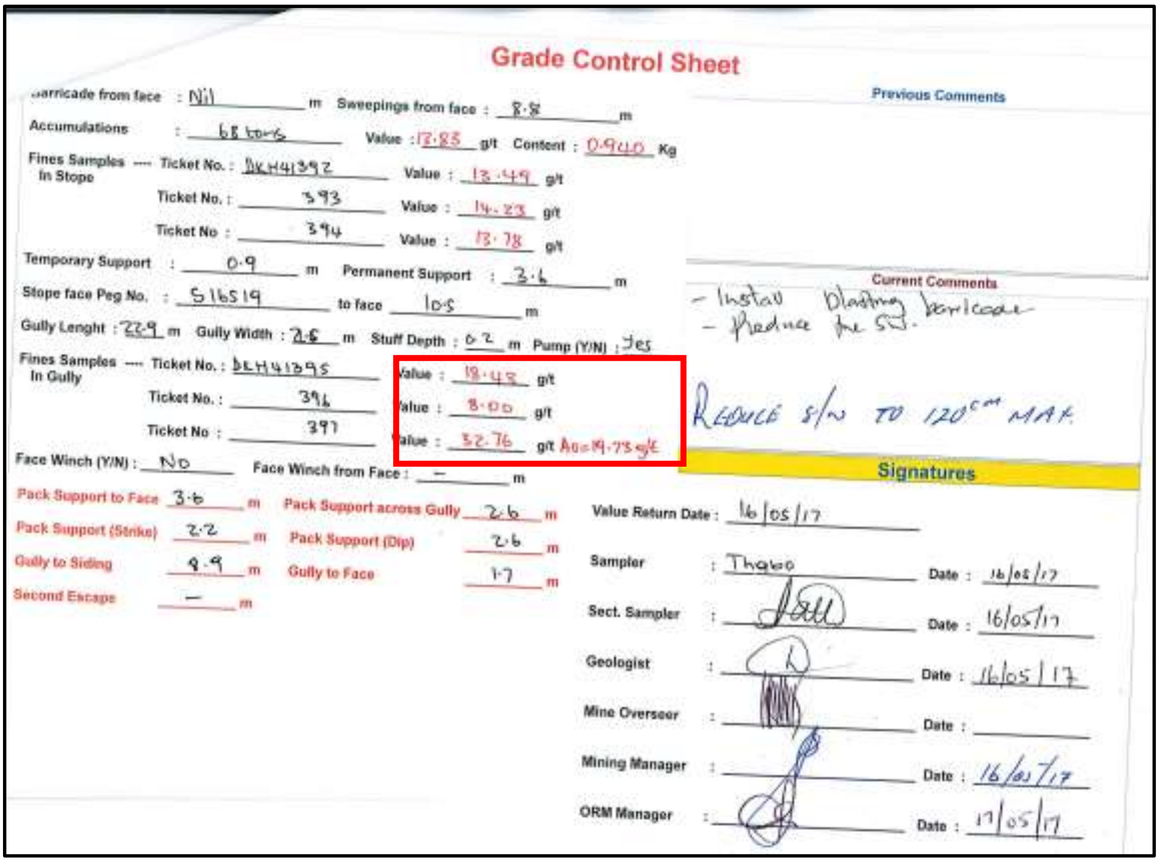


Figure 3.2 Equipment used to detect the RFID tags on the belt to plant (Doornkop Shaft, 2016)

3.2.2 Grab sampling reports done in advance strike gully

Grab sampling from the broken ore serves as the method of grade control. It is also known as muck or broken rock sampling (Dominy, 2010). Geologists and Samplers do the grab sampling in the advance strike gully at the depth of about 30cm and at interval of 10m. The main purpose is to determine grade values of the fines left in the advance strike gully. Grab sampling is a questionable method of sampling because it can easily give errors in terms of the true reflection of the grade in the advance strike gully. Although the grab sampling accuracy is questionable, it gives an indication of the metal content accumulated in the advance strike gully. The sampled ore is taken to the laboratory for analysis along with daily chip samples from underground.

The laboratory results are documented on the sampling sheet (see Figure 3.3), which is distributed to Geologist, Mine Overseer, Mining Manager and Ore Reserve Manager for signatures. The grab sample data collected is recorded on the sample sheet as enclosed by the red rectangle in Figure 3.3. The average grade per tonne is calculated from the three grab sampling values in the red rectangle. The average grade per tonne on the sampling sheet gives an indication of the gold metal accumulated in the strike gullies in comparison with the grade blasted from the stope face.


Grade Control Sheet

Barricade from face : Nil m Sweepings from face : 8.8 m
Accumulations : 68 tons Value : 13.83 g/t Content : 0.940 Kg
Fines Samples In Stope ---- Ticket No. : DKH41392 Value : 13.49 g/t
Ticket No. : 393 Value : 14.23 g/t
Ticket No : 394 Value : 13.78 g/t
Temporary Support : 0.9 m Permanent Support : 3.6 m
Stope face Peg No. : S16519 to face 10.5 m
Gully Lenght : 22.9 m Gully Width : 2.6 m Stuff Depth : 0.2 m Pump (Y/N) : Yes
Fines Samples In Gully ---- Ticket No. : DKH41395 Value : 18.43 g/t
Ticket No. : 396 Value : 8.00 g/t
Ticket No : 397 Value : 32.76 g/t Av=19.73 g/t
Face Winch (Y/N) : No Face Winch from Face : – m
Pack Support to Face 3.6 m Pack Support across Gully 2.6 m
Pack Support (Strike) 2.2 m Pack Support (Dip) 2.6 m
Gully to Siding 9.9 m Gully to Face 1.7 m
Second Escape – m

Previous Comments

Current Comments
- Install blasting barricade
- Reduce the SW.

REDUCE S/W TO 120cm MAX

Signatures
Value Return Date : 16/05/17
Sampler : Thabo Date : 16/05/17
Sect. Sampler : Date : 16/05/17
Geologist : Date : 16/05/17
Mine Overseer : Date :
Mining Manager : Date : 16/05/17
ORM Manager : Date : 17/05/17

Figure 3.3 Grab sampling results (Sampling Department, 2017)

3.2.3 Monthly survey tonnage measuring

Survey tonnage to be determined based on the surveyor's calculated volumes during the measuring month end and a survey measuring report is compiled. The compiled report has measurements such as workplace face advance, square meters achieved, face length, tonnage blasted and ASG tonnage accumulations. The research study analyses the accumulations per month from July 2017 to December 2017 as the report was initiated during the time.

3.2.4 Underground observations

To determine cleaning time of the stope face tonnes and advance strike gully, will assist when calculating the cleaning rate. The analysis of the cleaning time for advance strike gully in order to determine the time wasted during the long pull cleaning, as long gullies contribute negatively to ore cleaning process. The advance strike gully hanging wall fractures and convergence over distance is monitored through the convergence logger.

3.2.5 Belt sampling

To analyse the belt sampling report provided. This is a system on the surface belt whereby ore samples are taken with a sampling cutter timeously into the bin put below. The samples from the bin are taken to the laboratory for gold values analysis, thereafter, the laboratory will send a gold values report for each bin on the daily basis to the sampling department. Analysis of the gold values from the laboratory is done in order to compare it from the face grade as a mechanism of grade control. This is to track and ensure that the grades that are from the face are going to the plant.

3.3 Correlogram

A correlogram is a graph used to interpret a set of autocorrelation coefficients in which is plotted against the Alternating Series: If a time series has a tendency to alternate with successive observations on different sides of the overall mean, then the correlogram also tends to alternate. Positive correlation is when the data is slowly declining with the increase in lag and negative correlation is the opposite.

3.4 Chapter summary

Quantitative are essential to analyse the ore flow, grade reports and sampling sheet data through graphs and charts. Correlogram interpretation is important for the analysis of the depth, width and length in relation to the SCF. Advance strike gully conditions are one of the potential causes for low SCF at the operation for that specific measuring month, thus, the data analysis to be done to all information gathered from the advance strike gully. Although it is known that SCF can be caused by several apparent and real losses factors, however, the research study focuses on the strike gullies as one of the influences to SCF for that specific month as vamping comes after several months and sometimes there are challenges of recovering such ore due to high convergence rate. The data were collected by experienced Geologist, Sampler, Surveyor and Grade Officers; however, checks and balance were done in order to test for accuracy of the data. The next chapter presents the data and analysis of the findings.

4 ADVANCE STRIKE GULLY CONDITIONS

4.1 Advance strike gully parameters

The reef position in the raise is developed at a height of 2.7m from the footwall to ensure that there is sufficient gully depth when mining. Advance strike gullies are developed from the raise line during the ledging phase, thereafter; most of the advance strike gullies were developed at a depth less than 1.5m, by creating a step from the raise line resulting to the advance strike gully footwall not being on same elevation with the raise footwall. Figure 4.1 illustrates the Doornkop Shaft advance strike gully standard in terms of the height, depth and width.

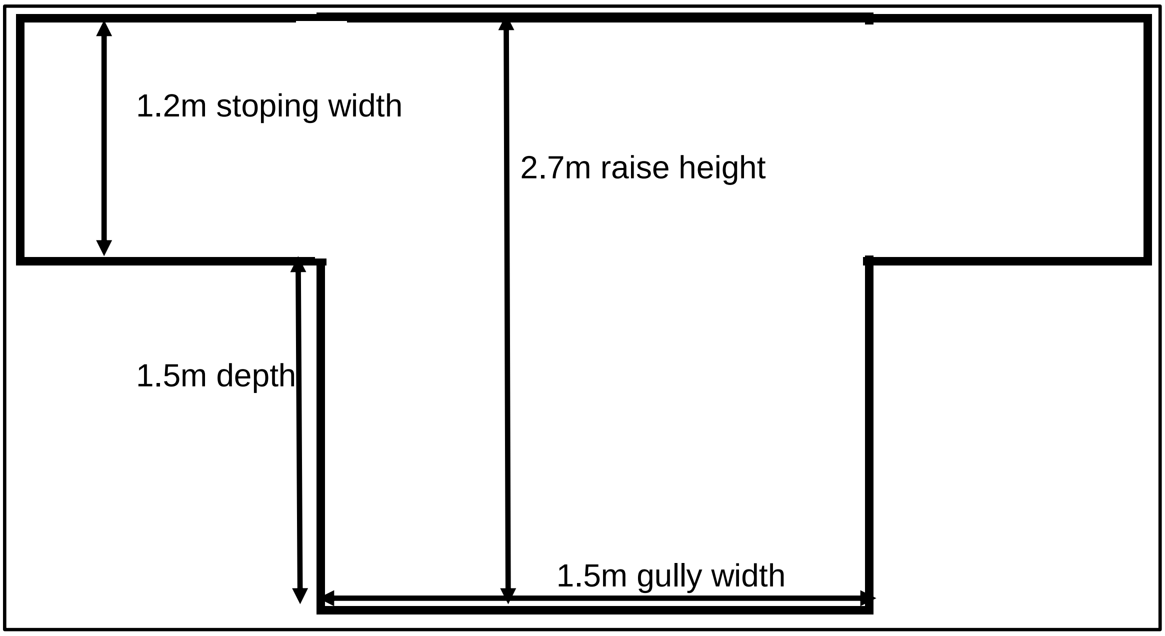


Figure 4.1 Advance strike gully standard

The depth of this condition worsens with the length of the advance strike gully, therefore creating a situation where there are spillages on the sides during scraping of the gully due to shallow depth. Shallow depth can result to off-reef mining more especially when change in strike occurs resulting on the advance strike gully being ripped to footwall in order to expose the reef in footwall. Ripping of footwall in the middle of the advance strike gully or close to the face may results in water accumulations leading to compaction of ore on the footwall. Doornkop Shaft implemented standards relating to the advance strike gully geometry. The advance strike gully geometry at the operation is 1.5m depth, 1.5m width and 90m length. Although in some cases, due to structural complexity, gully length is compromised as crosscuts are developed closer or further to each other leading to shorter or longer advance strike gully length and this affects the cleaning rate. Advance strike gully cleaning plays a critical role in the safety of employees, face advance improvements and delivery of equipment to the stope face. In the past decades little progress has been made in improving the stope cleaning system and this includes face cleaning, advance strike gully cleaning and center gully cleaning.

The improper cleaning of the advance strike gully results in ore compaction on the footwall. The compacted ore on the footwall can result to gold metal loss through the cracks and shallow advance strike gully. Different systems have been introduced in order to track the broken ore from underground sources. RFID tag is the most used system to track the ore movement. When a tag takes more than five shifts to be retrieved, the assumption is that ore has not been cleaned from the source; these locked up tonnes affect the SCF for that measuring month. Although the ore compacted in the advance strike gully cannot be easily linked with a specific month as it is a combination of broken ore from different months, ore quantification and grab sampling is done in order to have an indication of the amount of gold locked up in the advance strike gully. During the day to day face blasting, face and advance strike gully cleaning time becomes a concern, especially when the gully length increases. The increase in gully length creates constraints during the mining cycle, thereafter; most of the tonnage is left to accumulate in the advance strike gully, resulting in compaction when mixed with drilling water. Gold content is heavy thus, it tends to penetrate through the cracks of the advance strike gully or concentrate as fines at the footwall of the gully. Consequently, negatively affecting the SCF and MCF.

Figure 4.2 indicates the RFID tags return days retrieved at the surface belt from April 2017 to July 2017. The use and reporting of RFID tags started from April 2017 in the operation, hence only this period is covered. An average of 18 RFID tags are retrieved within five return days and less than five tags are retrieved between five to 18 return days. About two to three RFID tags are retrieved from the surface belt between 20 to 156 days. The stope sections where RFID tags return days is more than 20 days are not vamping sections but stoping sections. The analysis shows that there is accumulation of ore from underground sources and this accumulation can influence the SCF for that specific measuring month. Vamping is a vital step in mining processes; however, it is quite important to reduce the vamping percentage on the monthly basis by increasing the current sweepings in order to improve the SCF for that month.

This analysis somehow correlated with the belt grade and the SCF for April 2017, where the SCF was 69% to the plan of 81% refer to Figure 1.6. It has been confirmed that most of the RFID tags (refer to Appendix B) buried in the advance strike gully tonnages and siding of the advance strike gully take time to be retrieved on the surface belt and this gives an indication that advance strike gullies are not being cleaned efficiently during the measuring month affecting the depth, thereafter, leading to ore accumulations.

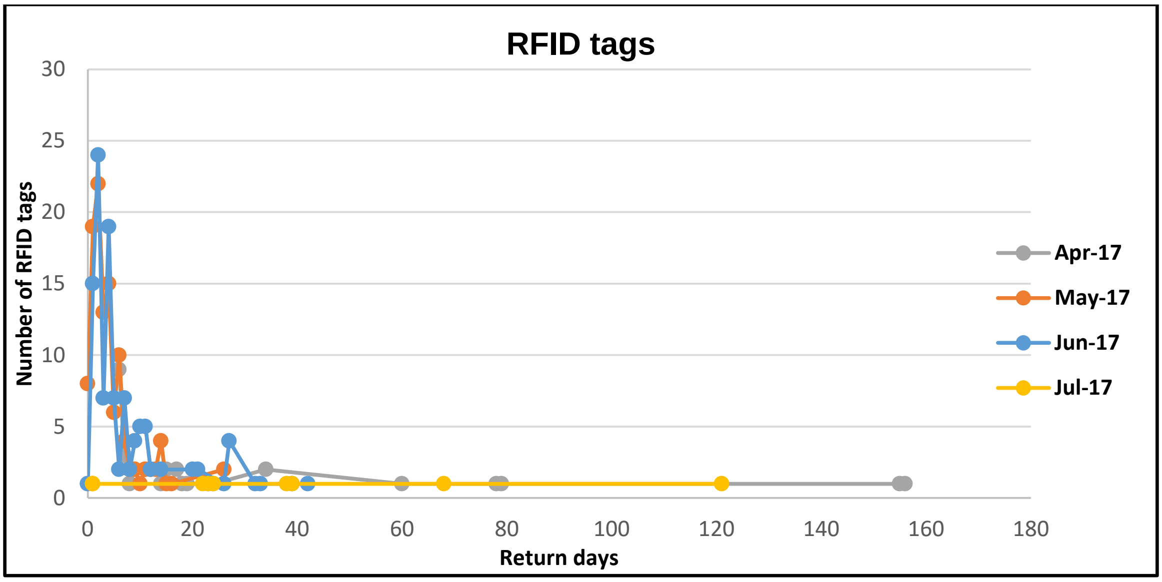


Figure 4.2 RFID tags analysis

4.1.1 Gully width

When the advance strike gully width is more than 1.5m, ore tonnages and fines can be left close to the walls of the advance strike gully. This accumulation close to the advance strike gully side walls arise because the scraper width is 1m and when winch rigging is done to standard, there are difficulties in cleaning ore in a wider gully.

Figure 4.3 shows the gully width and SCF from year 2013 to 2017 instead of 2012 to 2017 due to lack of data in 2012 and illustrates relationship between the gully widths and the SCF. Although it is highly known that SCF is caused by several apparent and real factors (see Figure 2.1), however, in this case there has been a trend of depression in mining quality leading to increase in accumulations during the months. The research focuses on increasing current sweepings percentage and reducing the vamping percentage in order to improve the SCF for that measuring month. In year 2013 to 2014 there was an increase in number of panels developing strike gullies at width of 0 to 1.5m and increase in depth from a range of 1.51m to 3m. When number of panels increase depth strike gully depth at 1.51m to 3m, thereafter, panels with strike gullies width below 1.5m reduced (see year 2014 to 2016 below). There is no clear indication that the width of the strike has an impact on the SCF as it has shown regression over the year's regardless compliance to the width.

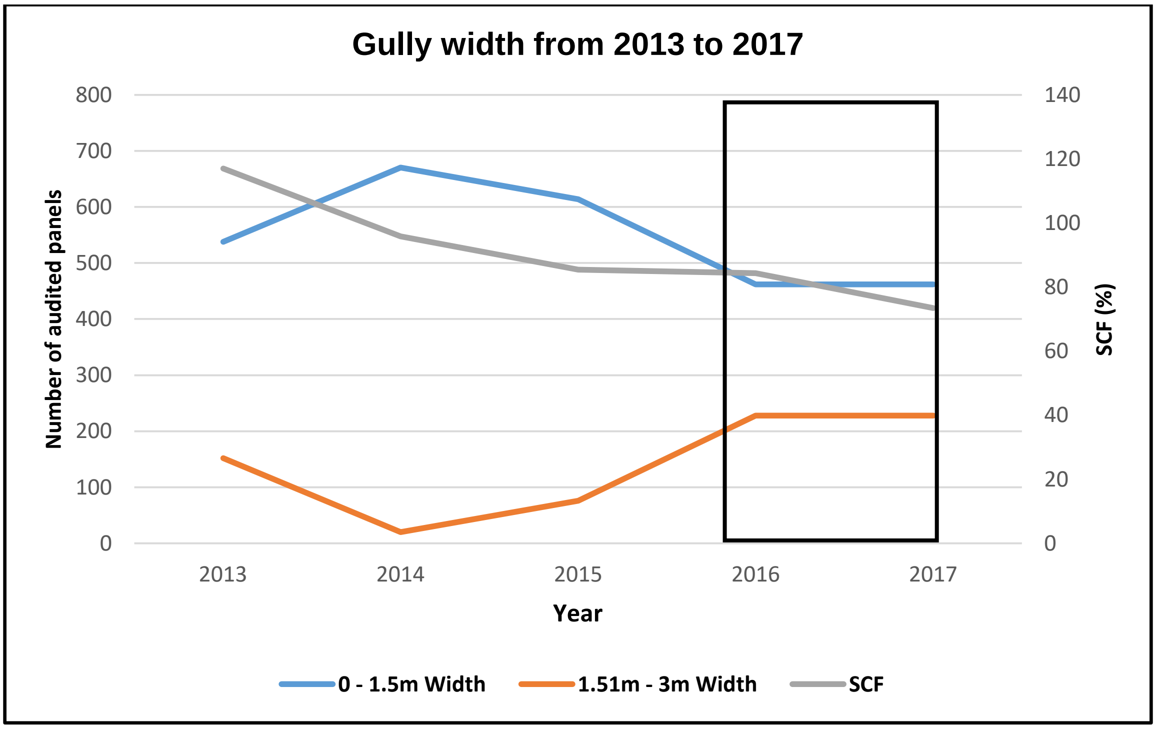


Figure 4.3 Gully width and SCF

Figure 4.4 shows the analysis of the gully width from January 2017 to December 2017 for 80 panels. The advance strike gully width data collection started from January 2017 in the operation, hence only this period is covered. From the pie chart, 52% of the panels have advance strike gully width greater than 1.5m. The footwall of the South Reef is siliceous and show competency, however, due to the poor rigging, longer advance strike gully and shallow depth, scrapers hits the sides of the advance strike gully removing packs support and this results in poor cleaning in the gully as the ore overflows to the sides of the gully. Only 44% of the panels have the correct width of 1.5m and 4% of advance strike gully were less than 1.5m.

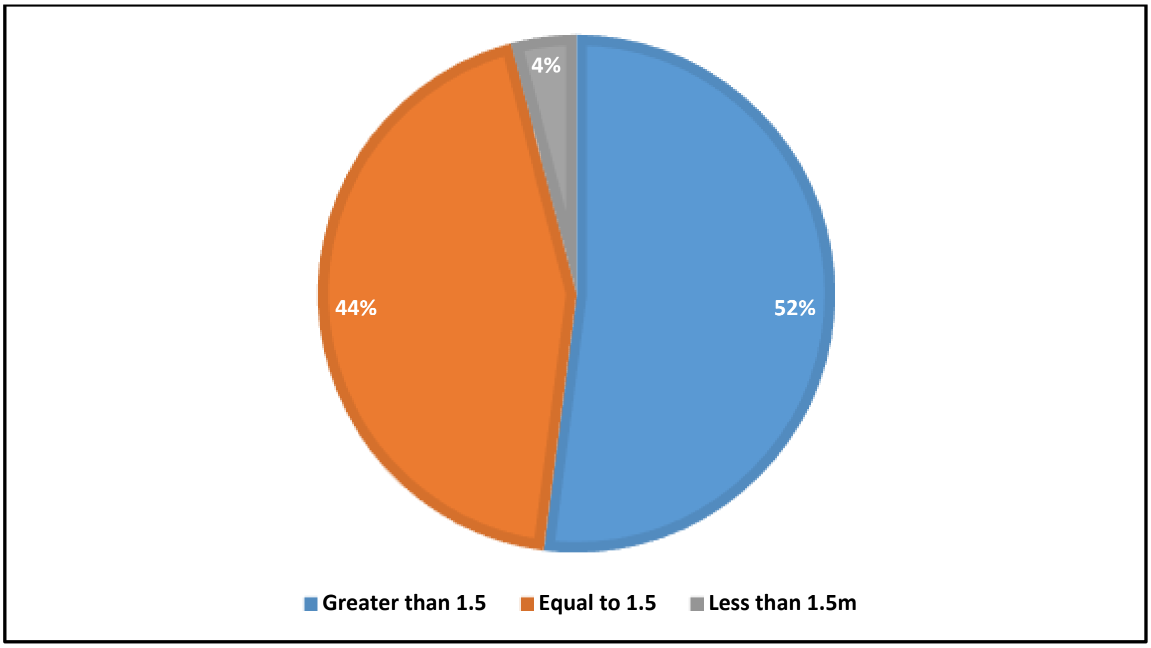


Figure 4.4 Advance strike gully width

Figure 4.5 indicates the gully width of a South Reef stoping section where the gully widths are wider than the required standard of 1.5m. Advance strike gully width increase due to miners developing advance strike gully width more than 1.5m and when scraper winch collides with the sidewalls. At a gully length of more than 90m, the possibility of a scraper to hit the gully sides and remove packs is high and this affects the quality of advance strike gully cleaning. The rock fragmentation size of the section was poor because the longer the scraping distance, rocks collide with each other causing fines, which accumulate on the sides of the advance strike gully. The condition where fines are left compacted in advance strike gully affects the belt grade and the SCF because ore blasted from the panel face does not reach the belt.

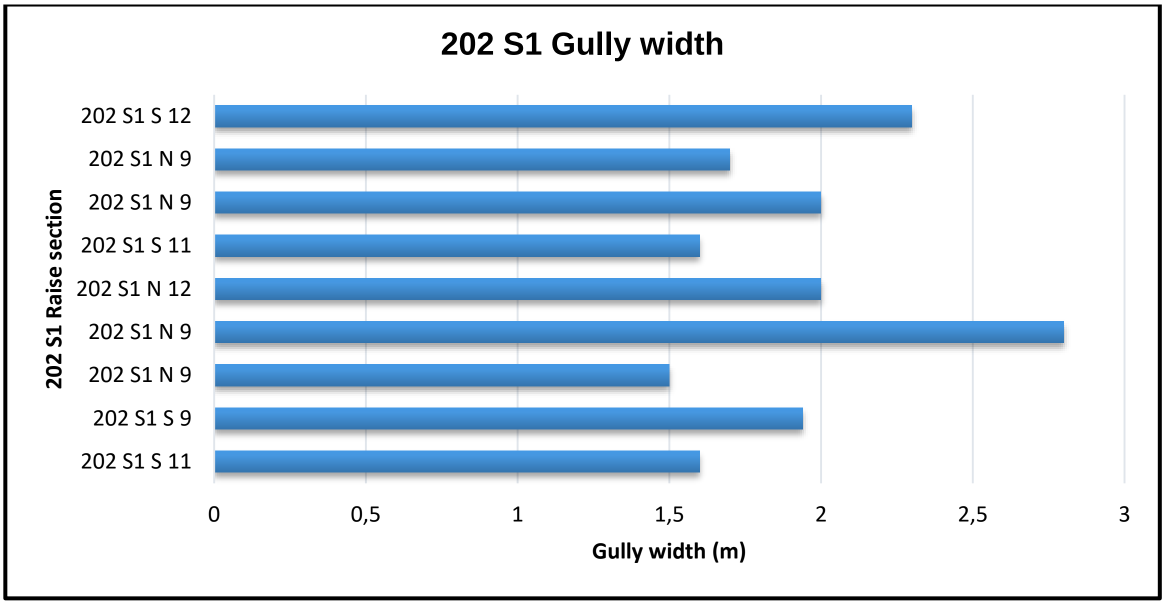


Figure 4 5 Gully width at 202 S1

Figure 4.6 indicates a condition after advance strike gully cleaning, showing the overflow of ore in the back areas due to the oversized gully width at shallow depth. This ore have to be swept during vamping, thus affecting the tonnage called for.

Figure 4.6 Ore accumulations on the advance strike gully side wall (Doornkop Shaft, 2017)

4.1.2 Gully depth

It is highly important that advance strike gully depth must be deep enough to accommodate blasted ore from the face. A gully condition where people travelling through the advance strike gully cannot stand upright, indicate that the advance strike gully is not cleaned to footwall or it is blasted at the depth less than 1.5m (Thompson, 2002).

Figure 4.7 indicates the analysis of advance strike gully depth for the period from April to July 2017 during the initial phase of the research study and data collection of advance strike gully depth stopped in July 2017. During Mondays Geologists, Surveyors and Samplers goes underground to do quality audits in order to improve quality mining. Strike gullies depth were measured using a chisel and a clinorule and these tools helped in getting the better measurements as in most cases strike gullies were found full of tonnage. About 49 panels were audited each month and 49% of those panels had advance strike gully depths between 1m and 1.4m. The advanced strike gully depth was measured by Geologist, Surveyors and Samplers. Gully depth is the difference between panel footwall and advance strike gully footwall. About 33% of the advance strike gullies were less than 1m in depth and only 18% of the advance strike gullies were to mine standard. These advance strike gully conditions result to poor cleaning where fines are compacted on the footwall.

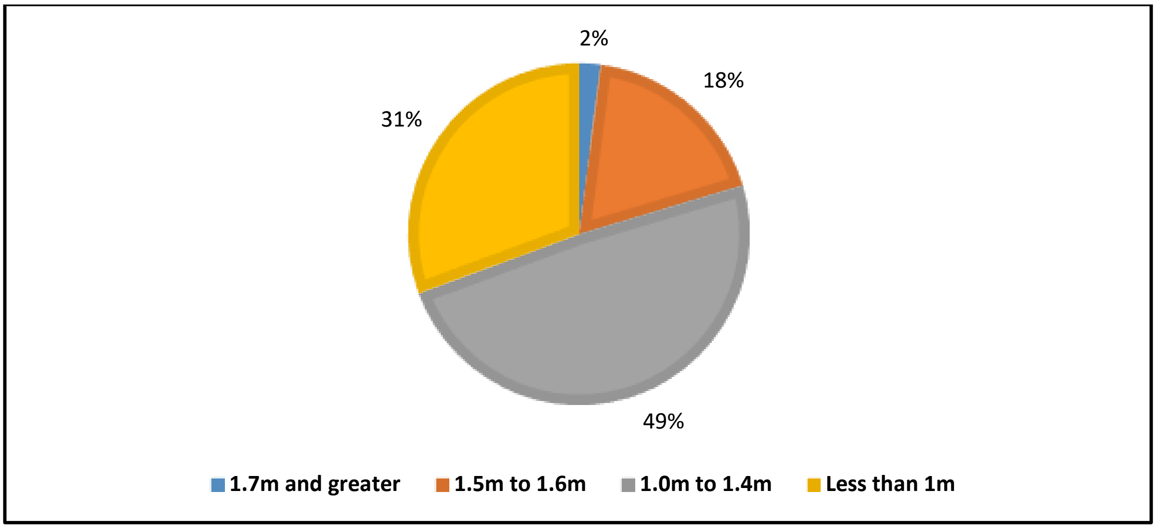


Figure 4.7 Gully depth percentages

Figure 4.8 shows the SCF from April to July 2017 in order to indicate the link between the advance strike gully depth and the SCF from the data. The SCF actual values show an increase from April to July 2017, however, the actual SCF is still below 81% budget. From April 2017 to May 2017, an average of 21 panels had gully depth less than one meter and which indicates that there is less dilution in the system. Panels having 1.5m strike gully depth shows an increase from June to July 2017.

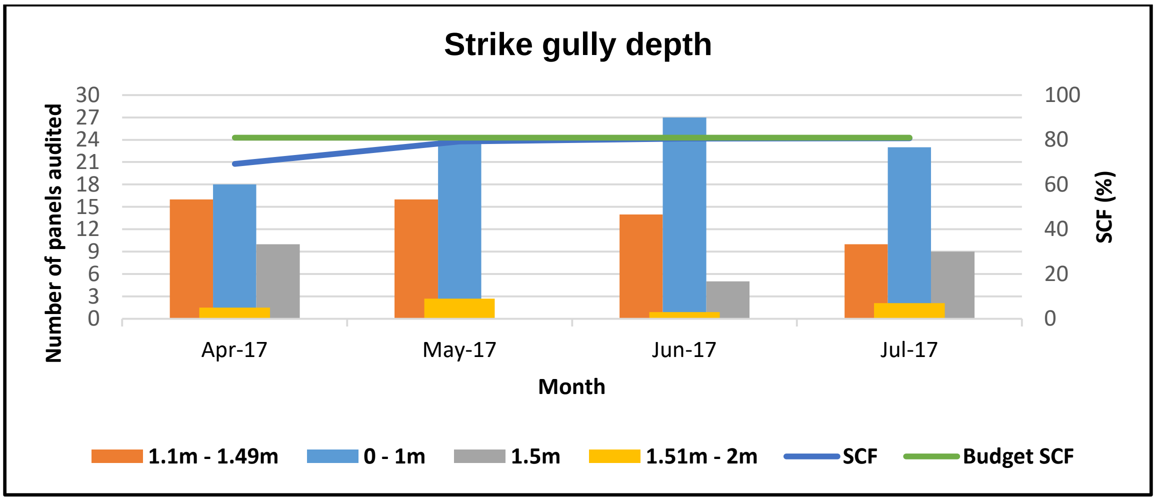


Figure 4.8 SCF from April to July 2017

Figure 4.9 showing one of the advance strike gully from a new raise line developed at a depth of 0.92m, which is less the 1.5m. When the ASG is blasted from the center gully, its footwall tends to be blasted higher than that of the center gully and in order to have the gully developed to mine standard, the footwall of the center gully must be the same as that of the advance strike gully. At Doornkop Shaft, ore passes are developed as Y-leg design and not every panel has its own ore pass.

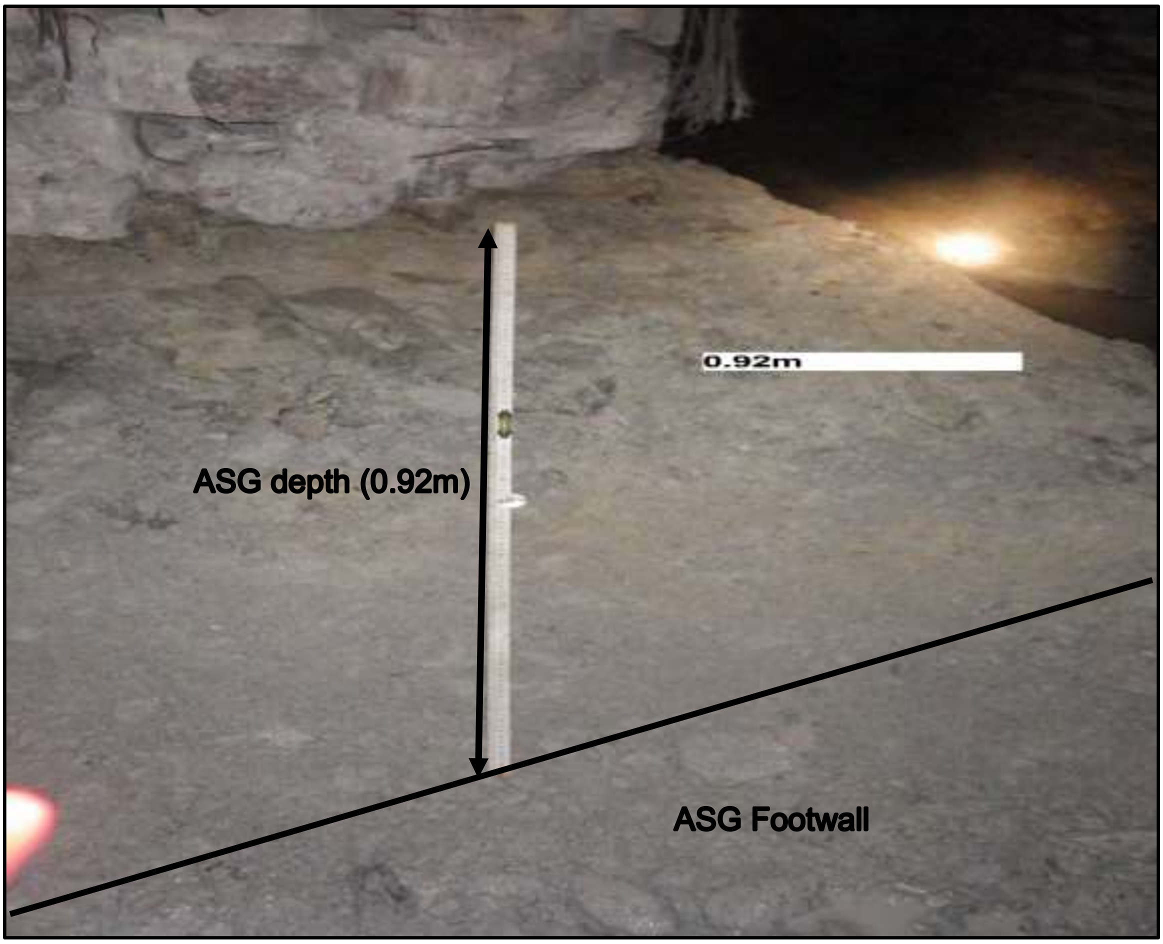


Figure 4.9 Shallow advance strike gully (Doornkop Shaft, 2017)

4.1.3 Gully length

Analysis of sampling data from 2013 to 2017 has been done, focusing on the advance strike gully length. Although advance strike gully lengths can exceed the standard of 90m due to the strikes of geological structures affecting the design. However, in Figure 4.10 the advance strike gully is developed from one raise line to another due to mining flexibility. Doornkop Shaft is using 37kw winches in the advance strike gully with the rope speed of 1.2m/s. The type of winch becomes a constraint when the advance strike gully length is more than 90m because ore will take time to be cleaned to ore passes and not all tonnage can be removed resulting to increased accumulation in the advance strike gully.

Figure 4.10 showing 202 S1 stopes advance strike gullies length from the center gully. Most of the advance strike gullies in this stope section are longer than 90m, creating difficulty in cleaning and grade loss to the back areas. The rate of convergence also depends on the distance from the centre gully to the face. In 202 stope section strike gullies converge affecting the daily cleaning of ore and the decision was made to rip all strike gullies from the centre gully. The longer the strike gullies at the section showed possible impact on the flow of ore at the operation which can affect the SCF as ore cannot be recovered easily after convergence of the hanging wall affecting ore cleaning from the face (see figure 4.26).

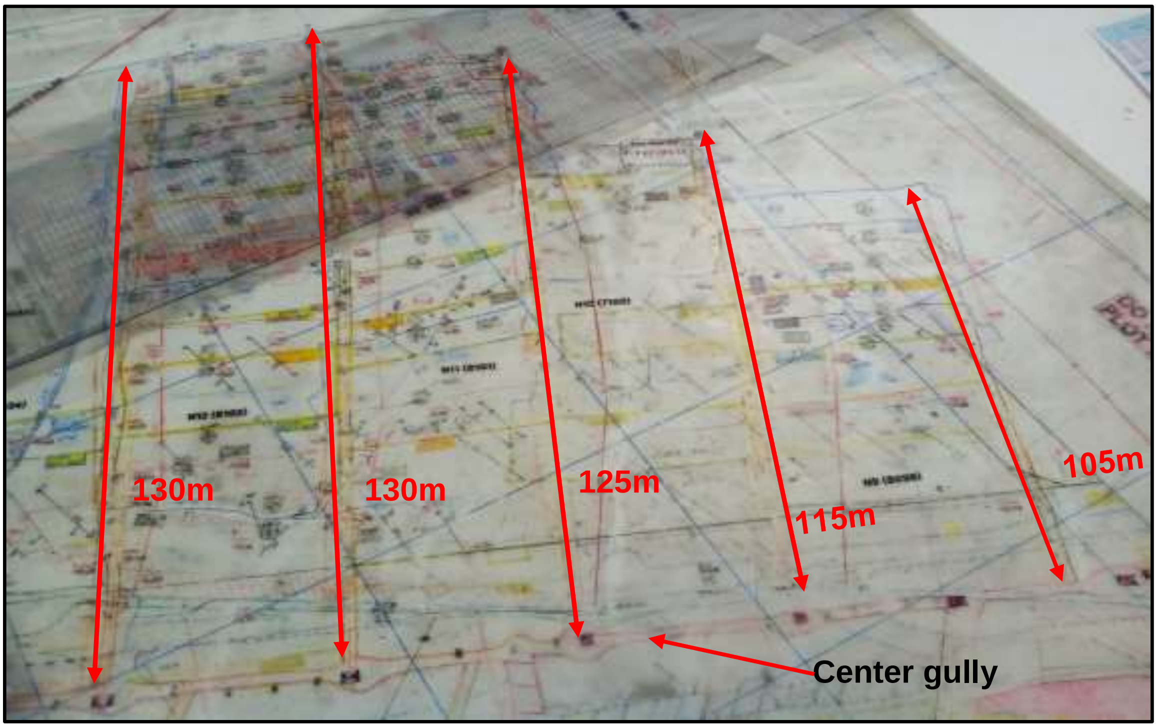


Figure 4.10 Advance strike gully length in a stope section (Doornkop Shaft, 2017)

Figure 4.11 indicates the gully length and SCF over a five-year period from year 2013 to 2017, excluding 2012 due to lack of data. A total of 690 panels were sampled from 2013 to 2017, whereby about 600 panels had advance strike gully lengths less than 90m and 90 panels has advance strike gully more than 90m. SCF over the years shown a continuous decrease and there has been an increase in panels with advance strike gully of more than 90m. It is well known that ASGs condition is not the only element that can lead to the decrease of the SCF, however, the research study seek to address the conditions in ASGs that can result to possible negative impact on the SCF. In year 2013 to 2015 the gully lengths were within the 90m mine standard, however, the SCF showed a downward trend because SCF can reduced due to apparent or real gold losses and not only ASGs condition. There has been an increase in gully length from year 2015 to 2017.

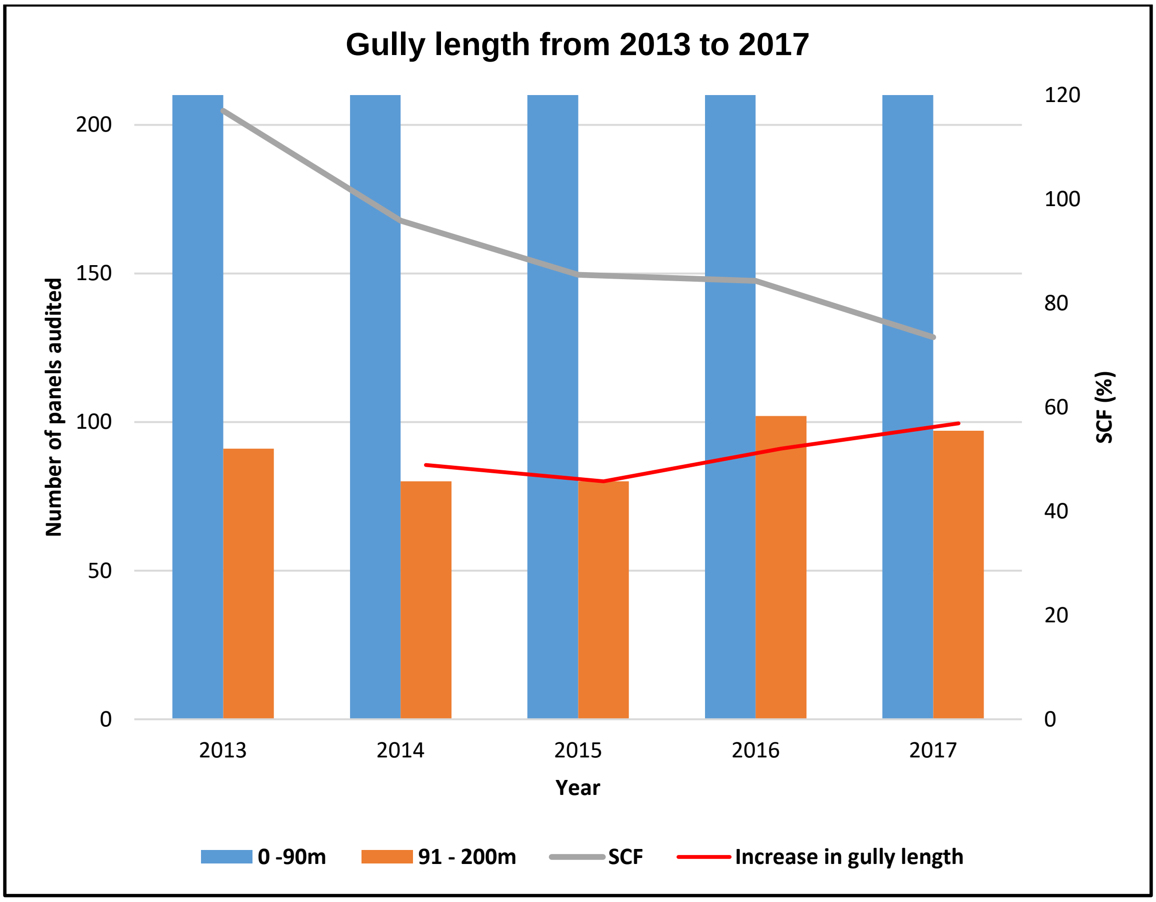


Figure 4.11 Gully length and SCF

Figure 4.12 shows the analysis of 80 panels from April to June 2017, 24% of the panel gully lengths exceeded 90m. Analysis shows that when the scraping distance is long and the depth is shallow, the cleaning is high. Long strike gully could also affect the face cleaning thus sweeps and lockup of gold.

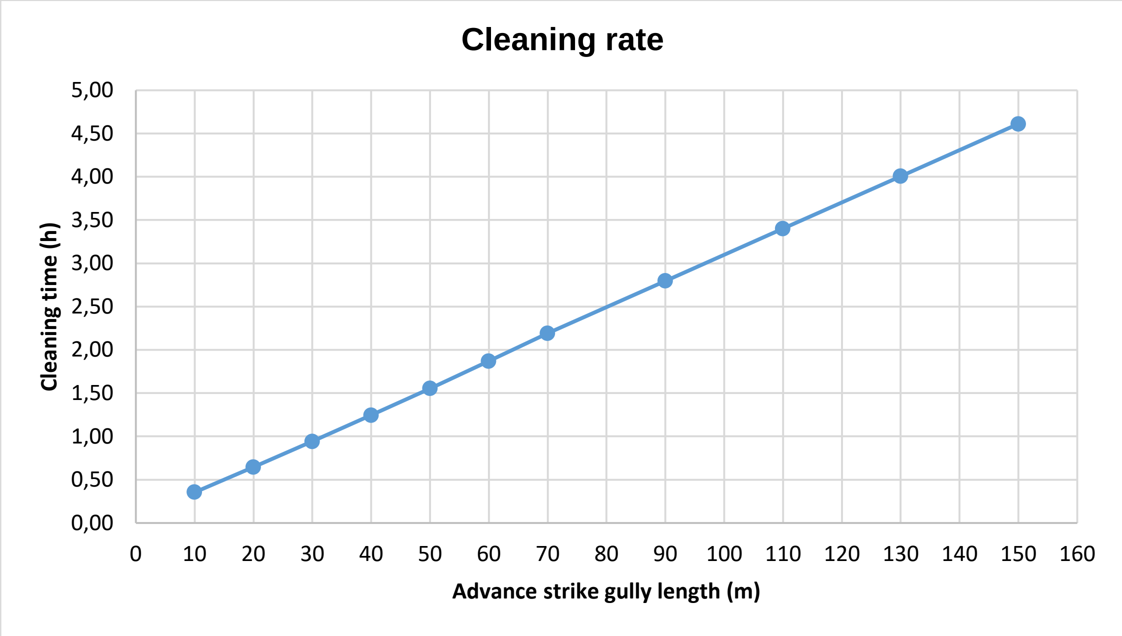


Figure 4.12 Advance strike gully length and cleaning rate

4.2 Offline ASG

Offline mining results when miners are not adhering to the survey mining layout. Offline mining leads to advance strike gully that are curved, thus, ore accumulates on the curves resulting to less ore scraped to the orepass. Thereafter, less ore to the orepass results to less ore to be hoisted. These conditions of reduced quantity ore in the ore flow system have a negative impact on the SCF.

Figure 4.13 shows offline mining from April 2017 to June 2017 (refer to Appendix C) and there be limitation of data as offline mining audit was introduced in April 2017. Averages of two panels were offline from April to June 2017 out of 69 panels. About three panels are measured each month from April 2017 to June 2017 and this offline condition creates obstruction when scraping ore to the orepass. The section where most of the offline mining happened was 192 N3 section where about three panels were cleaning in one strike gully and ore blockages could occur and spillages of ore on the sides and this lead to ore not reaching the ore pass during the month.

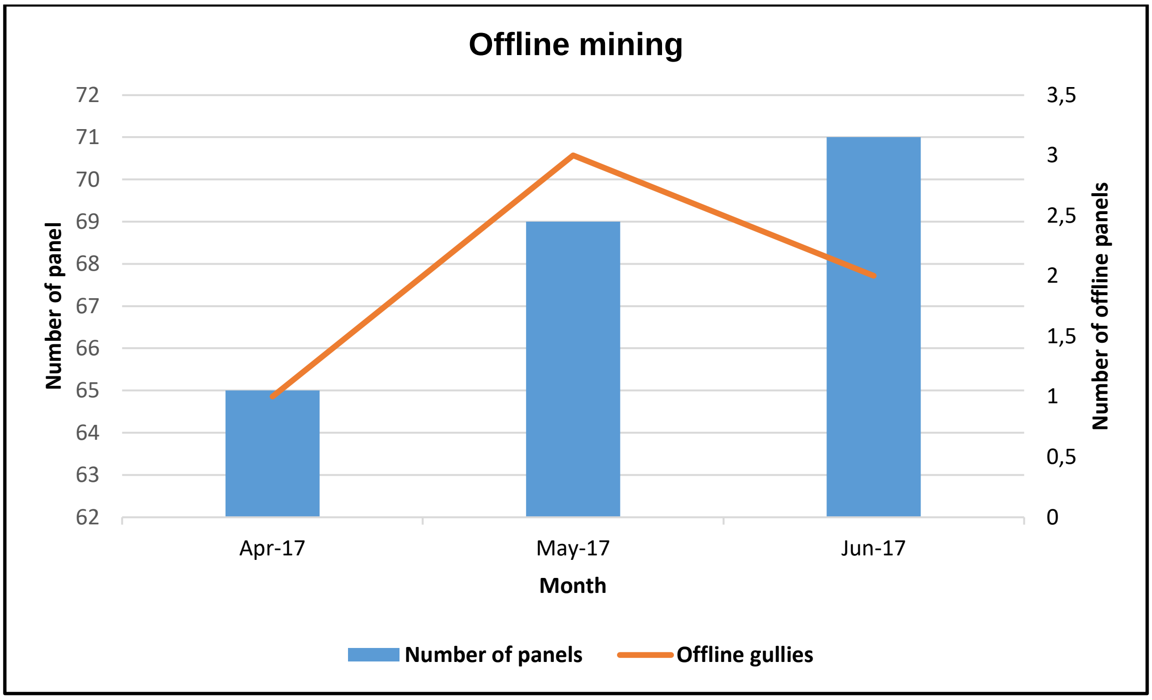


Figure 4.13 Offline mining at Doornkop Shaft

Figure 4.14 indicates offline mining observed in a stoping section and it happened where miners were not adhering to the survey notes.

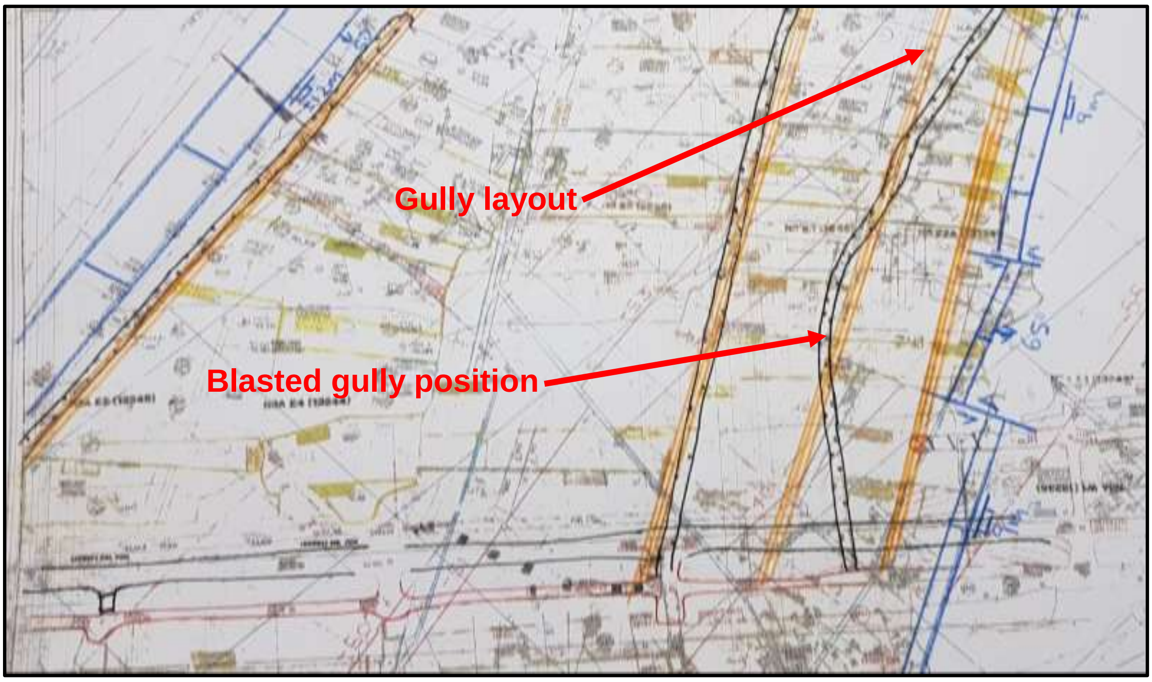


Figure 4.14 Offline advance strike gully at Doornkop Shaft (Doornkop Shaft, 2017)

4.3 Advance strike gully cleaning rate

The tonnes blasted from the stope face are cleaned from the face through the face winch scraper into the advance strike gully. Advance strike gully plays an important role in terms of stope cleaning. These scoops have the capacity of 1 tonne each and a fill factor of 80%. The fill time and tip time observed were about an average of five seconds combined. The longer the stope face, high stoping width and advance strike gully, the higher the cleaning time, the lower the cleaning rate. The emphasis of cleaning rate and time to the advance strike gully length is to ensure that there is an optimum advance strike gully length and to have efficient cleaning of broken rocks with minimum loss of metal content. Equation 3 was introduced in Rupprecht (2002) in order to calculate the cleaning rate.

$$CR = Qa \; x \; Ff \; x \; N \; x \; Eff \tag{3}$$

Where:

CRcleaning rate (t/h);

Qathe capacity of the scoop (m³/t);

Ffthe fill factor of the scoop (%); and

Effthe efficiency of scraping, usually in the order of 30%.

The number of trips per hour is calculated using Equation 4 (Rupprecht, 2002):

$$N = \frac{3600\ seconds}{\left(\frac{SDf+SDr}{Rs}\right)} + Ttip + Tfill \quad (4)$$

Where:

Nthe number of trips per hour;

SDfscraper distance forward;

SDrscraper distance return;

Rsscraper rope speed, usually 1.2 m/s;

TtipTime to tip in seconds; and

TfillTime to tip in seconds.

In order to achieve a high cleaning rate (CR), it is necessary to achieve reasonably high values of Qa, N, and Eff. Table 4.1 indicates the cleaning time and cleaning rate of certain panels. There is a regression on the cleaning rate of a panel with a longer gully length, consequently increased cleaning time. 202 S1 S10 panel has the longest gully length of 145m and a cleaning rate of 7 t/h and cleaning time of 2.8 hours.

Table 4.1 Cleaning rate of advance strike gully at Doornkop Shaft

Panels	Tons per shift (t)	Gully length (m)	Cleaning time (h)	N	Cleaning rate (t/h)
192 N3 E 2	52.4	115.0	1.8	18.3	8.8
197 S7 N 10	56.2	58.0	1.0	35.4	17.0
197 S7 N 3	60.3	46.0	0.9	44.1	21.2
197 S7 N 9	29.1	50.0	0.4	40.8	19.6
197 S7 S 10	92.5	30.9	0.9	63.7	30.6
197 S6 S 1C	74.9	88.6	2.0	23.6	11.3
202 S1 S 7A	50.4	39.2	0.6	51.2	24.6
202 S1 S 10	65.5	145.0	2.8	14.6	7.0
202 S1 S 9	34.8	115.0	1.2	18.3	8.8
202 S1 N 9	85.1	70.0	1.8	29.6	14.2
202 S1 N 11	5.4	104.0	0.2	20.2	9.7
202 S1 S 11	67.8	136.0	2.7	15.5	7.5
202 S1 S 13	60.7	98.0	1.8	21.4	10.3
202 S1 N 12	60.6	106.0	1.9	19.8	9.5

Figure 4.15 shows the advance strike gully length of different panels and their cleaning rate. 202 S1 S10 panel had 145 ASG distance resulting to about 8.8 t/h cleaning rate. The longer the ASG, the lower the cleaning rate and can result in ore in the stope faces not fully cleaned during the night shift.

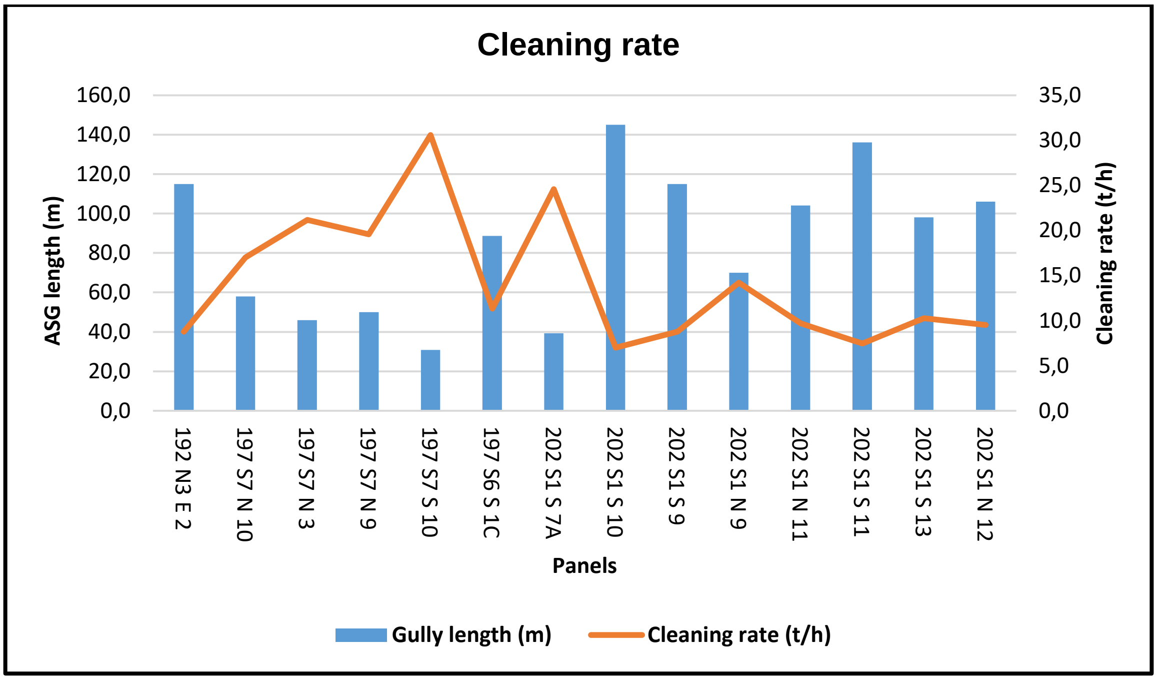


Figure 4.15 Cleaning rate in relation to the gully length

Figure 4.16 shows the cleaning rate of the panel audited from January 2017 to December 2017 when the report was initiated, where it illustrates that the longer the advance strike gully, the lower the cleaning rate. Cleaning rate reduces as advance strike gully length increases and when the advance strike gully length is 90m, the cleaning rate is 10.2 (t/h).

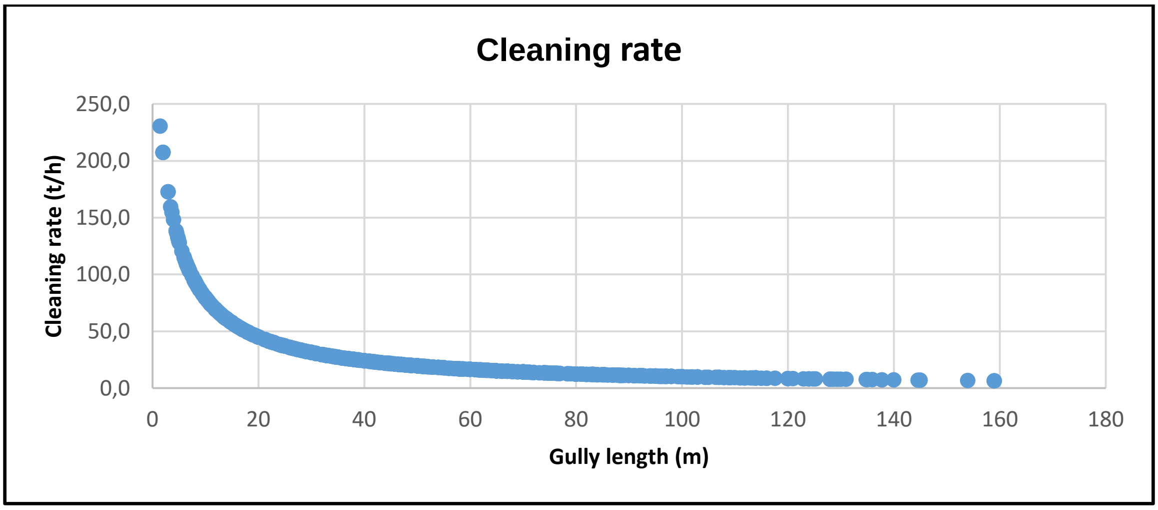


Figure 4.16 Analysis of cleaning rate against the advance strike gully distance

Figure 4.17 indicates the different gully length ranging from 20m to 120m having an average face length of 30m, stoping width of 120cm, density of 2.72 t/m^3 and 97 tonnage. The data used is not realated to specific measurements or month, however, constant figures. When the cleaning rate decreases, the cleaning time increases and the opposite is the true. The cleaning time at a distance of 90m is 2.64 hours and cleaning rate of 37.16 t/h. In some instances, the advance strike gullies are not cleaned to footwall due to winch breakdowns, thus, the cleaning time increases and creating condition where employees crawl in gullies when entering the stope face. The strike gully cleaning throughput at different gully length shows than gully length more than 90m has a negative impact on the ore cleaning, thereafter, affects the SCF.

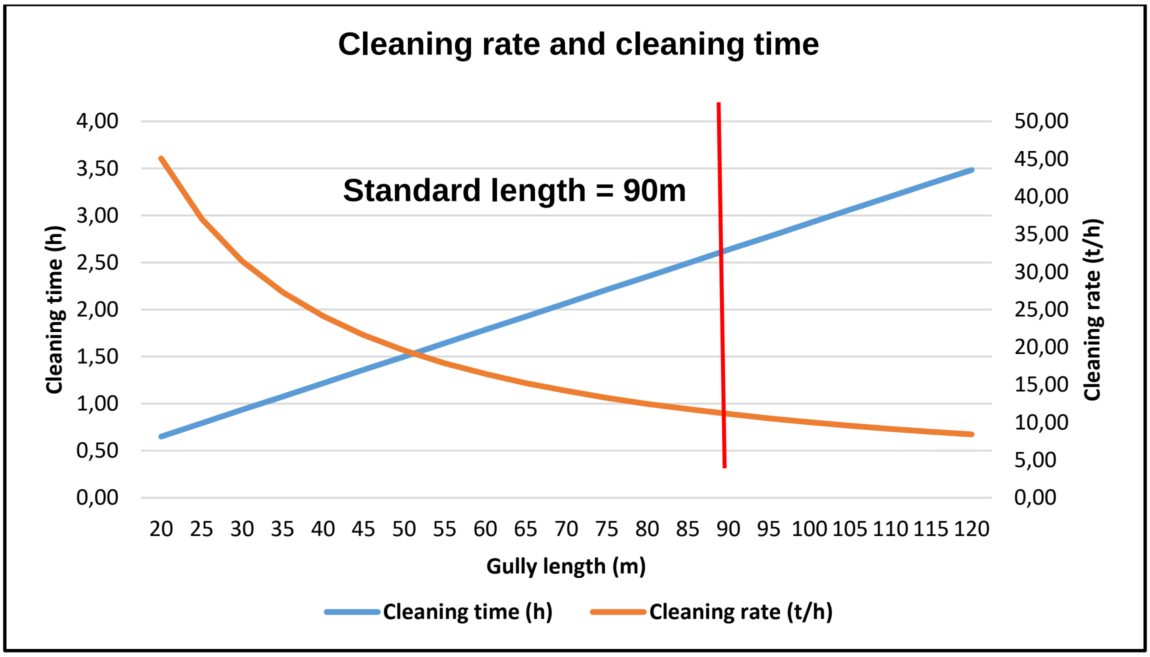


Figure 4.17 Cleaning rate and cleaning time

4.3.1 ASG cleaning time

Ore from the stope face is cleaned into the ore pass through the advance strike gully and there are factors for good ore cleaning in terms of time such as good winch capacity, winch rigging, and advance strike gully length and depth. These factors affect the cleaning rate and the throughput of advance strike gully cleaning if not complied to. Rupprecht (2003) adopted the theoretical gully cleaning rate where the throughput of cleaning the advance strike gully at different lengths can be calculated using Equation 5 – 8:

$$Time\ per\ trip\ gully\ (S) = \frac{Return\ trip\ distance\ (m)}{Rope\ speed\ (s)} \quad (5)$$

$$Total\ time\ per\ trip\ (s) = \frac{Time\ per\ trip\ + Turning}{digging\ time} \quad (6)$$

$$Tons\ per\ trip\ gully\ (t) = Scoop\ capacity\ (t)\ \times Fill\ factor\ (\%) \quad (7)$$

$$Tons\ per\ hour\ (tph) = \ (Tons\ per\ trip\ gully\ (t)/(Total\ time\ per\ trip\ (h) \qquad (8)$$

Table 4.2 The efficiency of advance strike gully cleaning

Gully length	Return distance	TP trip gully (s)	Total time per trip (s)	tons per trip gully (t)	Tons per hour	Blasted tons	Time to clean (h)
10	20	20	25	1,8	77,76	91,92	1,18
20	40	40	45	1,8	43,20	92,92	2,15
30	60	60	65	1,8	29,91	93,92	3,14
40	80	80	85	1,8	22,87	94,92	4,15
50	100	100	105	1,8	18,51	95,92	5,18
60	120	120	125	1,8	15,55	96,92	6,23
70	140	140	145	1,8	13,41	97,92	7,30
90	180	180	185	1,8	10,51	97,92	9,32
110	220	220	225	1,8	8,64	97,92	11,33
130	260	260	265	1,8	7,34	97,92	13,35
150	300	300	305	1,8	6,37	97,92	15,36

Figure 4.18 shows the advance strike gully cleaning throughput. The throughput when cleaning the advance strike gully depends on the length of the advance strike gully. The longer the advance strike gully, the longer it takes for broken ore to be scraped to the ore pass and this delay can affect the SCF. The shorter the advance strike gully the high the throughput and the opposite is true.

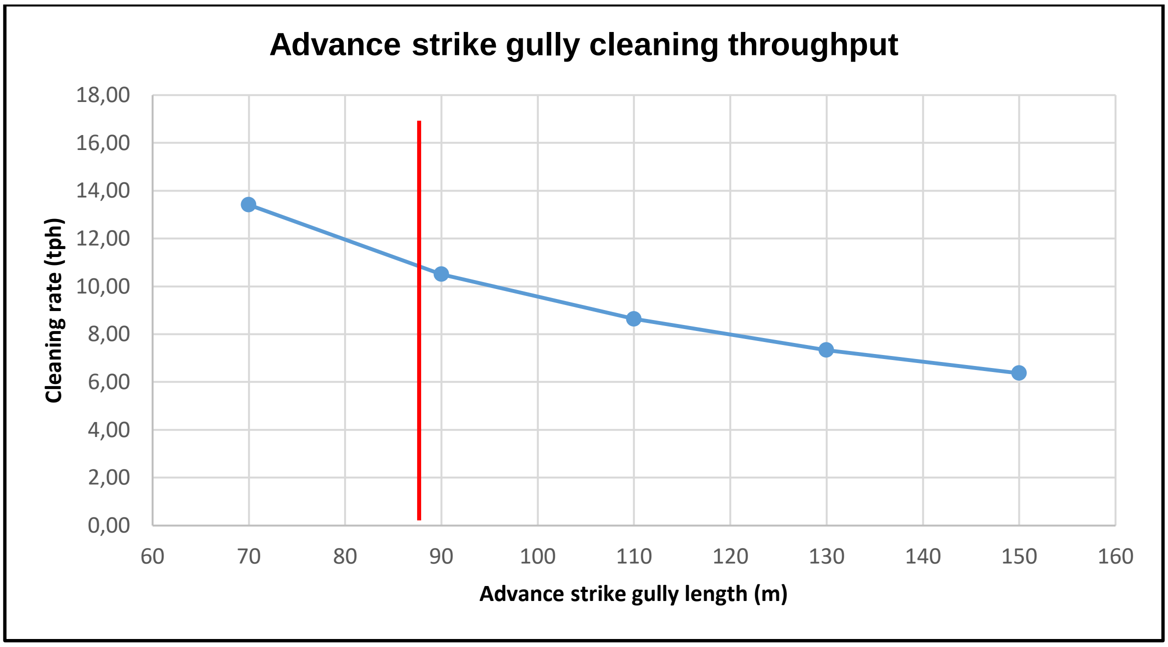


Figure 4.18 Advance strike gully cleaning throughput

4.4 Sweepings

On the day when the blasting month is ending, 23 blasting shifts at Doornkop Shaft, the survey department has to measure all panels based on advance in the month of the sweepings position, which should be within 9m from the face. The measurements give an indication of the total amount of ore removed from the stope panels. The monthly measuring is done in order to have an idea of the amount of tonnage cleaned as per survey measurements with the tonnage blasted as per advance measured.

Figure 4.19 shows the number of panels that failed sweepings from January 2017 to December 2017 and this period is used due to lack of data before 2017 (refer to Appendix D). Out of 80 panels audited nine panels failed sweepings, this has an impact on the SCF and MCF. In most cases the stope face sweepings pass, however, the strike gully would have ore accumulations which is not all removed during the month end and can affect the SCF. The impact of failed sweepings resulted in 23%. The month of June 2017 had the highest failed sweepings, this resulted to low SCF.

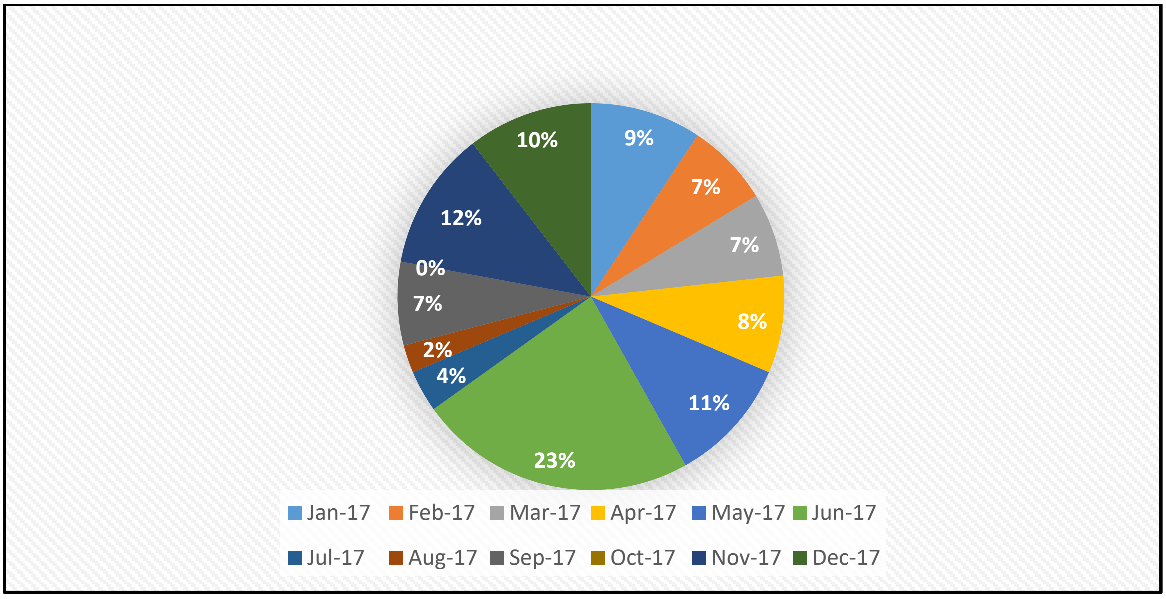


Figure 4.19 Failed sweepings

Figure 4.20 The SCF from January 2017 to December 2017 shows fluctuation as an upward or downward trend. Failure to sweep panels to standard can have an impact on the SCF, although in this instance only 9 panels failed sweepings. In most case when stope faces are clean, ASGs were full of blasted ore. (Figure 4.20). When the panels failing sweepings increases, the SCF can be reduced, although in this case it is not totally clear due to the percentage of failed panels during 2017.

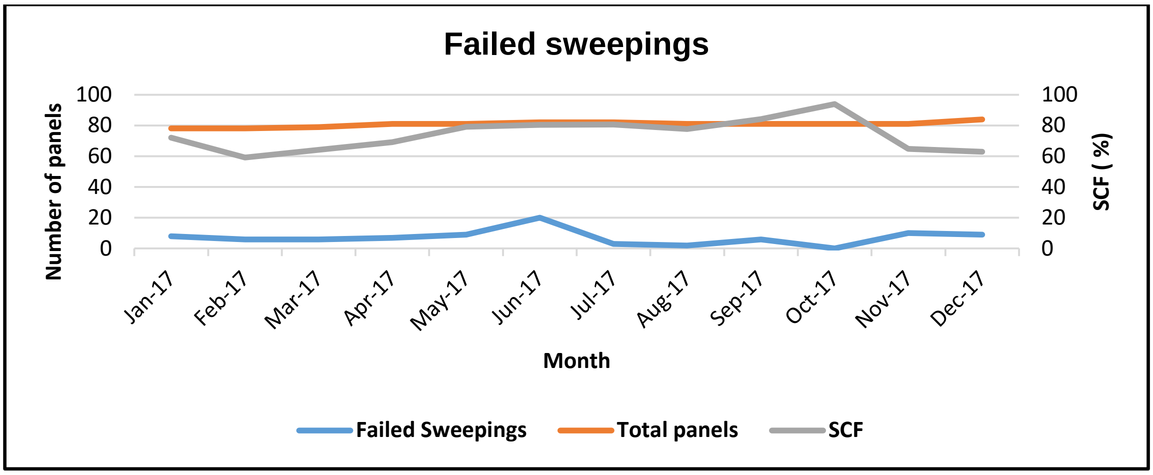


Figure 4.20 Comparison between the SCF and number of panels that failed sweepings

4.5 Advance strike gully locked-up tonnage

The ore that accumulates in advance strike gully footwall is often fines and contains high metal content. The advance strike gully accumulations is a combination of ore from different production month, however, in each month there is a necessity to quantify the amount of accumulation left as locked-up tonnage in order to have a clear indication of where the discrepancy tonnage comes from.

Figure 4.21 is showing the amount of tonnes measured in the advance strike gully on survey measuring month. Although the advance strike gully tonnes cannot be easily traced to a specific month, as it is a combination tonnage of different blasting periods. The SCF is affected as the amount of tonnage locked-up in the ASGs increase, because the ore called for by survey department is not hoisted to surface.

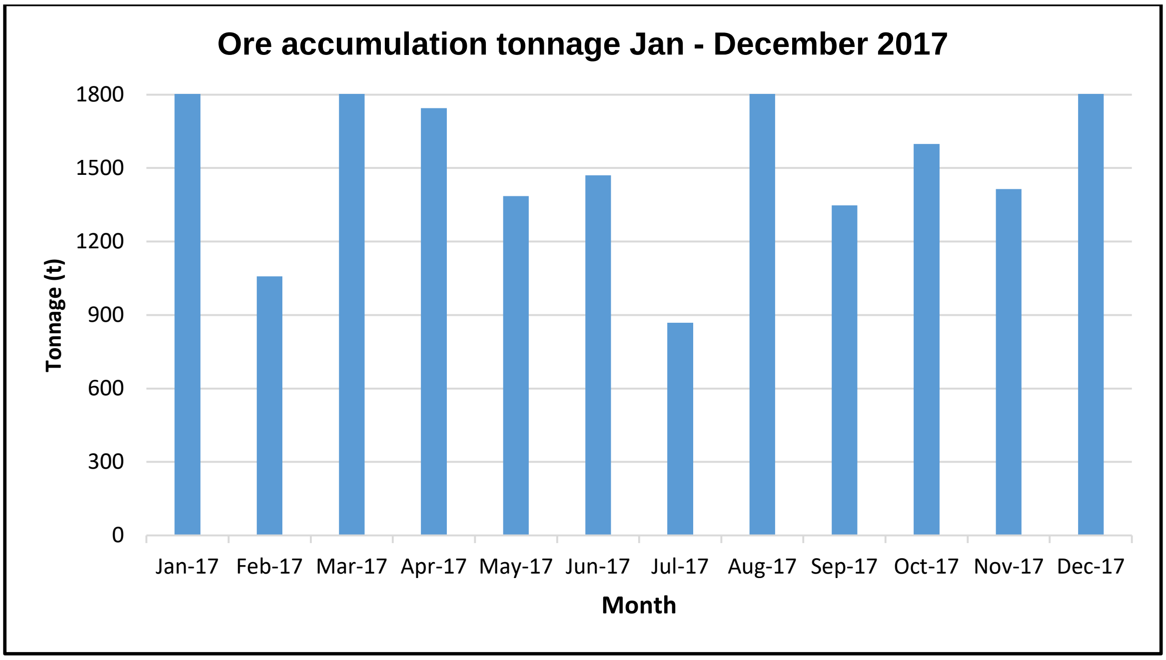


Figure 4.21 Ore accumulation in the ASG

Figure 4.22 shows the revenue of gold lost from advance strike gully accumulations. The gold price assumed as R572 000/ Kg, 6.1Kg of gold in the ASG and the recovery grade averaging to 4.01g/t. About R 38, 430, 000 can be lost over a year period if advance strike gully are not cleaned to footwall. The concept of efficient cleaning of strike gully reduces the vamping percentage which comes at a cost and can results in better gold recoveries. Also limit the strike gully length to 90m standard.

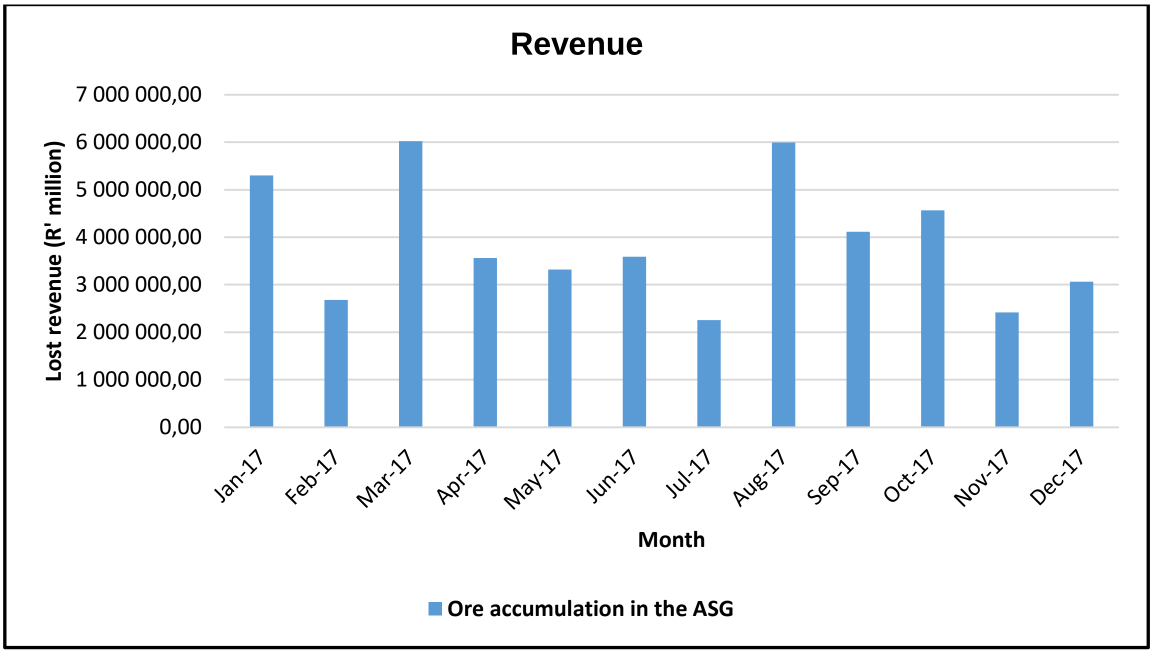


Figure 4.22 Revenue lost due to gully tonnage accumulations

Figure 4.23 indicates the SCF before and after adding the advance strike gully accumulations. Advance strike gully accumulations are combination of several months tonnage, however if about 90% is removed every month as a standard, there will be a slight increase in tonnage, grams per tonnage and gold. The SCF increased with about 16% when the advance strike gully accumulations are cleaned and if strike gullies are less than 90m length. Additional tonnage from the advance strike gully to the flow of ore system has a potential of increasing the SCF.

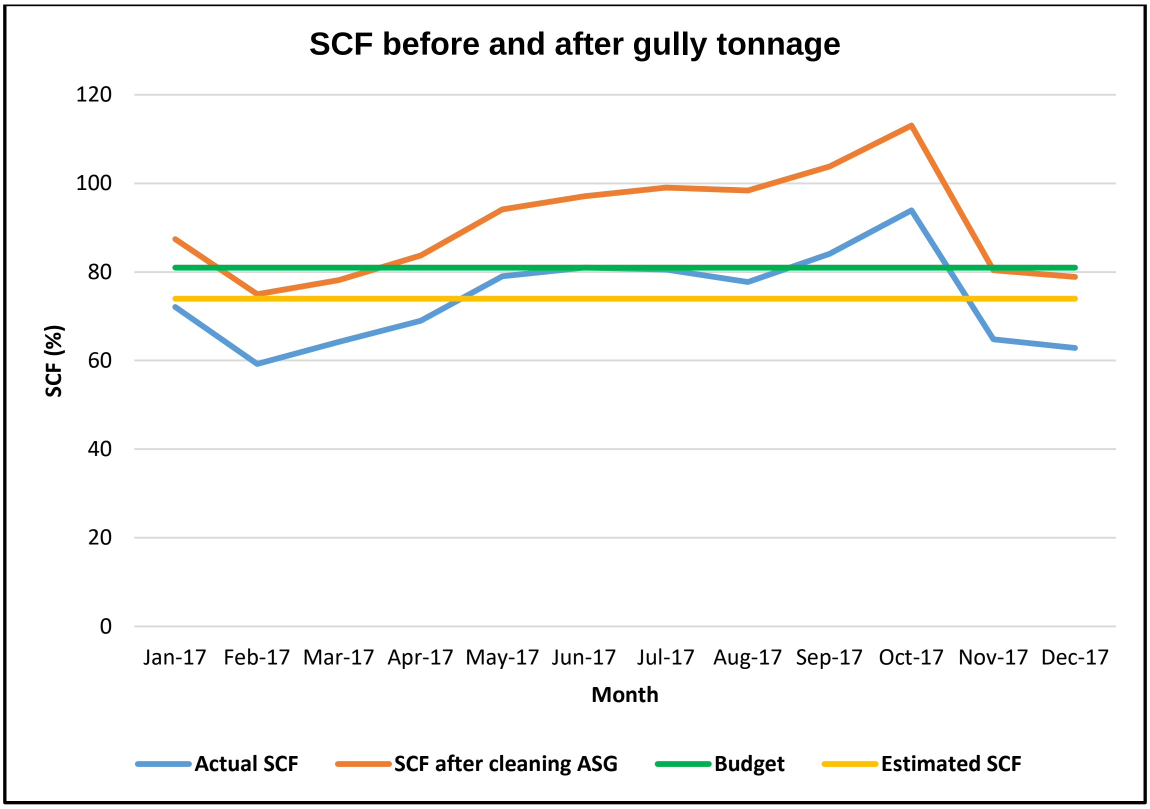


Figure 4.23 Actual SCF and estimated SCF

4.5.1 The ore grade in advance strike gully

The grade indications in advance strike gully were done through grab sampling and the data were analysed. Although grab sampling has limited accuracy, it does give indication of the grade accumulated on the footwall during the shift.

Figure 4.24 indicates the grab sampling from January to December 2017 on different stope panel ASGs. There are anomalies between the face grade and grab sampling where the advance strike gully is between 0 and 90m from the center gully (Block A). The grab sampling grades has spikes at a distance less than 60m and this shows that grab sampling can give irregularities. This is not meaning that grade is a function of distance. Where the advance strike gully is more than 90m, the face grade and gully grades correlates. This correlation indicates that when the advance strike gully is more than 90m not all metal ore is cleaned to the orepass resulting to gold metal loss.

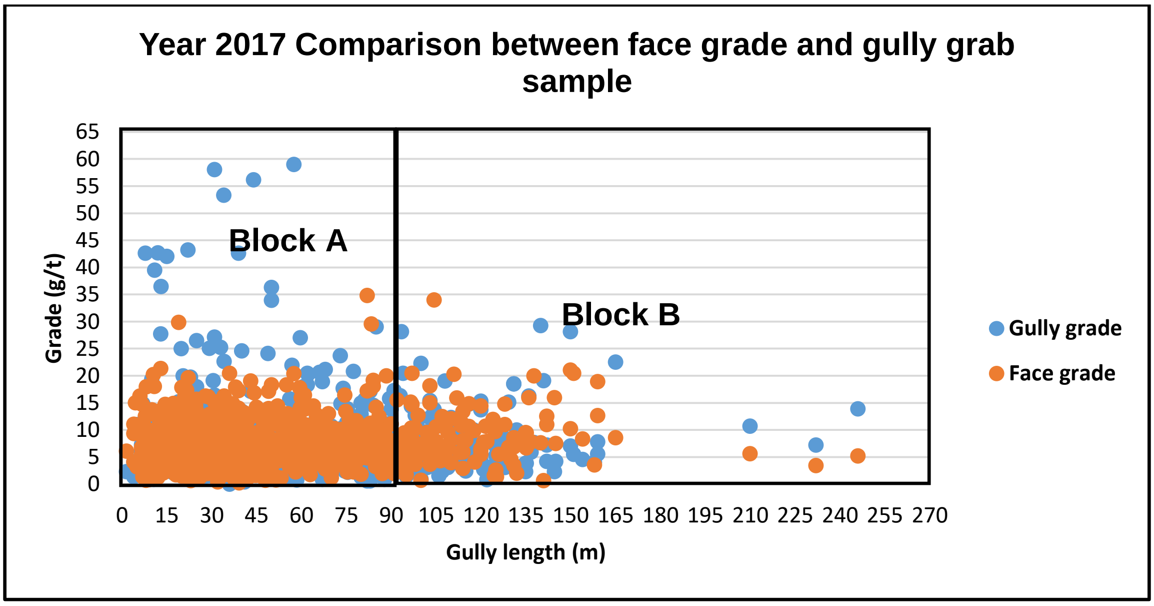


Figure 4.24 Face grade and gully grab sampling in 2017

4.5.2 The belt grade from belt sampling

The belt sampling helps the operation to track and compare the grade of ore broken from the underground face and the grade of ore before the plant. Figure 4.25 below the face grade, belt grade and the SCF from year 2012 to 2017. In year 2012 to 2014, the face grade and belt grade trends were more or less similar and from 2014 to 2017 the face grade increased whereas the belt grade is almost constant. The situation where the face grade is higher than the belt grade can be explain in terms of several conditions, however, the most outstanding condition can be because ore is still accumulated from different underground sources and this can affect the SCF. From 2013 to 2017 SCF showed a continuous drop.

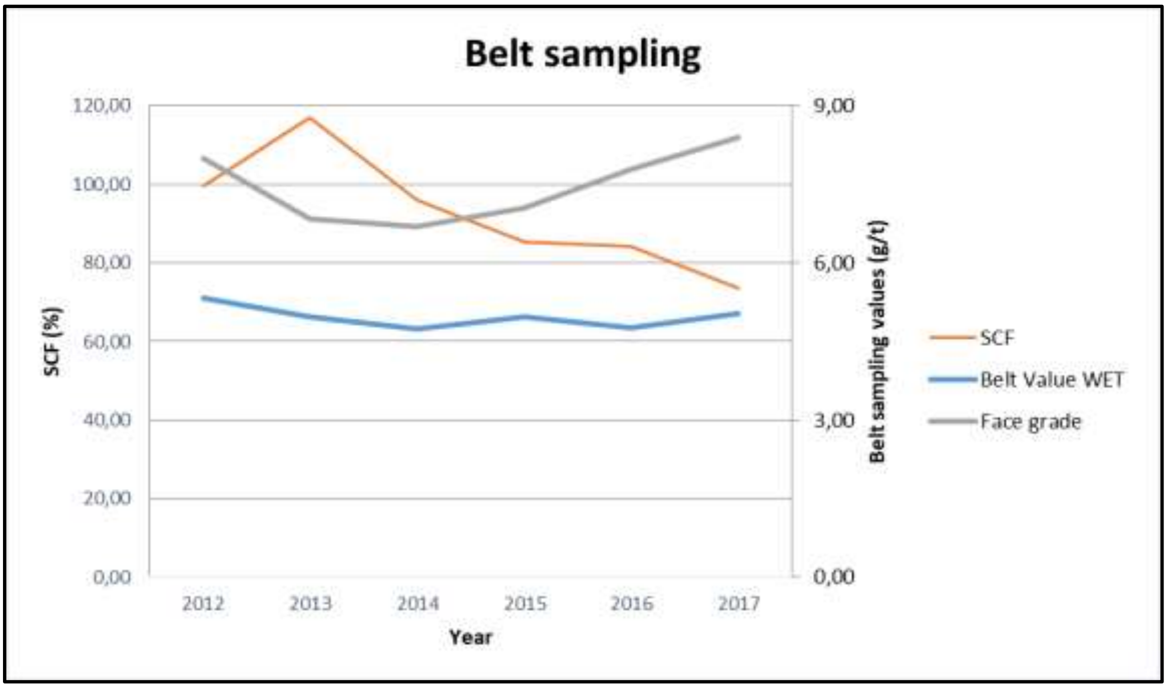


Figure 4.25 Belt sampling from year 2012 to 2017

4.6 Ground condition in advance strike gully

The increase in closure rate can lead to the fall of ground (FOG) and causing packs support to subside. Figure 4.25 indicates the closure rate of the advance strike gully and time during the shift. Two closure rate meters were installed at 197 S7 stope section at a certain distance from the center gully. Logger 8074 is installed 39m from the center gully and logger 8071 64m from the center gully. Both logger 8071 and 8074 show a convergence rate of 40mm over 16 days. This convergence rate creates an assumption that for every blasting shift there is about 2.5mm convergence rate in 197 S7 stope panels.

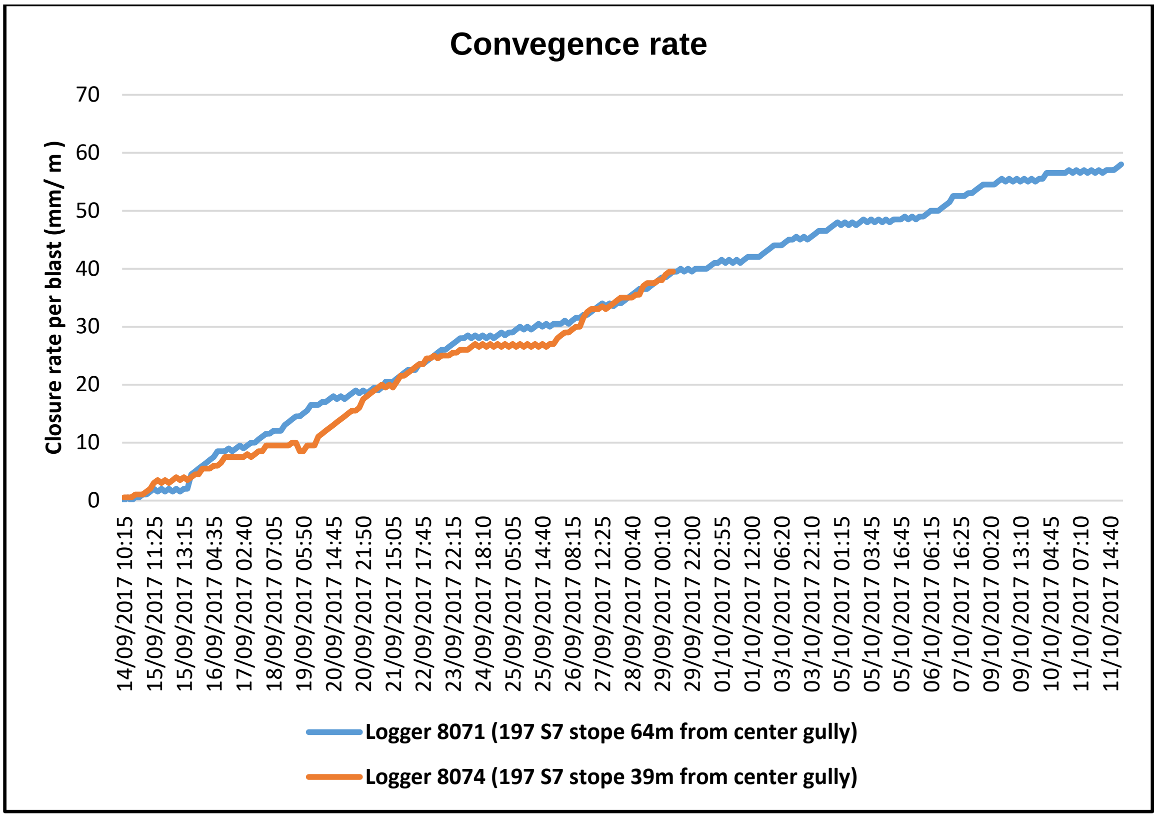


Figure 4.26 Closure rate per meter blasted

There is an assumption that the rate of convergence increases when the blasting face is further away. Most of the advance strike gully more especially in different raise line such as 202 S1 and 197 S8 showed high convergence rates and this is a safety concern. Figure 4.26 indicates high convergence in one of the advance strike gully and this convergence can be due to overcharging of explosive and stress, thus, can result to a fall of ground.

Figure 4.27 Convergence in advance strike gully (Doornkop Shaft, 2017)

4.7 Proposed method

4.7.1 *Optimisation of the ASG depth and width*

Figure 4.27 shows the difference between the actual ASG dilution tonnage and theoretical dilution tonnage. The calculation was done theoretical taking into consideration the actual ASG depth and width, thereafter, calculate the theory tonnes using the actual ASG depth and width for April until July 2017. The graph does only focus on four month data because ASG depth collection system was implemented late March 2017. In June and July months the strike depth and width was to standard, however, the actual gully tonnes are about 1800 tonnage. The increase in actual gully tonnage is an indication of an increase in lock up tonnage in strike gullies during the survey measuring month. The actual ASG tonnages are more than the theory tonnage.

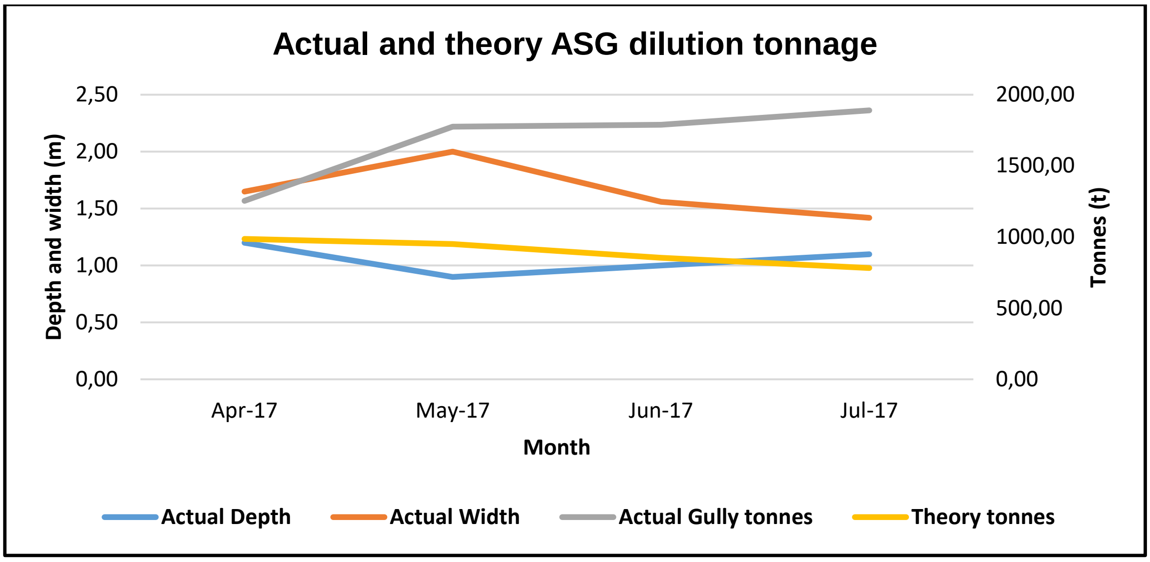


Figure 4.28 Actual and theoretical ASG dilution tonnage

Figure 4.28 shows actual SCF and the theoretical SCF. There is an increase on the actual gully tonnes as from April 2017 to July 2017 compared to the theoretical tonnes as per normal calculation of ASG depth, width and length during the months. Unfortunately, the measuring of advance strike gully depth, width and length on a weekly basis was enrolled in April 2017 due to an increase in accumulations. The actual gully tonnes trend creates an impression that there are ore accumulations in the gullies and if not removed during the month can affect the SCF for that month. Although SCF can be affected by variety of elements, ASGs is seen as a critical issue in the study. Vamping at the operation takes place after mining is complete at the raise section and this can be after a year or two. Thereafter, there is no guarantee that ore accumulations from strike gullies can be easily be removed, more especially in areas where there is high convergence rate affecting the gully height and fall of grounds.

During the initiation of ASG measuring on a weekly basis, SCF has shown an upward trend. The more the dilution tonnage, the higher the negative impact it has on the grade, therefore, ASGs must be blasted to standard.

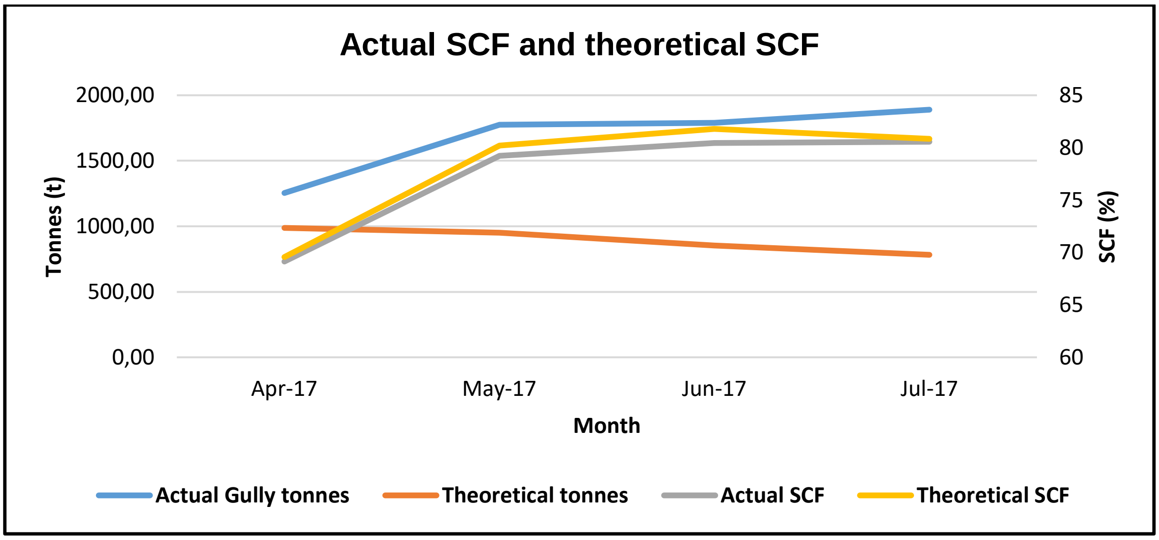


Figure 4.29 Actual and theoretical SCF

Figure 4.29 shows the relationship between the SCF, ASG depth and width. In the instance where the ASG depth is shallow and the ASG width is more than the 1.5m standard, the SCF decreased, thereafter, confirming that developing the ASG not to standard has a negative impact on the SCF. The scraper winch scoop width is 1m and the standard ASG width is 1.5m at the operation. The recovery of broken ore at the ASG more than 1.5m can lead to ore not efficiently recovered towards the ASG sides and the assumption is to recover the ore fully during the vamping process. Due to the Argillite parting above the South Reef conglomerate the operation is experiencing difficulties of proper cleaning in ASG as scrapers struggles to move hitting the hanging wall in the ASG and this normally happened when the ASG are less than 1.5m depth (202 S1 RSE).

This obstruction can result in failure to recover ore during the stope phase and the vamping phase, thereafter, affecting the SCF and the MCF. When the ASG width is less than 2m until 1.42m showed an increase on the SCF. This also give an indication that when gully width is too wide ore accumulates on the ASG corners and better recovery of ore is when the ASG width is smaller and this is because the scrapper width is 1m.

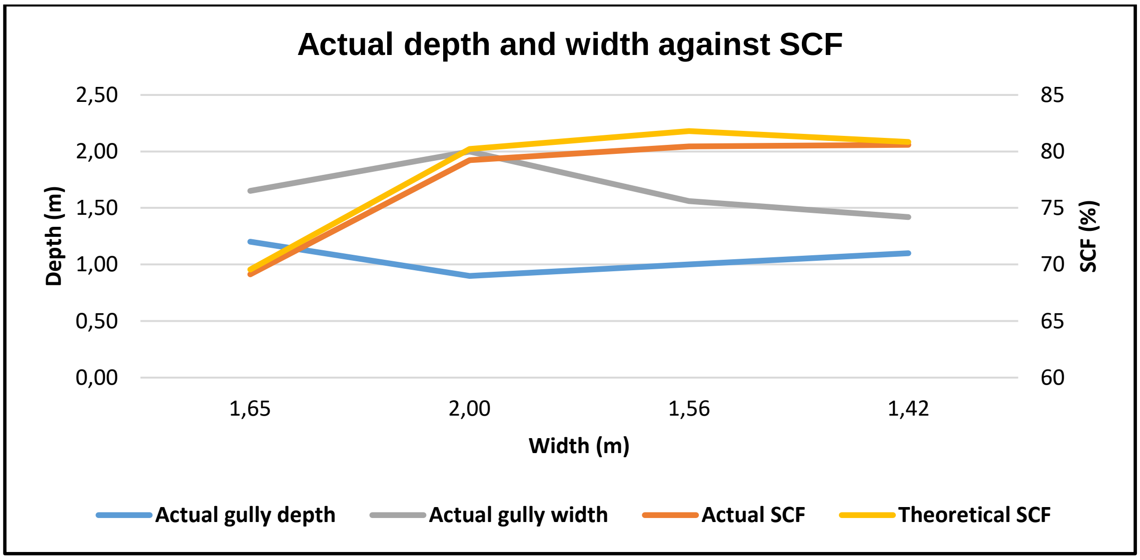


Figure 4.29 Actual depth and width against SCF

Figure 4.30 shows the relationship between the ASG depth, width and the SCF. Shallow depth ASG development leads to minor dilution compared to deep ASG development and the wider the ASG width, the more the negative impact on the head grade and the challenges of cleaning the ASG.

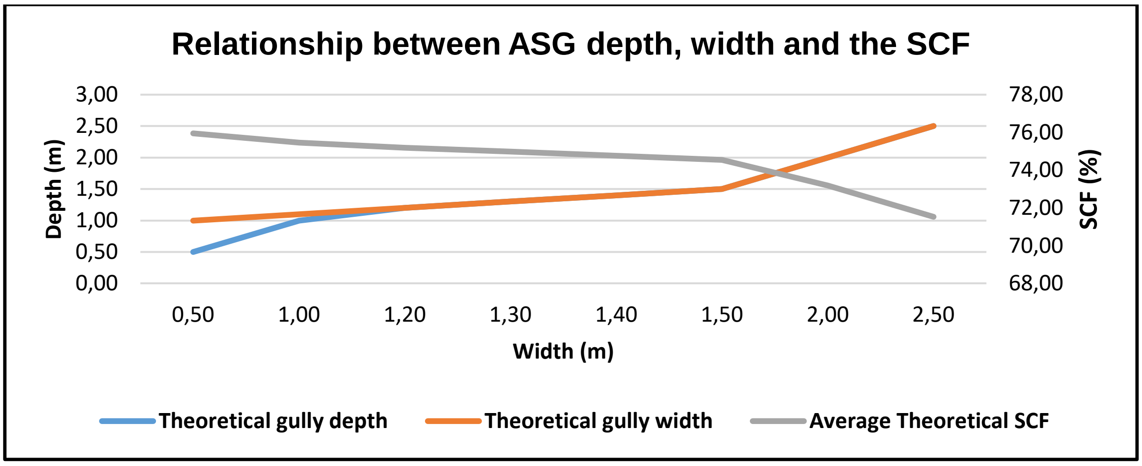


Figure 4.30 Relationship between ASG depth, width and SCF

Figure 4.31 shows the combined relationship between the actual SCF and the proposed SCF over two years period. The proposed SCF is higher than the actual SCF and this gap emphasises that mining 1.5m of both ASG depth and width improves the SCF. The proposed averages of the SCF are higher than the actual SCF.

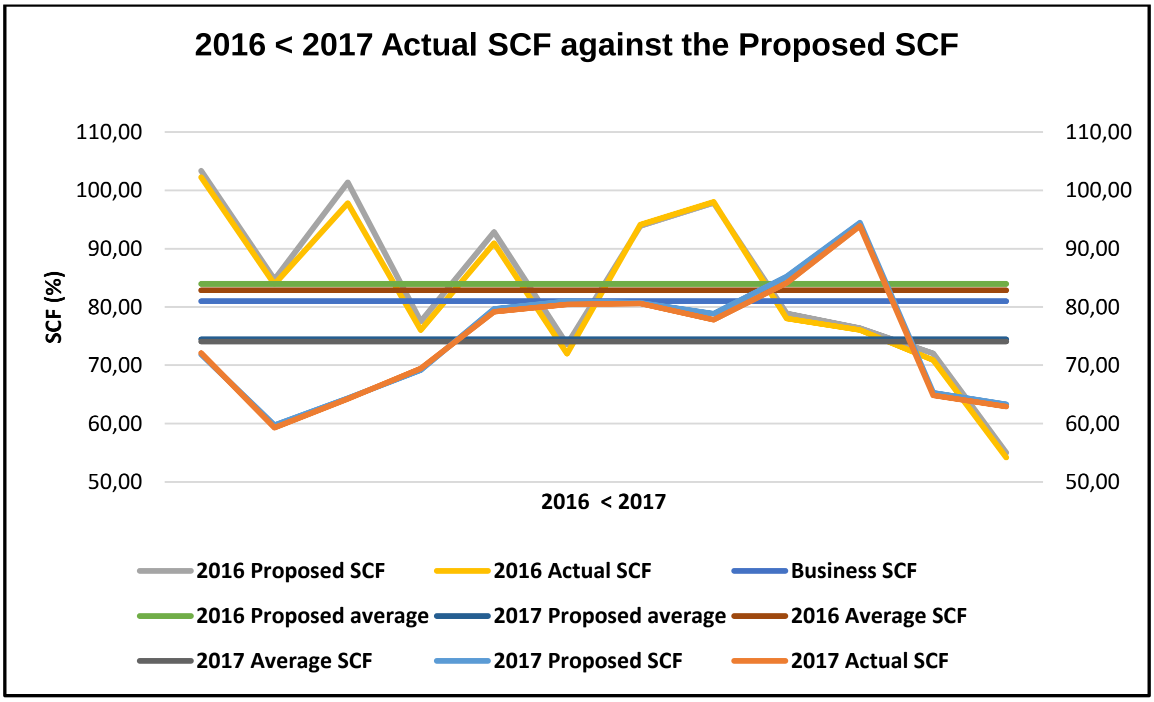


Figure 4.31 Actual SCF against the proposed SCF

Table 4.3 present the assumed revenue and the proposed revenue. The less the ASG dilution, the better the average grade, thereafter, leading to a gain in revenue. The proposed revenue was calculated using the theoretical tonnages into the ore flow and the more the tonnages developed from the advance strike gully has a negative impact on the recovery grade. The actual dilution tonnages from April to July 2017 (refer to Figure 4.27) were more than the theoretical tonnes and this lead to assumptions that advance strike gullies are developed more than the required standard of 1.5m depth by 1.5m width or possible inaccuracy in measuring dilution tonnes. If advance strike gullies are developed at the mining standard of 1.5m width and 1.5m depth, there can be a gain of R 746 700,07 to the operation. The wider and deeper the strike gullies the more the dilution and this affect the head grade.

Table 4.3 Assumed revenue and proposed revenue

Milled tonnage	Recovery grade (g/t)	Gold (kg)	Gold price (R/kg)	Assumed Revenue ®	Proposed	Milled tonnage (t)	Recovery grade (g/t)	Gold (kg)	Gold price ®	Proposed Revenue ®
53011	3,79	201,0281	572000	R 114 988 047	Jan-16	54310,67	3,70	201,03	571999,00	R 114 987 845
51366	4,69	240,884	572000	R 137 785 646	Feb-16	50777,57	4,74	240,88	571999,00	R 137 785 405
57434	4,52	259,763	572000	R 148 584 409	Mar-16	55552,08	4,68	259,76	571999,00	R 148 584 150
49819	3,98	198,4101	572000	R 113 490 555	Apr-16	48860,61	4,06	198,41	571999,00	R 113 490 357
54729	4,30	235,2913	572000	R 134 586 622	May-16	53699,70	4,38	235,29	571999,00	R 134 586 387
49490	4,45	220,424	572000	R 126 082 531	Jun-16	48409,44	4,55	220,42	571999,00	R 126 082 311
50745	4,24	215,3413	572000	R 123 175 215	Jul-16	50785,89	4,26	216,55	571999,00	R 123 864 399
52304	4,26	223,0191	572000	R 127 566 922	Aug-16	52303,88	4,26	223,02	572000,00	R 127 566 922
54254	3,79	205,7351	572000	R 117 680 457	Sep-16	60587,59	3,40	205,74	572000,00	R 117 680 457
49459	4,33	214,2103	572000	R 122 528 304	Oct-16	49217,86	4,35	214,21	572000,00	R 122 528 304
57445	4,57	262,5159	572000	R 150 159 094	Nov-16	60609,77	4,57	276,98	572000,00	R 158 431 666
53400	3,69	197,0923	572000	R 112 736 817	Dec-16	55518,34	3,55	197,09	572000,00	R 112 736 817
				Assumed value (2016)						Proposed Revenue (2016)
				R 127 447 052						R 128 193 752
										R 746 700

4.7.2 *ASG length optimisation*

ASG length optimisation contributes on the improvement of the SCF, although this section does not show the changes on the SCF in relation to the ASG length.

The longer the ASG, the more the time it takes for cleaning the ore. Figure 4.32 shows the relationship between the ASG length, time and the cleaning rate.

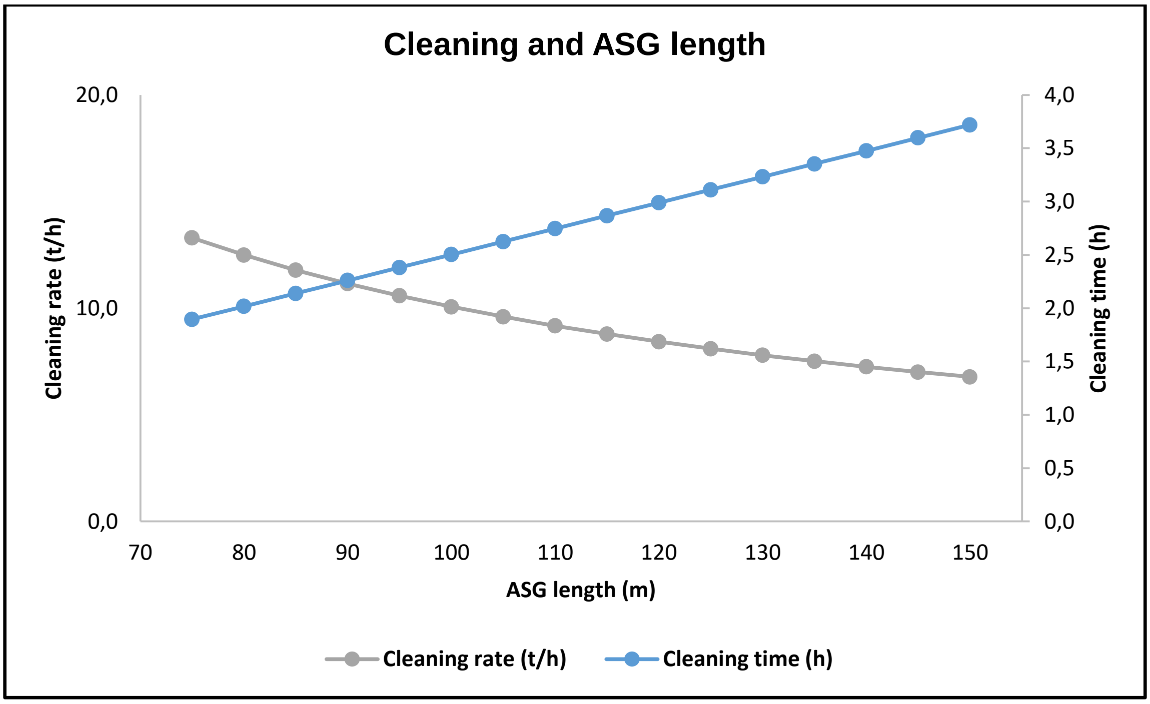


Figure 4.32 Relationship between cleaning rate and gully length

4.7.3 *Correlogram interpretation*

The correlogram (Appendix F) was done using the data set of the strike gully depth, width, length and SCF for the year 2017. This is to try and correlate the strike gully depth, width and length with the SCF. Although it is quite known that the SCF can be affected by different elements and not only the ASG conditions.

Figure 4.33 shows the relationship between depth, width, length and SCF. The depth and length has shown positive correlation towards the SCF as per the correlogram graph. The variogram of the depth, width and length shows similarities in terms of the direction.

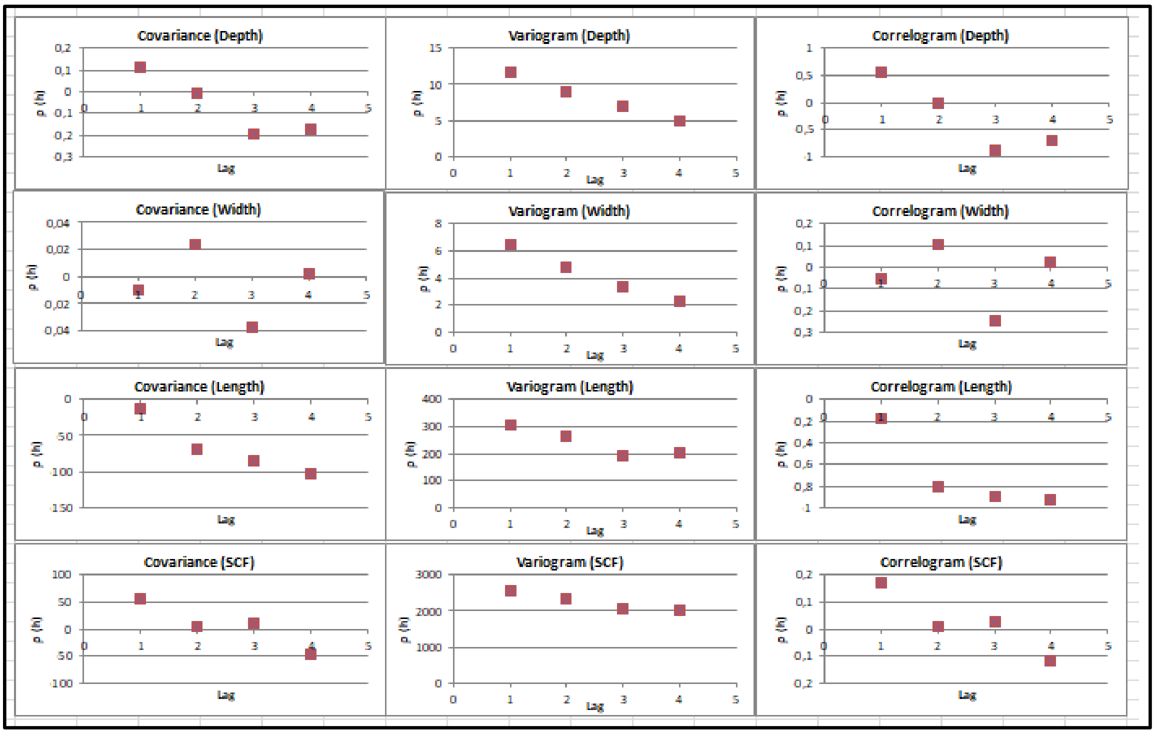


Figure 4.33 Correlogram of depth, width, length and SCF

4.8 Chapter summary

This chapter presented the analysis of the ASG condition at the operation. The ASG geometry and conditions have shown an impact on the SCF. An average of two panels was measured offline during the month. The capacity of the winch, the distance of the winch to the stope face and the advance strike gully length influence the cleaning rate and time. Thereafter, the research study shows that the longer the advance strike gully the low cleaning rate and high cleaning duration.

In most cases panels do pass sweepings on the face as per mine standard, however, every survey measuring month and even towards milling month there are locked up tonnage in strike gullies. The face grade sampling from year 2014 to 2017 showed and upward trend, however, the belt grade and the shaft call factor showed an opposite trend. This upward trend of the face grade has an indication that not all the ore is cleaned from the stope faces and the gullies. Constant cleaning of the strike gullies can possibly improve the SCF and not wait for vamping period as it can lead to a possible ore loss due to convergence and additional cost to the operation. If sweepings are not done properly it results in locked up tonnage. Locked up tonnage in advance strike gully are associated with gold metal content, thus, tonnage must be removed during the month of blast to avoid tonnage being locked up. Due to high convergence rate in the operation as shown at Figure 4.25, sweepings must be done to mine standard to avoid loss of metal from the stopes.

ASG should be to the right depth of 1.5m to cater for high convergence rate as it can be an obstruction when advance strike gully are shallow and there is high convergence rate. The ASG depth and width development has an impact on the belt grade as when over blasted it can cause dilution. This impact is as a result of extra waste combining with ore leading to high dilution; therefore, it is important to blast ASG at the standard depth and width. About R 38, 430, 000 lost in year 2017 due to ore accumulations in advance strike gullies. If advance strike gullies are developed at 1.5m depth and 1.5m width, Doornkop Shaft can gain about R746 700, 00 (refer to Table 4.3). The correlogram interpretation shows the positive relationship of the depth and length with the SCF more than the width. The following chapter will provide conclusions and recommendations of the research study.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter provides conclusions and recommendations of the research study. Section 5.2 presents the summary with the reference to the research objectives. Further research is presented in Section 5.3.

5.2 Conclusions

In the current mining practice, there has been a regression in terms of quality mining as per mine standards. There has been a downward trend on the SCF from year 2012 to 2016 and increasing trend from May 2017. The quality development of the advance strike gully width, depth and length is essential to grade. Failed sweepings influence locked up tonnage and stope face sweepings should not pass if the advance strike gully has ore accumulations because panels pass sweepings whereas strike gullies are full of broken ore. Advance strike gully must be cleaned to footwall in order to remove the ore accumulation as it is mostly fines left and fines contains high gold metal content. Doornkop Shaft can benefit R746 700, 00 (refer to Table 4.3), if developing ASG at the correct mine standard of 1.5m depth and 1.5m width.

Flow of ore tracking is essential in the mining industry; therefore, RFID tags system must be used at all times in order to track the ore from underground sources for better controls and management. The correlogram correlation of the strike gully depth and length shows a trend relationship to that of the SCF.

5.3 Recommendations

There should be a dedicated travelling way into the stope face in order to improve the cleaning time and to avoid employees from crawling when entering the stope face. It is important to blast the ASG depth and width as per mine standard because it can improve the grade and SCF as ore will be recovered efficiently from the strike gullies. It is highly recommended that ASG development must be as per mining dimension standard. There should be reduction in vamping percentage during the actual months in order to increase the current sweepings and this can increase focus to the SCF for that specific month. The bigger the gap between the current mining and vamping, the lesser chances of full recovery of ore at the operation due to fall of grounds and high convergence rate. This is because vamping is not being done where sections are still mining but when mining of the section is finished and by then the level of subsidence can be high limiting the chances of ore recovery. Closure rate meters must be installed in each stope section in order to get the broad overview of the convergence rate.

5.4 Further research

The research study shown that there is high discrepancy in the operation, therefore, there is a need to do further research on the flow of ore and identifying possible sources of such discrepancies. Further analysis of the RFID tags should be done in order to understand the entire flow of ore. The research could not determine the costs of reducing the crosscut interval to less than 180m, therefore, further investigation must be done in order to better plan and optimise the ore body. There is limited historical reference of projects focusing on the strike gullies, thereafter, scientific statistics is required. The operation had just initiated the closure rate meter in few working places. Further data collection and analysis of the closure rate meter is necessary.

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7 APPENDICES

7.1 Appendix A

Doornkop Shaft monthly accumulation template

DOORNKOP MONTHLY ACCUMULATIONS																					
CPM	WORKING PLACE	SWEEPS FROM FACE	BLASTING BARRICADES	STOP BEHIND BLASTING BARRICADES(m)	STOP HEIGHT (m)	FACE LENGTH (m)	FACE ADVANCE (m)	PAS BOOKED M²	ACTUAL M²	ON/OFF REEF	GRADE	KG's	GULLY TONS	FACE TONS	TOTAL TONS	IS THERE A PUMP? YES/NO	SW (cm)	FACE WINCH	GULLY DEPTH (m)	ESCAPE GULLY (BLASTED)	IS THERE A REEF DETECTOR

7.2 Appendix B

Advance strike gully RFID tags

Read Date	Tag	Working Place	Issue Date	Days
2017-04-24 15:02:40	A5728	197 s6 n2 gully	2017-04-18	6
2017-04-24 21:30:42	A5729	197 s6 s1b gully	2017-04-18	6
2017-04-25 14:16:39	A5756	197 s6 s1a gully	2017-04-19	6
2017-04-25 07:43:12	A5757	197 s6 s1a gully	2017-04-19	6
2017-04-26 01:19:12	A5772	197 s6 n2 gully	2017-04-20	6
2017-04-26 16:17:33	A5772	197 s6 n2 gully	2017-04-20	6
2017-04-26 07:04:50	A5773	197 s6 n2 gully	2017-04-20	6
2017-04-26 01:10:35	A5779	197 W1B E1 gully	2017-04-20	6
2017-04-30 14:36:57	A5806	197 S7 �N10 gully	2017-04-24	6
2017-04-13 20:24:20	A5643	197 ��W1A-N1 gully	2017-04-06	7
2017-04-25 07:36:12	A5728	197 s6 n2 gully	2017-04-18	7
2017-04-25 07:28:54	A5729	197 s6 s1b gully	2017-04-18	7
2017-04-04 01:27:09	A5474	192 n3 w4 gully	2017-03-27	8
2017-04-14 16:12:36	A5589	192 n3 e3 gully	2017-04-05	9
2017-04-14 02:20:36	A5589	192 n3 e3 gully	2017-04-05	9
2017-04-15 06:38:36	A5614	197 ��W1A-N1 gully	2017-04-04	11
2017-04-17 11:36:53	A5624	203 S1 N 12 gully	2017-04-06	11
2017-04-16 01:00:09	A5615	197 ��W1A-N1 gully	2017-04-04	12
2017-04-24 15:03:52	A5699	197 s6 n2 gully	2017-04-12	12
2017-04-17 12:07:11	A5615	197 ��W1A-N1 gully	2017-04-04	13
2017-04-25 07:36:50	A5699	197 s6 n2 gully	2017-04-12	13
2017-04-26 00:10:14	A5698	197 s6 n2 gully	2017-04-12	14
2017-04-25 09:12:45	A5659	197 W1B E1 gully	2017-04-10	15
2017-04-25 03:22:53	A5659	197 W1B E1 gully	2017-04-10	15
2017-04-10 09:23:12	A5463	197 S7 N 9 Gully	2017-03-24	17
2017-04-10 08:26:01	A5463	197 S7 N 9 Gully	2017-03-24	17
2017-04-11 09:09:53	A5485	202 S1 N 12 gully	2017-03-24	18
2017-04-12 23:03:45	A5454	197 S7 N 9 Gully	2017-03-24	19
2017-04-16 22:05:17	A5405	197 S7 N 7 gully	2017-03-24	23
2017-04-17 01:29:53	A5405	197 S7 N 7 gully	2017-03-24	24
2017-04-19 18:21:52	A5339	197 W1B E1 gully	2017-03-16	34
2017-04-19 16:09:32	A5339	197 W1B E1 gully	2017-03-16	34
2017-04-10 03:25:16	A4438	192 s4 w11 gully	2017-02-09	60
2017-04-28 21:31:09	A4439	192 s4 w11 gully	2017-02-09	78
2017-04-29 00:47:46	A4439	192 s4 w11 gully	2017-02-09	79
2017-04-15 23:02:40	A2889	192 N3 E 2 gully	2016-11-11	155
2017-04-16 19:48:53	A2889	192 N3 E 2 gully	2016-11-11	156

7.3 Appendix C

Offline advance strike gully from April 2017 to June 2017 (Doornkop Shaft)

SHIFTBOSS AND MINE OVERSEER'S PENALTIES (April 2017)				
CPM	W/PLACE	COMMENTS	M² Achieved	M² Deducted
RE008881	RE008881:192 S5 W 1A	Offline Mining	459	459
RE013182	RE013182:192 N4 E 14	Offreef Mining	288	30
RE007963	RE007963:192 N5 E 6	Offreef Mining	49	49
RE013245	RE013245:192 N3A E 5	Offreef Mining	246	17
RE007895	RE007895:192 N3 E2	Offline Mining	431	30
RE007896	RE007896:192 N3 E 3	Offreef Mining	199	38
			4112	623
		Penalty includes Mine Overseer and Shiftboss		
RE008101	RE008101:202 S1 N 11	Offreef Mining	295	22
RE008102	RE008102:202 S1 N 12	Offreef Mining	211	40
RE008439	RE008439:202 S1 S 12	Offreef Mining	227	30
RE008895	RE008895:202 S2C S 6	Offreef Mining	361	40
RE008902	RE008902:202 S2C N 5	Offreef Mining	287	287
RE008842	RE008842:197 W1A N 1A	Offreef Mining	101	101
RE013193	RE013193:197 W1B W 1A	Offreef Mining	137	137
RE008860	RE008860:197 S4 S 3A	Offreef Mining	45	45
		Only the Shiftboss to be Penalised		
RE008201	RE008201:197 S8 S 3	Offreef mining	84	84
RE008165	RE008165:197 S7 S 6	Panel Not Planned	38	38
RE008161	RE008161:197 S7 S 3	Offline/Offreef Mining	313	45
RE007884	RE007884:197 S6 S 1	Offreef Mining	150	7
		Only the Shiftboss to be Penalised		

MINE OVERSEER'S, SHIFTBOSSES AND MINERS PENALTIES May 2017				
CPM	W/PLACE	COMMENTS	M² Achieved	M² Deducted
RE007978	192 N5 W 7	OFFLINE MINING	440	32
			4600	32
RE008157	197 S7 N 9	GULLY SPAN 3.2	403	50
RE008182	197 S8 N 5	OFFLINE MINING	431	50
			6001	100
RE013777	202 S2C S 5 D/D	PANEL NOT PLANNED	419	419
RE013776	202S2C S 5 U/D	PANEL NOT PLANNED	225	225
			5447	644

MINE OVERSEER'S, SHIFTBOSSES AND MINERS PENALTIES (June 2017)				
CPM	W/PLACE	COMMENTS	M² Achieved	M² Deducted
RE007971	192 N5 W 4	OFFLINE MINING/OFF REEF	280	37
RE007971	192 N5 W 4	SWEEPINGS FAILED		
RE008003	192 N6 W 1	Panel Planned Pay S/Boss	119	0
RE008855	192 S5 E 1D	OFF REEF	269	56
RE008855	192 S5 E 1D	SWEEPINGS FAILED		
RE008854	RE008854:192 S5 E 1C	SWEEPINGS FAILED		
RE013182	192 N4 E 14	OFF REEF	223	22
RE013352	192 N3 W 6 DOWN DIP	PANEL NOT PLANNED	9	9
RE007895	192 N3 E 2	OFF REEF	259	13
RE008879	192 S3 W 1B	OFF REEF	382	22
			3554	159
RE008178	197 S8 N 1	OFFLINE MINING	441	35
RE008178	197 S8 N 1	SWEEPINGS FAILED		
RE008887	RE008887:197 S8 N 1A	SWEEPINGS FAILED		
RE008159	197 S7 S 3	OFF REEF	255	255
RE008157	RE008157:197 S7 N 9	SWEEPINGS FAILED		
RE008159	197 S7 N 11	OFF REEF	230	40
RE007871	197 S6 N 1A	OFF REEF	31	6
RE007870	197 S6 N 1B	OFF REEF	93	37
			5076	373
RE008842	197 W1A N 1A	OFF REEF	332	46
RE008102	202 S1 N 12	OFF REEF	283	6
RE013542	202 S2C N 1B	OFF REEF	140	51
RE008897	RE008897:202 S2C S 8	SWEEPINGS FAILED		
RE008900	202 S2C N 3	OFF REEF	93	9
			4638	112

7.4 Appendix D

Monthly sweepings report and ore flow (Doornkop Shaft)

CPM	WORKING PLACE	SWEEPING DISTANCE
RE008918	RE008918:192 S5 W 1B	0,0
RE008881	RE008881:192 S5 W 1A	0,0
RE007984	RE007984:192 N6 E 1	
REAA:1.1 - I Van Schalkwyk		
RE007976	RE007976:192 N5 W 6	8,0
RE007973	RE007973:192 N5 W 5	7,0
RE007963	RE007963:192 N5 E 6	8,0
RE007962	RE007962:192 N5 E 5	7,8
RE007968	RE007968:192 N5 W 3	
RE007960	RE007960:192 N5 E 3	9,0
RE007961	RE007961:192 N5 E 4	
REAB:1.1 - W Bartlett		
RE013243	RE013243:192 N3A E 1	
RE013245	RE013245:192 N3A E 5	6,8
RE007944	RE007944:192 N3 W 7	7,7
RE007919	RE007919:192 N3 W 5	8,5
RE007920	RE007920:192 N3 W 6	7,8
REAE:1.1 - J Fourie		
RE013194	RE013194:192 N4 E 16	5,2
RE013556	RE013556:192 N4 E 15A	3,0
RE008078	RE008078:192 N4 E 15	7,0
RE013168	RE013168:192 N4 W 14	7,4
RE013211	RE013211:192 N4 W 15	5,4
REAC:1.1 - H Scheepers		
REA:1.1 - A Dube		
RE008537	RE008537:202 S3 S 4	5,2
RE013782	RE013782:202 S3 N 1A	6,0
RE008512	RE008512:202 S3 N 1	
RE008515	RE008515:202 S3 N 4	9,0

7.5 Appendix E

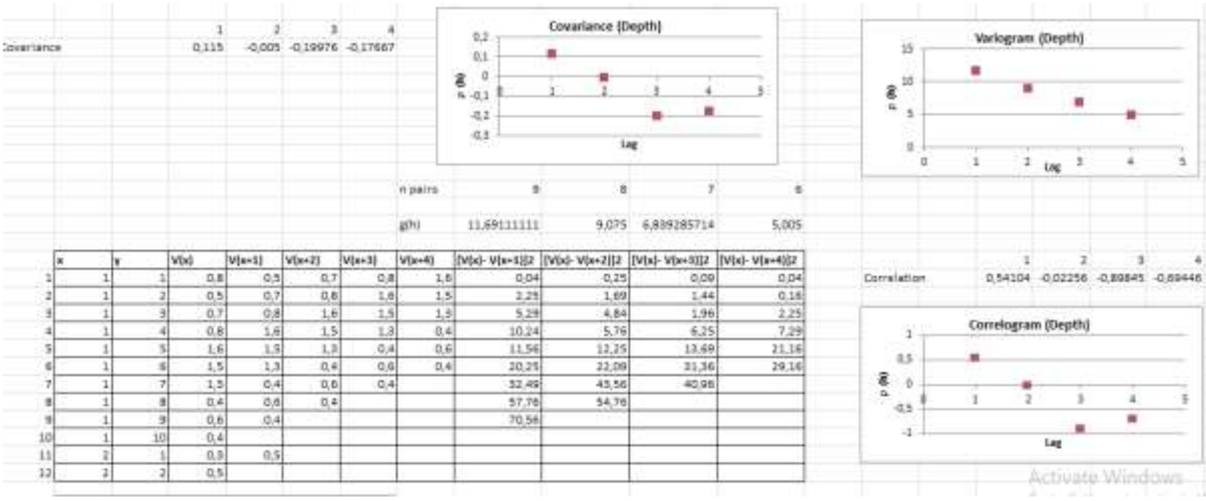
Ore flow report (Doornkop Shaft)

	SHAFT :	DOORNKOP SR				
		2018/10/27 06:25				
			Jul-17			
			%	m / m² / tons	g/t	Grams
	RD	**2,72**				
	CUT-OFF CMG/T			735		
1	Stope Reef cmg/t based on current samp (3 decimals)		225	960,260		
	Cmg/t below cutoff based on current samp		-149	586		
	Cmg/t above cutoff based on current samp		343	1078		
2	SW (excl. Gullies, **incl. Recl.**) (3 decimals)			122,674		
	SW (excl. gullies, **excl. M^3 Recl.**)			122,674		
3	FACE REEF G/T				7,83	
	Face Grade (incl dilutions, excl gullies) cmg/t			912		
	Face Grade (incl dilutions, excl gullies) g/t				7,41	
	Reef M^2 below cutoff based on current sampling		23,89	3109	4,77	49528
	Reef M^2 above cutoff based on current sampling		76,11	9905	8,79	290385
4	TOTAL REEF M^2 (excl. fault, dykes, os M^2)		100,00	13014	7,83	339914
	Off Reef M^2 (Off reef mining) (excl faults/dykes) OS M^2		4,98	682		
	Total M^2 (Reef M^2 + OS M^2) Excl fault/dykes			13696		
5	**STOPE REEF TONS (excl. M^3 Recl)**		100,00	43424	7,83	339914
6	STOPE REEF PACKED TONS		0,00			
7	STOPE WASTE TONS PACKED		0,00			
8	GULLY DILUTION TONS		4,35	1889		
9	CUBIC / EXTRA		0,85	370		
10	FAULT / DYKE TONS		0,00			
11	WASTE / OFF REEF STOPING TONS		5,69	2470		
	Dilution in stopes (Flt, Dyke, Off Reef mining)		5,69	2470		
96	Equiv m^2(reef+fault+waste+converted)			13696		
16	RECLAMATION / CUBIES / etc. (M^3 TONS)		0,00	0		0
12	**TOTAL STOPE TONS**		**110,89**	**48153**	**7,06**	**339914**
13	DEV. REEF TONS BROKEN		4,90	2127	3,58	7608
136	Extra Waste Tons from Reef Dev **(excl. M3 Recl.)**		2,31	1003		
14	**TOTAL ORE TRAMMED**		**115,79**	**50280**	**6,91**	**347521**
15	VAMPING OLD GOLD TONS		0,87	377	7,96	3002
16	Dev Waste to dump (CPM Correction)			0		
17	DEV. WASTE TONS TO MILL		0,51	222	0,00	0
18	U/G TRANSFERS (1)		0,00			
21	REEF SENT to WASTE ROCK DUMP		0,00	0	0,00	0
20	FLASHING TONS		0,00			0
21	ADD U/G SOURCES TO MILL (Qual + Mud)		0,35	150	0,00	0
22	REEF BALLAST RECLAIMED		0,00	0		0
23	**AVAIL FOR HOISTING (Survey Call)**		**117,513**	**51029**	**6,87**	**350523**
24	**DISCREPANCY**		25,21	10949		
25	**TOTAL TONS HOISTED**		**142,73**	**61978**	**5,66**	**350523**
26	Sludge tons +					
27	SHAFT STORAGES - BEGIN +		0,00			
28	SHAFT STORAGES - END -		0,00			
29	**SUB TOTAL**		142,73	61978	5,66	350523
30	STOCKPILES AT # - BEGIN +		0,00	0		0
31	STOCKPILES AT # - END -		0,00	0		0
32	**SUB TOTAL**		142,73	61978	5,66	350523
33	SURFACE SOURCES +					
34	Waste dumps +					
35	Slimes dam +					
36	Reef ex sorting +					
37	Waste washings +					
38	Railway bins - begin +					
39	Railway bins - end -					
40	**TOTAL TO PLANT**		**142,73**	**61978**	**5,66**	**350523**
41	STOCPILE AT PLANT - BEGIN +		0,00			
42	STOCKPILE AT PLANT - END -		0,00		0,00	0
43	**SUB TOTAL**		142,73	61978	5,66	350523
44	MILL BINS / SILOS - BEGIN +		2,88	1250	4,91	6132
45	MILL BINS / SILOS - END -		6,33	2750	4,85	13344
46	**TOTAL INVENTORY BEGIN**		2,88	1250	4,91	6132
46 A	**TOTAL INVENTORY END**		6,33	2750	4,85	13344
47	**TOTAL TONS MILLED**		**139,27**	**60478**	**5,68**	**343311**
	CHECK		139,27			
48	**MCF** (3 dec)	GAF / Available for Hoisting	82,531			
	SCF (Shaft Gold Delivered Dry / Available for Hoisting		80,578			
	PCF (GAF/Shaft Gold Delivered Dry) also (MCF/SCF)		102,424			
	PRF (3 dec)	Gold Rec / GAF	94,960			
50	**MRF** (3 dec)	MCF x PRF	78,371			
51	**GOLD RECOVERED**			**60478**	**4,54**	**274709**
52	RESIDUE			60478	0,241	14581
53	**GAF**	Recovered + Residues		60478	4,78	289290
33	Total Linear Reef metres			**141,8**		
	Ave Raise Width			1,75		
161	Ave Raise Height			2,71		
	STANDARD Ave Reef Width			1,50		
	STANDARD Ave Reef Height			2,70		
	Reef Metres Over/Under breaking %		17,2			
	Total Linear Waste metres			**797,7**		
	ACTUAL Ave Waste Width			3,2		
	ACTUAL Ave Waste Height			3,1		
	STANDARD Ave Waste Width			3,0		
	STANDARDL Ave Waste Height			3,0		
	Waste Metres Over/Under breaking %		6,7			
	TOTAL Reef + Waste Metres Over/Under Breaking %		8,2			
	Total Linear Metres (waste & reef)			**939,5**		
	Total Equivalent Reef metres			26,4		
	Total Equivalent Waste metres			83,6		
	Total Equivalent Metres (waste & reef)			110,0		
89	Milling Width			162,3		
	Smart Rail tons & Belt Value WET			60542	4,86	294212
	Smart Rail Tons DRY			**58120**	4,86	282444
	Moisture Factor (from gold allocation sheet)			4,00		
	No. of Skips hoisted (shaft figure)			6225		
	Skip Factor (shaft figure)			9,7		
	Hoisted Tons DRY (based on skip factor)			**58120**		

Christine Safar Central Survey Room 27 Tel: 057 231 2141

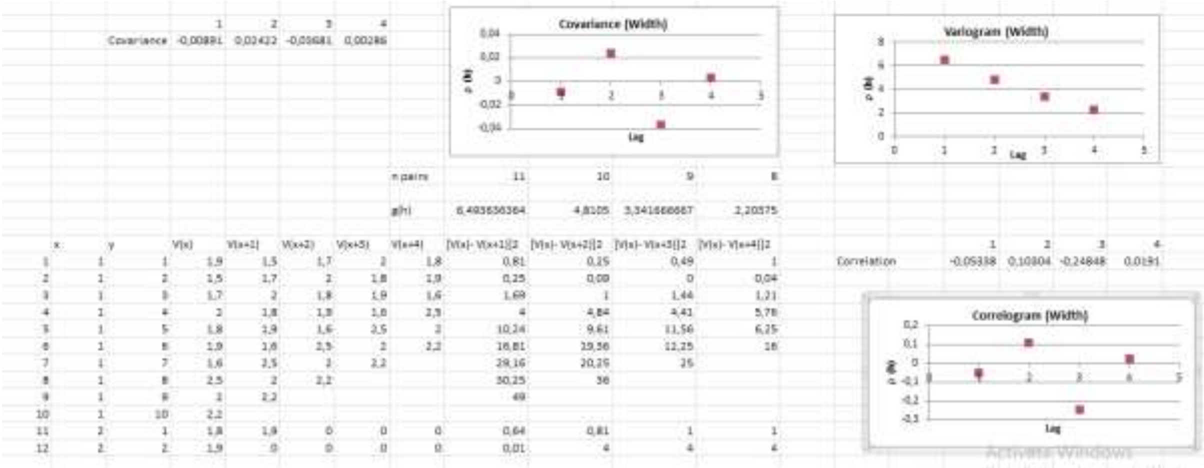
7.6 Appendix F

Correlogram spread sheet for depth, width, length and SCF



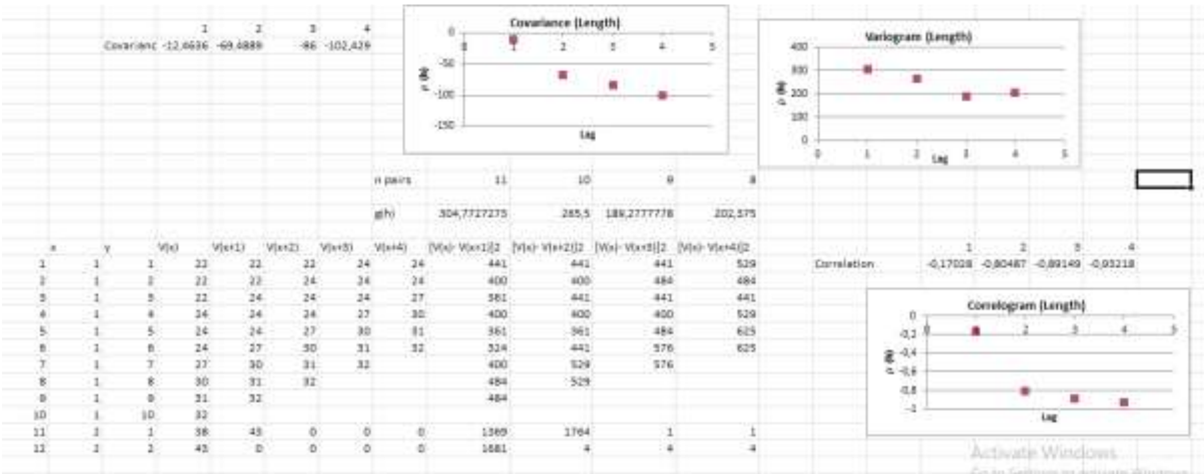
	1	2	3	4
Covariance	0,115	-0,005	-0,19976	-0,17667
n pairs	9	8	7	6
g(h)	11,69111111	9,075	6,839285714	5,005
Correlation	0,54104	-0,02256	-0,89845	-0,69446

	x	y	V(x)	V(x+1)	V(x+2)	V(x+3)	V(x+4)	[V(x)- V(x+1)]2	[V(x)- V(x+2)]2	[V(x)- V(x+3)]2	[V(x)- V(x+4)]2
1	1	1	0,8	0,5	0,7	0,8	1,6	0,04	0,25	0,09	0,04
2	1	2	0,5	0,7	0,8	1,6	1,5	2,25	1,69	1,44	0,16
3	1	3	0,7	0,8	1,6	1,5	1,3	5,29	4,84	1,96	2,25
4	1	4	0,8	1,6	1,5	1,3	0,4	10,24	5,76	6,25	7,29
5	1	5	1,6	1,5	1,3	0,4	0,6	11,56	12,25	13,69	21,16
6	1	6	1,5	1,3	0,4	0,6	0,4	20,25	22,09	31,36	29,16
7	1	7	1,3	0,4	0,6	0,4		32,49	43,56	40,96	
8	1	8	0,4	0,6	0,4			57,76	54,76		
9	1	9	0,6	0,4				70,56			
10	1	10	0,4								
11	2	1	0,3	0,5							
12	2	2	0,5								



	1	2	3	4
Covariance	-0,00891	0,02422	-0,03681	0,00286
n pairs	11	10	9	8
g(h)	6,493636364	4,8105	3,341666667	2,20375
Correlation	-0,05338	0,10804	-0,24848	0,0191

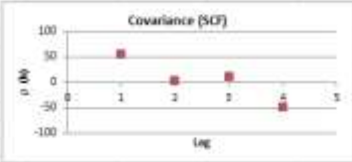
	x	y	V(x)	V(x+1)	V(x+2)	V(x+3)	V(x+4)	[V(x)- V(x+1)]2	[V(x)- V(x+2)]2	[V(x)- V(x+3)]2	[V(x)- V(x+4)]2
1	1	1	1,9	1,5	1,7	2	1,8	0,81	0,25	0,49	1
2	1	2	1,5	1,7	2	1,8	1,9	0,25	0,09	0	0,04
3	1	3	1,7	2	1,8	1,9	1,6	1,69	1	1,44	1,21
4	1	4	2	1,8	1,8	1,6	2,5	4	4,84	4,41	5,76
5	1	5	1,8	1,9	1,6	2,5	2	10,24	9,61	11,56	6,25
6	1	6	1,9	1,6	2,5	2	2,2	16,81	19,36	12,25	16
7	1	7	1,6	2,5	2	2,2		29,16	20,25	25	
8	1	8	2,5	2	2,2			30,25	36		
9	1	9	2	2,2				49			
10	1	10	2,2								
11	2	1	1,8	1,9	0	0	0	0,64	0,81	1	1
12	2	2	1,9	0	0	0	0	0,01	4	4	4

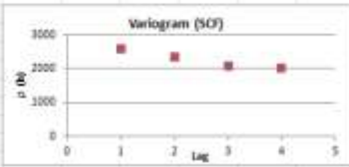


	1	2	3	4
Covarianc	-12,6636	-69,4889	-86	-102,429
n pairs	11	10	9	8
g(h)	304,7727273	285,5	189,2777778	202,575
Correlation	-0,17028	-0,80487	-0,89149	-0,93218

	x	y	V(x)	V(x+1)	V(x+2)	V(x+3)	V(x+4)	[V(x)- V(x+1)]2	[V(x)- V(x+2)]2	[V(x)- V(x+3)]2	[V(x)- V(x+4)]2
1	1	1	22	22	22	24	24	441	441	441	529
2	1	2	22	22	24	24	24	400	400	484	484
3	1	3	22	24	24	24	27	361	441	441	441
4	1	4	24	24	24	27	30	400	400	400	529
5	1	5	24	24	27	30	31	361	361	484	625
6	1	6	24	27	30	31	32	324	441	576	625
7	1	7	27	30	31	32		400	529	576	
8	1	8	30	31	32			484	529		
9	1	9	31	32				484			
10	1	10	32								
11	2	1	38	43	0	0	0	1369	1764	1	1
12	2	2	43	0	0	0	0	1681	4	4	4

	1	2	3	4
Covarianc	56,0666	4,13991	11,2543	-47,9945

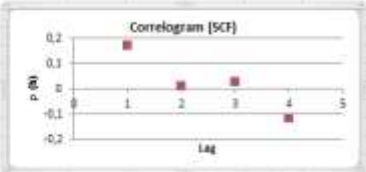




n pairs	10	8	7	6
g(h)	2568,789749	2353,555575	2081,18671	1996,075582

x	y	V(x)	V(x+1)	V(x+2)	V(x+3)	V(x+4)	[V(x)- V(x+1)]2	[V(x)- V(x+2)]2	[V(x)- V(x+3)]2	[V(x)- V(x+4)]2
1	1	94,0975	97,9867	77,999	76,0425	70,8586	8667,108192	9406,414745	5928,848414	5651,544263
1	2	97,9867	77,999	76,0425	70,8586	54,1467	9213,441399	5775,850382	5482,259697	4738,752401
1	3	77,999	76,0425	70,8586	54,1467	72,0828	5624,852351	5335,175131	4802,075208	2615,98527
1	4	76,0425	70,8586	54,1467	72,0828	59,2437	5190,090564	4467,398014	2514,689902	4635,270482
1	5	70,8586	54,1467	72,0828	59,2437	64,2167	4334,720821	2415,396534	4500,10484	2942,375293
1	6	54,1467	72,0828	59,2437	64,2167	69,1365	2318,103167	4366,909199	2834,887961	3389,181273
1	7	72,0828	59,2437	64,2167	69,1365		4235,773557	2729,400629	3273,747923	
1	8	59,2437	64,2167	69,1365			2625,913297	3160,314572		
1	9	64,2167	69,1365				3048,881222			
1	10	69,1365								
2	1	79,2107	80,4577	0	0	0	8116,910407			
2	2	80,4577	0	0	0	0				

	1	2	3	4
Correlation	0,17049	0,01038	0,02906	-0,11415



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